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Agricultural Mechanization and Agricultural Transformation

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BACKGROUND PAPER FOR
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Transforming Africa's Agriculture

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Executive Summary

This paper discusses the current state of agricultural mechanization in Africa and its potential contribution to agricultural and broader economic transformation. This background paper reviews the factors likely to influence farmer demand for mechanization in Africa and details different existing and potential mechanization supply models. Although an empirical analysis of mechanization demand and the effectiveness of supply chains is beyond the scope of this paper, in part due to data limitations, this paper suggests that demand for mechanization may be emerging in some parts of Africa. It also suggests that private sector-driven supply models are better positioned to meet this demand than direct government involvement and certain types of subsidized programs. The paper then identifies possible areas for government support to complement private sector leadership in developing mechanization supply chains.

A renewed focus on agriculture's potential contribution to economic transformation in Africa has resulted in increased attention paid to agricultural mechanization. Nevertheless, African agriculture still relies predominantly on human muscle power, in contrast to other developing regions that have experienced rapid increases in agricultural mechanization over the past few decades. Efforts to promote mechanization in previous decades largely consisted of state-led interventions, which failed due to the lack of demand for mechanization among farmers (Pingali et al 1987).

This paper attempts to overcome some of the misconceptions that drove these programs by reviewing definitions of agricultural mechanization and its role in agricultural intensification processes. The paper draws on Boserup (1965) and Ruthenberg's (1980) theory of agricultural intensification and Hayami and Ruttan's (1970; 1985) induced innovation theory. According to this framework, agricultural intensification is driven by increased population pressure and rising demand for agricultural products. This in turn prompts mechanization, both through the adoption of existing and the development of new technologies. Essentially, mechanization can be expected to be adopted by farmers when the appropriate conditions arise and would not be profitable in the absence of such conditions.

The paper then delves further into the components of demand for mechanization, specifically in Africa. Specifically, it discusses the effects of farm size, labor saving, market demand, the availability of complementary technologies, and demonstration on developing demand. It also describes the sequential nature of mechanization demand as postulated by Pingali et al (1987): in which power-intensive operations (plowing, threshing and harvesting) are mechanized before control-intensive ones (planting, weeding, winnowing) and animal power (where feasible) is adopted before the transition to mechanized power. As a result of the components and sequences of demand, we predict that demand for mechanization in Africa is expected to exhibit significant spatial variation, meaning that existing national surveys and other data may fail to accurately capture patterns of demand.

Our analysis then turns to mechanization supply chains in Africa, focusing on manufacturing, importation, service provision, and ownership. The analysis suggests that where demand has emerged, the private sector has been relatively responsive to meet demand. Private dealers tend to import the types of machinery demanded by farmers, for which markets for spare parts and repairs may be relatively developed, while governments tend to import the brands of machinery accessed

through concessional loans, which do not possess these advantages. Moreover, government importation and subsidization of machines may produce distortionary effects on the private importation and distribution channels. Similarly, individual machine owner-operators appear to have an advantage over government-subsidized service-provision enterprises, as they are usually able to achieve higher utilization rates in addition to obtaining benefits from using machines on their own farmers.

Despite the apparent advantages for the private sector in machine distribution and service provision, there are significant roles for African governments to play in promoting mechanization. Perhaps the most significant of these roles is providing public goods, including infrastructure, technical R&D, and economic research. Other potential roles include capacity building, removing distortionary policies, facilitating access to credit and formulating viable strategies. However, the private sector is still better positioned to drive mechanization in areas where demand has emerged and government policies should aim to play a facilitative and supportive role.

Despite a history of disappointment, agricultural mechanization may finally be in position to contribute to an agricultural transformation in parts Africa. Demand for mechanization appears to have emerged in certain systems and where it has, the private sector has often demonstrated its potential to efficiently supply machines and hiring services. However, the evidence base surrounding mechanization in Africa is still quite limited. Significant further research is required to better understand the changing nature of mechanization demand in Africa and the extent and effectiveness of different supply models in meeting it.

1. Introduction

It is widely believed that in order for Africa to achieve its growth and poverty reduction goals, it will have to transform agricultural through sustainably intensifying production. (Pretty et al 2011). Efforts by African governments and the donor community, including the Comprehensive African Agriculture Development Programme (CAADP), have focused on increasing investments and improving strategy implementation in response to this need. In the Maputo Declaration of 2003, African governments agreed to spend 10% of national budgets in the agricultural sector in order to achieve a target of 6% annual growth. The CAADP platform, along with many policymakers and scholars, recognizes the importance of agricultural mechanization in promoting the intensification that may be required to transform African agriculture and bring about broader growth and development outcomes.

While mechanization levels in North Africa are on par with those in Asia and Latin America, humans are the main power source for agricultural production in Sub-Saharan Africa (SSA), although there are different estimates of the exact levels of mechanization. Until recently, sustained adoption of agricultural mechanization- through engine-powered machinery and animal traction- has been limited to a few areas in Sub-Saharan Africa, much of which has been on large-scale commercial farms. While there was a major push towards agricultural mechanization by African governments during past decades, these largely failed due to lack of demand amongst farmers (Pingali et al 1987). In the aftermath of the failure of state-led mechanization, farm power availability declined in Africa during the 1980s and 90s, while growing rapidly throughout other developing regions (Mrema et al 2008).

Nevertheless, demand for mechanization may have begun to emerge in some parts of Africa in recent years, prompting a renewed focus on mechanization. Where demand for mechanization has existed, private supply chains have formed around it in a number of cases, providing machines and equipment, hiring services and repair services. Although they may be quite responsive to farmers' demand, private supply chains are not always fully developed, often due to crowding out/distortion caused by government policies and programs, the high fixed investments required, or other market failures that need to be overcome through additional support. This emphasizes the importance of establishing an appropriate and supportive policy framework to enable private supply channels to effectively meet demand. However, there is still a paucity of research and knowledge about mechanization demand, the current extent of mechanization and its effects on production, labor and other outcomes.

This paper will draw mostly from the recent literature on the emerging demand for mechanization, the extent to which private and public supply chains have formed to meet such demand, and the role of government policies in influencing mechanization outcomes. Much of the literature addressed in the paper comes from the work of Pingali and Binswanger, who advanced the Bosreupian theory of mechanization as part of intensification process. This paper assesses the available evidence to describe and compare the different types of supply chains for mechanization in Africa, paying particular attention to the adoption of engine-powered mechanization among small, medium and large scale farmers[1]. Much of this evidence is drawn from a mechanization-focused survey conducted by IFPRI/SARI in Northern Ghana, as similar surveys have not

1 Although the supply chains for animal traction are also important components of mechanization, they are part of broader livestock supply chains, which are beyond the scope of this paper.

been conducted in other African countries and national-level data does not adequately cover mechanization. Although there is not sufficient data for this paper to attempt to answer empirical questions about mechanization, it finds that while mechanization trends exhibit significant spatial variation, there do appear to be case of emerging private demand for mechanization among farmers of different sizes. Farmer to farmer service provision appears to be the most effective method of meeting this demand where it exists, while government direct and subsidized service provision may encroach on the private sector's comparative advantage in providing mechanization services. However, the paper discusses a number of constructive roles for governments to play in promoting mechanization in the context of overcoming the constraints to broader agricultural transformation. These roles include the provision of public goods such as training, research and knowledge, favorable trade policy, infrastructural development, and facilitating access to credit.

In the following section (Section 2) we give a set of definitions of mechanization drawn from the literature. The definitions are given from the perspective of the role of mechanization in agricultural intensification processes. We then discuss the demand side of mechanization in Section 3, in which we discuss the main factors contributing to demand for mechanization among different types of farmers. We also attempt to describe observable demand patterns of mechanization in Africa. In Section 4, we focus on the supply side of mechanization, considering mechanization supply as a chain with many different actors including manufacturers, importers and distributors, as well as mechanization service providers and machinery maintenance providers. In Section 5 we focus on the role of governments in mechanization and provide an overview existing and potential of government policies affecting mechanization. We also try to identify potential areas in which government intervention could help to promote mechanization as a facilitator of agricultural transformation. We provide a set of concluding recommendations in Section 6.

2. Definitions and Concepts

Definitions of Mechanization

FAO defines mechanization as "the application of tools, implements and machinery in order to achieve agricultural production" (Clarke 1997). These can all be operated by manual, animal or engine (fossil fuel or electric) power. Essentially, agricultural mechanization represents technological change through the adoption of non-human sources of power to undertake agricultural operations. Mechanized agricultural operations can be grouped into power and control intensive functions. Mechanization of power intensive agricultural operations, such as land preparation, threshing, grinding and milling, is characterized by non-human sources of energy input to replace human and animal ones required in the operations. On the other hand, mechanized control intensive operations, such as planting, weeding, winnowing, fruit harvesting, require greater human judgment and mental input in addition to energy (Pingali et al 2007). Grain harvesting can be thought of as both a power and control intensive operation (Binswanger 1986; Pingali 2007). Some literature also separates stationary operations, such as milling, water lifting, and threshing, from mobile operations, which include plowing, weeding, and harvesting (Rijk 1999). Distinctions between power and control intensive operations, and stationary and mobile operations, are important for understanding the demand for mechanization. As shown in later sections, mechanized operations often have certain sequential patterns. Engine-powered irrigation and transport are two activities that are sometimes included in mechanization. However, in this paper we exclude them in most cases, except where they complement the mechanization of other agricultural operations.

Mechanization and Agricultural Intensification

Mechanization is part of the agricultural intensification process. According to Boserup (1965) and Ruthenberg (1980), and from the perspectives of long-term evolution of farming systems and agricultural technology, agricultural intensification is defined as the increased application of labor and other inputs per unit of land (intensified use of inputs) and more frequent cropping of land through reducing fallow periods (intensified use of land). However, in agricultural economics literature that does not focus on the long-term evolution of farming systems, agricultural intensification is exclusively referred to the intensified use of inputs, while the intensified use of land that often leads to the expansion of cropping areas by reducing forest or fallow land is referred to as agricultural extensification (Tachibana et al 2001).

Treating farming system evolution as well as technologies used under different farming systems as endogenous processes, Boserup (1965), (and later further formalized and tested by Pingali et al. (1987), Binswanger and McIntire (1987) and McIntire et al. (1992)), links agricultural intensification with increased demand for agricultural products. Such increased demand is the result of population growth and improved market access, including both domestic and international market access (which expands agricultural demand beyond farmers' own subsistence needs).

In response to the increases in demand for agricultural products, intensification in agricultural production is also a process of agricultural technological changes, in addition to the increased use of agricultural inputs. Mechanization is a key component of the technology that allows agricultural production to be intensified. When more land has to be brought under cultivation to meet increased market demand, or when existing land has to be more intensively cultivated, which requires more labor use per unit of land, mechanization will be adopted. Therefore, the dynamic relationship between land and labor (or changes in land-labor ratio in particular), as part of the intensification process, is another key factor influencing mechanization. Thus, mechanization, particularly the demand for mechanization, can also be explained by applying the induced technical change framework developed by Hayami and Ruttan (1970, 1985).

Beginning in the early 1970s, Hayami and Ruttan (1970, 1985) and Binswnger and Ruttan (1978) formulated a model of induced technical change in which the development and application of new technology is endogenous to the economic system (Ruttan 2002). This framework allows us to assess emerging demand for mechanization as part of a technology adoption process. The induced technical change model emphasizes agricultural technology innovation and adoption as a continuous sequence often biased toward saving the limiting factor – land or labor - as the relative scarcity of land or labor endowment is reflected in the change in their relative prices (Hayami and Ruttan 1970). In this model, alternative agricultural technologies are developed (and adopted by farmers) to facilitate the substitution of relatively abundant (cheap) factors for relatively scarce (expensive) factors (Ruttan 2002). Mechanical technology is designed to substitute power and machinery for labor and is "labor saving", while biological and chemical technology is "land saving." Moreover, changes in land and labor productivity are relatively independent (Griliches 1968), indicating that adoption of labor-saving technology by farmers is not necessarily driven by an incentive to improve land productivity, which is the case for the adoption of biological technology.

Given the relatively high land-to-labor ratio on agricultural endowments in many African countries, mechanization may play a greater role in African agricultural intensification than

it did in the intensification processes observed in the Asian Green Revolution (GR). In most Asian countries during the GR, land-to-labor ratio was low and rural non-farm employment opportunities were few. In some parts of African countries, including parts of Ghana, Nigeria, Senegal and Zambia, land is more abundant than in many Asian countries that underwent the Green Revolution (Nin-Pratt and McBride 2014). In addition, the urbanization process is more rapid in many African countries in recent years, as many of them rely on natural resource exports, and also as the service sector accounts for a much larger share of their economies than most Asian countries did at similar levels of per capita income. Such structural characteristics of some African economies also lead to the development of "consumption cities" in which urbanization occurs without industrialization (Gollin et al 2013). Migration to the urban areas as well as increased employment opportunities in non-farm services in the rural areas could create pressure on rural wages (Byerlee 1974), even though agricultural land productivity, measured by yield, is still much lower in most African countries than in the post-GR Asian countries. As a result, demand for labor-saving technology could become a necessary condition for further agricultural intensification in some African countries at least in areas with better market access and higher opportunity costs of rural labor. Thus, it is possible that the lack of labor-saving technology limits the potential returns to certain types of land saving technology such as improved seeds, and application of fertilizers and pesticides, unless such labor constraints can be overcome through mechanization (Nin-Pratt and McBride 2014).

3. Demand for Mechanization

Sufficient demand as a precondition for successful mechanization

In general, demand for mechanization emerges at the point when it becomes cost effective for farmers to use it over other available options. Thus, policy interventions aimed at promoting mechanization must first confirm whether sufficient demand is indeed present. Nearly all of the 30 mechanization schemes in Africa from 1945-1987 studied by Pingali et al (1987) failed to recognize the lack of demand amongst farmers. This is seen as one of the key factors that led the governments in these countries to introduce tractors at an inappropriate stage. Without demand in place, tractor hiring services quickly collapsed under these programs, and machines were often left idle, scrapped, or abandoned (Pingali et al. 1987).

It is reasonable to argue that promoting mechanization when demand is insufficient tends to be socially suboptimal and can also have adverse equity effects. As Pingali (2007) argues that where the potential and demand for aggregate land expansion is limited, increased tractor use by medium and large scale farmers is likely to displace tenant farmers or hired labor provided by landless farmers. While this effect has been observed in South Asia (Lockwood et al 1983; Jabbar et al 1983; Singh et al 2013), there is little evidence of it occurring in Africa. Although displacement and adverse equity effects do not appear as strong as suggested by a wave of cross-continental ILO studies in the early 1970s, they nevertheless remain important concerns going forward (Mrema et al 2008).

Components of Mechanization Demand

As mentioned before and further discussed below, demand for mechanized agricultural operations often increases sequentially. Drivers that determine agricultural intensification also influence the sequences of mechanization demand. Moreover, such demand sequences are also affected by

different agro-ecological conditions and the availability of technologies and the ability to maximize their utilization.

Farm Size and Mechanization

In a society where there are both large and small farmers, tractors can be essential for expanding the aggregate area cultivated by large farms, for whom hired labor represents a high proportion of their production cost. The economies of scale associated with a large machine such as a tractor have also made mechanization a more attractive technology to such farms (Binswanger 1986). As a result, the first tractor owners in most developing countries are typically larger farmers, who also provide hiring services to non-owners when it helps them maximize their tractors' utilization.

Such trends have been observed in Asia. In Punjab, India, tractor owners typically own 4 times as much land as tractor hirers (Singh et al 2013); in Thailand, tractor hirers also had much greater landholdings than non-hirers (23 acres compared to 9 acres) (Chancellor 1971). While a significant share of mechanization in Asia has been adopted by smallholders (as described later) cases from Asia show that mechanization is often driven by large farm sizes and enables farmers to further expand their landholdings, though this is not a prerequisite for mechanization to be profitable.

Mechanization in many parts of Africa appears to be following this pattern. North African agricultural has long been characterized by large farm sizes. Meanwhile, Ghana and Zambia are Sub-Saharan examples of countries with land dynamics suitable to mechanization, with rapidly rising farm sizes in recent years leading to medium-scale farmers (5-100 ha) cultivating the largest share of national cropland (Jayne et al 2014). In the 2013 IFPRI/SARI survey of medium-to-large farmers in Northern Ghana, over half of tractor owners cited land expansion as the primary motivation for their investment (Chapoto et al 2014). In the same survey, farmers who hired in tractor services also expanded their land more than those who did not use tractors, though at a much lower rate than tractor owners did (Houssou et al 2015). Likewise, land expansion appears to be a major factor for the adoption of mechanization in Southern Nigeria, mostly to expand the input area of input-intensive rice cultivation, but does not seem to apply in the North, where it substitutes for household labor on small, intensively-cropped farms and allows for the pursuit of off-farm income generation (Takeshima et al 2013). In general, the presence of households with large farm sizes and the potential for area expansion suggests that mechanization is more likely to be feasible, though it is clear that mechanization may also be profitably adopted in the absence of these conditions.

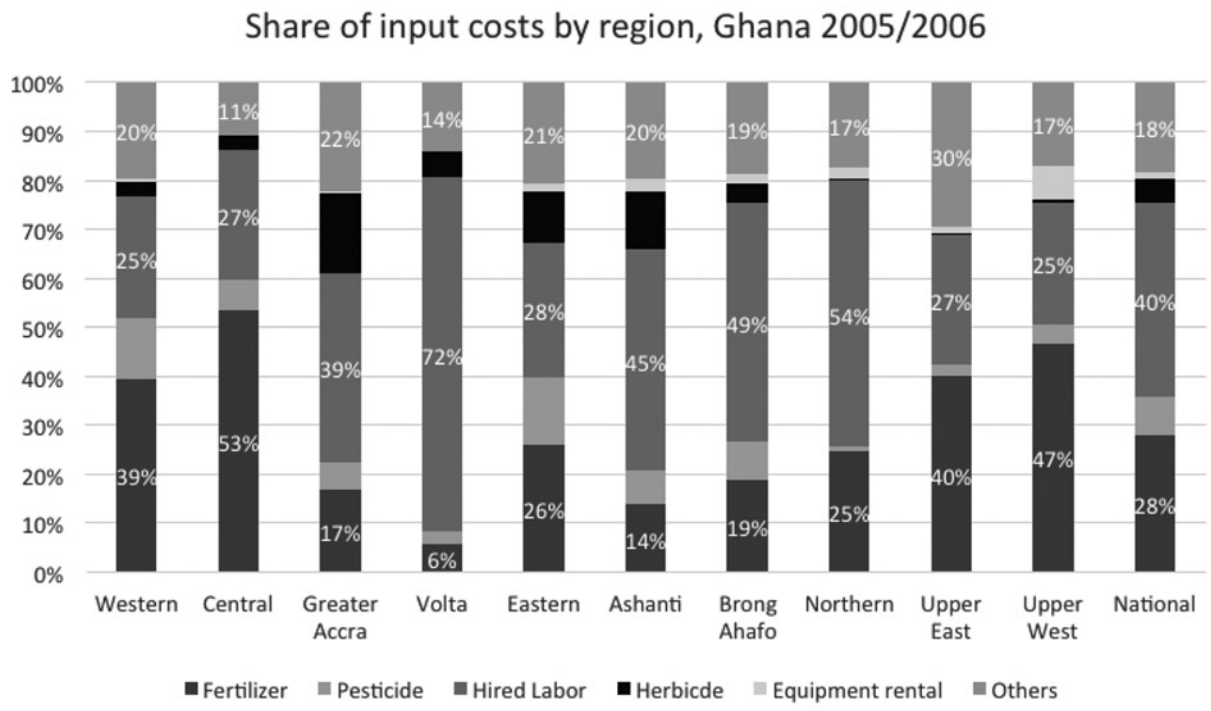
Labor Saving Effects of the Mechanization of Certain Operations

Mechanized plowing significantly reduces the amount of labor required for land preparation and typically results in small decreases in the labor required for weeding and harvesting (Pingali et al 1987). Where hired labor represents a relatively large share of production costs, even smaller farmers, begin to demand mechanization technology when labor cost starts to rise in order to reduce their labor and total production costs. For example, according to data from GLSS 5 (Ghana Living Standards Survey 5) for 2005-06, hired labor represents 40% of paid input costs on average in Ghana, compared to 28% for fertilizers (Figure 1a)[2]. This cost share is even higher in the relatively land abundant northern regions of Ghana, even though per capita income is lower in the north than in the south in Ghana; the share of hired labor costs is around 50% in Northern

2 Note that Ghana's fertilizer subsidy was not in effect during the GLSS5 period, but was during the GLSS 6 period

region and Brong Ahafo regions of Ghana, which are two of the more mechanized regions in land preparation. Interestingly, fertilizer and hired labor both account for a lower share of total production costs in GLSS 6 (Figure 1b), along with an increased share of expenditure on herbicides, which can also be considered a labor saving technology through limiting weed growth. The share of expenditure on hired equipment also rose significantly in Northern and Upper West regions, to 14 and 17 percent, respectively, though it is not clear what type of equipment this refers to. This may reflect the trends of mechanization adoption that took place during this period in Northern Ghana.

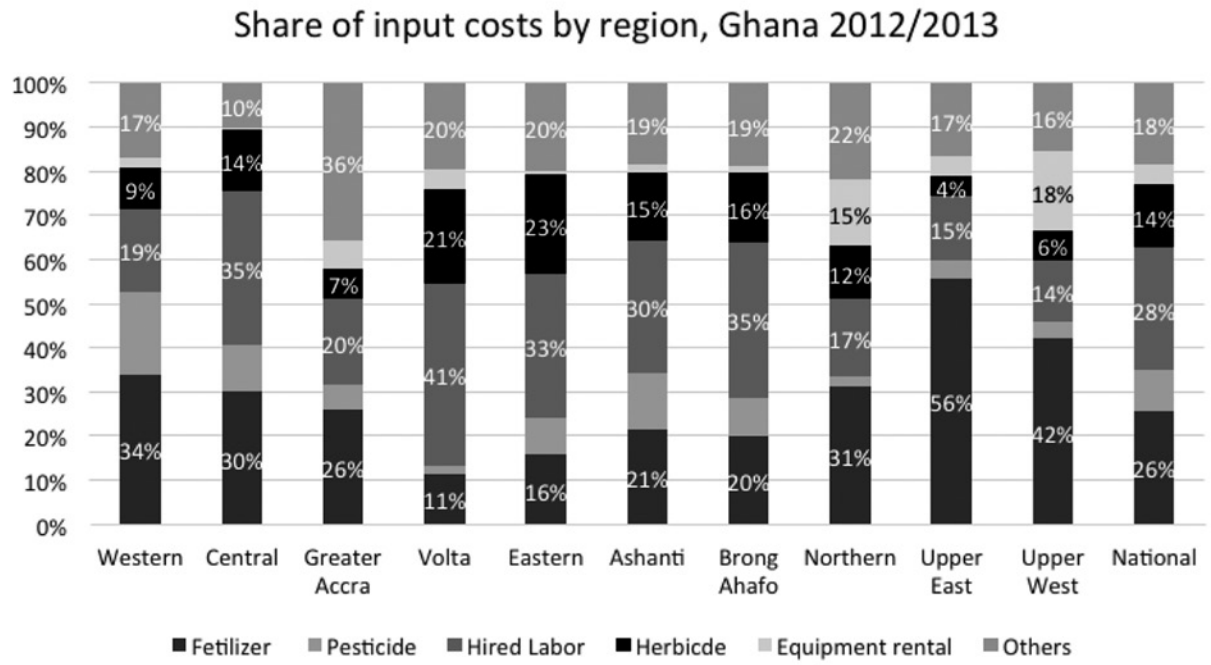
Figure 1a: Shares of Input Costs by Region, 2005/06



Source: Authors' calculations using GLSS 5 data (GSS 2008)

While mechanized land preparation reduces required labor for this operation, it does not necessarily reduce the overall demand for labor. In a survey conducted in Botswana, Panin (1995) finds that, among the surveyed farmers, tractor use actually increased labor requirements compared to fields plowed using draught animals, as tractor plowing reduced the labor input for plowing, but raised the required labor for weeding, harvesting and threshing. In regions where draught animals are not an option for plowing (including many parts of West Africa), tractor-based mechanization typically enables farmers to save labor for weeding as well as land preparation, as weeds typically regrow more slowly in fields plowed by tractors (Pingali et al 1987) In this case, mechanization likely increases overall profitability for farmers. These labor saving benefits are one of the reasons why mechanization has recently spread widely among smallholders in many Asian countries, even where farm sizes are small. Bangladesh and other South Asian countries are often cited as prime examples for this (see Success Story 1).

Figure 1b: Shares of Input Costs by Region, 2012/13



Source: Authors' calculations using GLSS 6 data (GSS 2014)

Reducing the drudgery associated with farming is often used by many African countries' governments to justify their intervention in promoting mechanization. Such drudgery is part of the nature of farming. However, it seems that such drudgery has increasingly become important in explaining opportunity cost of labor, particularly for youth farmers. Many agricultural operations are strenuous and are often carried out by women and children. It is often believed that drudgery of manual agricultural labor can make farming unattractive to youth and influences them to seek off-farm employment that can be potentially less productive (Mrema et al 2008). However, while this theory appears plausible, empirical evidence for this is still scarce.

Success Story 1: Emerging Mechanization Demand among Smallholders in Bangladesh:

Although almost 60% of smallholders in Bangladesh have farm sizes less than 0.2 ha and 80% have less than 0.6 ha, many of them reported to use power tillers in a recent IFPRI survey (Ahmed 2013). According to Biggs et al. (2011), over 80% of land preparation in Bangladesh is done by 2-wheel power tillers, mainly imported from China. Power tiller hiring services operate beyond land preparation and include threshing, water pumping and transport (Diao et al 2014). A similar situation also exists in Sri Lanka, also a smallholder dominant Asian country, where 80% of land preparation is done by 2-wheel power tillers (Biggs et al 2011; Chancellor 1971). However, the feasibility of mechanization among such extremely small scale farmers in Asia may be also due to the prevalence of irrigated rice production, which covers 55% of cultivated area in Bangladesh (Biggs et al 2011).

Demand for labor saving mechanization can be high in Africa when timing of operations significantly affects productivity. Labor bottlenecks occur due to short planting windows in semi-arid areas with few days of rainfall and in areas with bimodal rainfall that practice multiple cropping, where the first season's crop must be harvested and threshed before plowing and planting for the second season can take place (Cossar 2015). In the latter case, the combination of mechanized plowing, harvesting and threshing, along with irrigation and improved cultivars, has been instrumental in allowing two or three rice crops to be grown in a year in many parts of Asia (Pingali et al 1987; Pingali 2007). In high-population density areas, overcoming such seasonal labor bottlenecks is considered the one of most significant potential advantages of tractorization (Boserup 1965). In the IFPRI/SARI survey of medium-to-large farmers in Ghana, timeliness of plowing was the second most common motivation for owning a tractor among farmers in the Savannah and Transition zones after area expansion (Chapoto et al 2014). In these areas, with typical rainfall window of 45 days, farmers are faced with significant potential yield losses from delayed planting; a one day delay for planting maize in Ghana can result in a loss of 1% of potential yield and a two-week delay can cost between 30 and 55% of potential yield (Houssou et al 2014). Similar observations have been made for maize in Zambia by Haggblade (2005). This provides an incentive not only for farmers to use tractors over hired labor, but also makes ownership more attractive than obtaining services from the hiring market, which cannot always be relied upon to arrive on time or at all. Houssou et al (2014) find that accounting for the timeliness benefits of owning a tractor revealed tractors to be profitable for 83% of owners as compared to 54% when considering service provision revenues alone.

Demand for mechanization as a labor-saving technology may be high in Africa because of recent economic structural changes in many countries leading to the scarcity of rural labor. As structural change unfolds, more rural households are diversifying into non-farm income activities, which creates an additional opportunity cost for family farm labor (Diao et al 2014). In many African countries, the scarcity of rural labor may thus make mechanization attractive if domestic food production possesses a comparative advantage over imports. Substantial demand for mechanization can exist in some areas of a country where even urbanization is still low for the country as a whole. Ethiopia and Tanzania have 80% and 70% rural populations, respectively, and demand for mechanization is increasing in some areas of these two countries. As observed in field visits conducted by IFPRI, privately owned combine harvesters and tractors, as well as power tillers are common in some areas in Ethiopia and Tanzania. Increased demand for hired services by smaller farmers is often one of the main reasons mentioned by machinery owners, who are often medium to large scale farmers, to justify their investments in costly machinery[3].

Market Demand

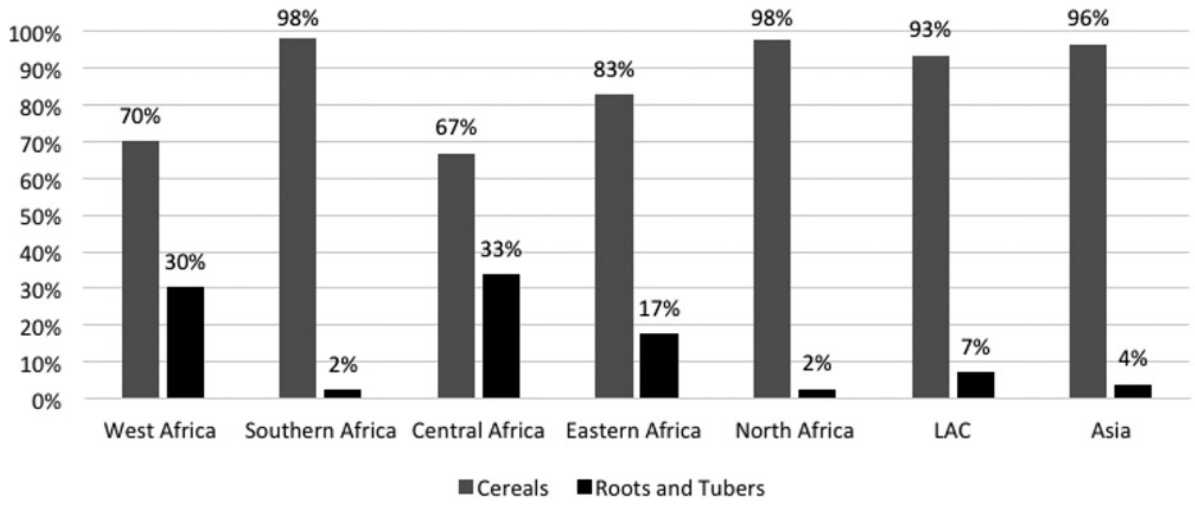
As mentioned above, sufficient market demand for agricultural products is a key driver of intensification. Without assurances of market access for their products, farmers will be reluctant to expand commercial production into potentially available cropland (Chamberlin et al 2013). In

3 Concerns remain regarding the potential labor displacement effects of mechanization. The overall effects are complicated because labor saving through mechanization on certain farming operations have ambiguous effects on overall labor requirements when subsequent operations are also considered. Tractorization can increase aggregate overall farm labor demand when it leads to aggregate area expansion and/or facilitates the adoption of labor-intensive inputs. Even where mechanized plowing reduces the per area labor requirements for weeding and harvesting, such effect is likely to be outweighed by the increase in land under cultivation. This is an important rebuttal to some criticisms lodged against mechanization, especially in Africa, which appears to have greater potential for labor demand growth through area expansion, compared to the displacement observed in parts of Asia (Pingali et al 1987). More broadly, the actual labor displacement effects must be assessed within the framework of labor markets function, and effects of mechanization on local food price that also affect real wages. On this, evidence in Africa still appears scarce.

Ghana, intensification as a whole and mechanization in particular appear to be fairly correlated with market access (Cossar 2015). However according to Binswanger and Savastano (2014), elements of intensification (not including mechanization) appear to be only slightly correlated with population density and market access in the six LSMS-ISA countries.

Urbanization and structural change increases demand for the crops consumed by the urban population, which favors cereals over roots and tubers. Cereals typically have higher labor requirements than roots and tubers in certain concentrated time periods, in addition to their greater marketability. Urban staples such as teff, wheat, and rice are considered by Alesina et al (2013) as more conducive to mechanized plowing, or "plow-positive," while rural staples such as cassava and yam are "plow-negative" as land preparation typically requires the construction of mounds by hand (Ngeleza et al 2014). The area shares of "plow-negative" crops like cassava and yam are relatively higher in Africa, compared to Asia or Latin America (FAOSTAT 2015). Mechanization is also not suitable in areas with tree crop systems, such as cocoa and oil palm, and is even constrained for cereal crops in forest zones by the difficulty of removing tree stumps that can damage equipment. Therefore, mechanization may be more readily adopted in grassland areas with cereal and other marketable staple cropping systems. In the areas dominated by roots, tubers, and tree crops, additional technological innovations may be required for increasing the demand for mechanization. Figure 2 illustrates the area cultivated under cereal and roots and tubers by African sub-region, compared with Sub-Saharan Africa as a whole, Latin America and the Caribbean, and Asia.

Figure 2: Share of cultivated area of cereals and roots/tubers, by region (2014)



Source: FAOSTAT

Complementary Technologies

The costs and accessibility of complementary non-labor inputs may also affect the returns from mechanization, and thus demand for it. As predicted by Boserup (1965), the adoption of land-saving technologies such as chemical fertilizers during the intensification process requires additional labor input, which thus creates demand for mechanization. Binswanger (1978) found that though yields were significantly higher on farms in South Asia that plowed with tractors, almost all of these instances could be attributed to greater use of fertilizer. Indeed, mechanization appears to be correlated to fertilizer and herbicide use in Northern Ghana, with herbicide being used as a

complement to tractors, killing weeds before tractor plowing (Cossar 2015). Moreover, Nin-Pratt and McBride (2014) find that the use of land-saving technology in Ghana is generally inefficient except when combined with mechanization, suggesting that the availability of mechanization is important for making the use of labor-intensive technologies feasible.

The relationship between demand for mechanization and the availability of complementary technologies is further demonstrated in rice irrigation systems in West Africa. Power tillers and harvesters in Kpong Irrigation System in Ghana were initially brought in through government subsidy and are being hired out by owner-operators to cover the entire irrigation system area (though this may only be possible because there are many small plots close together). Private investors have subsequently brought in power tillers and combine harvesters, the latter of which are used on 48% of the system's area (Takeshima et al 2013). The profitability of irrigated rice production appears to have spurred demand for mechanized tillage and harvesting, along with demand for seeds, fertilizer chemicals, a land leasing market, and private milling. While the sequence of technology adoption is unclear, it is apparent that mechanization plays a key role in a successful instance of agricultural transformation (Takeshima et al 2013).

It is important to clarify that mechanization generally does not directly improve yields, as there is typically no significant difference in yields between tillage with hand hoes, animal traction and tractors. The exception to this is where heavy soils cannot be tilled by hand and where mechanized plowing can better incorporate crop residues (Pingali et al 1987). However, mechanization may indirectly improve yields by inducing the adoption of complementary technologies and allowing time-sensitive operations to be completed during the appropriate intervals as discussed above.

Utilization and Income Generation Potential

The scope and profitability of service provision is an important component of medium to large farmers' demand for mechanization equipment, although the details of different service provision models will be discussed in its own section. Where there is high demand for mechanization among farmers, tractor owners can benefit from hiring out mechanization services, even if area expansion is not possible due to land constraints or a weak tenure system. This holds true for both tractors and animals, where the hiring market has helped owners surpass the breakeven acreage plowed to realize a profit on their investment (Houssou et al 2013, 2014). Beyond hiring out services to local farmers, some owners may opt to migrate with their machines to areas with different seasons for plowing and harvesting. In China, this has enabled small sized combine harvester owners to be active 8 months per year, a model which will be discussed in depth later in this paper (Zhang et al 2015). The use of tractors and power tillers can also be extended to functions beyond land preparation by using the engine to power a tractor-mounted threshing machine or water pump or through hiring out transport services. However, if the hiring market is unattractive for the primary use of tractor in plowing, which can occur due to a lack of farmer demand for hiring-in such services, fragmented farmland that increases the cost of service provision, or service charges being depressed by government subsidized provision, then the incentive for owning machines is reduced.

Learning and Demonstration of Mechanization's Benefits

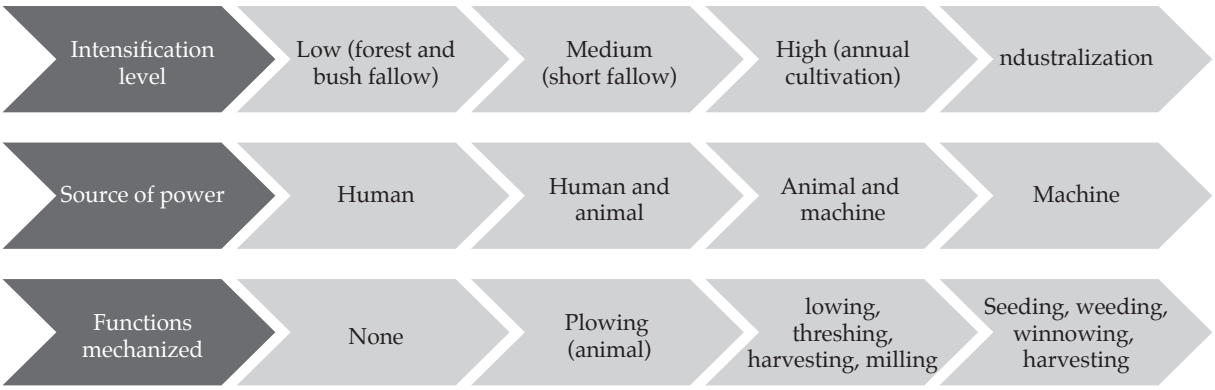
Learning and technology spillover effects may be important for explaining the diffusion of mechanization technology. Tractors and other large machines are highly visible technologies whose effects can be observed from their owners' farms as well as being sampled by hiring in services

(Cossar 2015). Indeed, 90% of surveyed tractor owners in Ghana hired in services before purchasing their machines (Chapoto et al 2014). When new owners are familiar with service provision models as well as the machines themselves, it may also help them overcome the adjustment costs of tractor adoption. The potential for these effects underscores the importance of developing networks of tractor owner-operators for spreading demand across potential owners. Demonstration has in fact been cited as a major motivation for a number of government tractor schemes and appears to have had such an effect in Thailand and Malaysia, despite the financial unsustainability of those programs (Chancellor 1971). However, empirical evidence is scarce in Africa as to how much learning and spillover affect the demand for mechanization.

Sequences of Mechanization Demand

Now that the components of mechanization demand have been identified, this section turns to discuss the sequences in which demand for different modes of mechanization emerges. As described by Pingali et al (1987), the demand for mechanization emerges sequentially based on the different functions being mechanized, the different types of mechanization technology and different categories of farmers. Power intensive functions, beginning with plowing and including threshing, milling and transport, are the first to be mechanized while control intensive functions, such as weeding and winnowing, are typically only mechanized when wage rates have dramatically risen (Pingali et al 1987). It is also believed that stationary operations are typically mechanized before mobile operations (Rijk 1999). Demand for animal power, where feasible, also typically emerges before the demand for machine power (Pingali et al 1987). Figure 3 provides a general illustration of these processes.

Figure 3: Overview of sequential adoption of mechanization



Source: Adapted from Pingali et al 1987

Demand for mechanized plowing

Plowing is typically one of the first major operations to be mechanized. Both animal and tractor plowing for land preparation is adoptable only after the shift to annual cultivation.

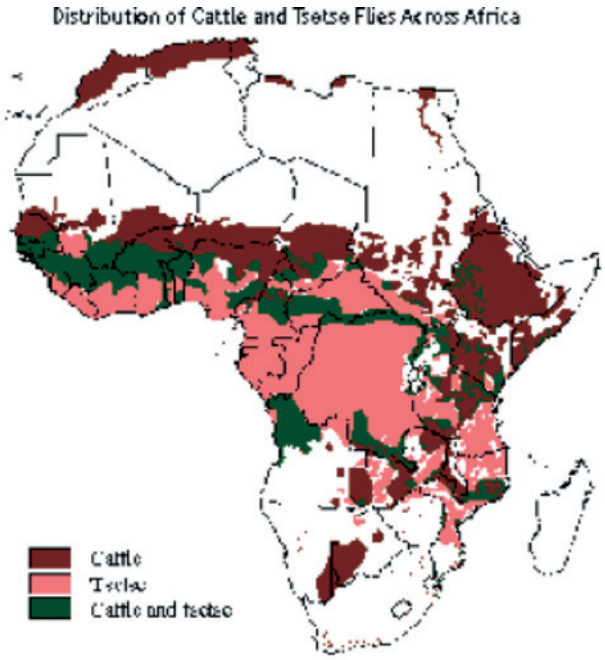
Demand for Animal traction

According to Pingali et al (1987)'s framework, animal traction becomes profitable in the grass fallow stage. At this point, population density is at least 16-64 persons per sq. km and the requirement of removing tree stumps from fields disappears but there is still ample land for fodder

crops and grazing. However as systems further intensify, land for grazing and fodder crops begins to disappear, making maintaining draught animals more difficult.

The presence of tsetse flies, which cause trypanosomiasis in cattle, can be a prohibitive constraint to keeping livestock, though their presence is reduced as population density increases (Pingali et al 1987). Figure 4 shows the distribution of cattle and tsetse flies across Africa, indicating that tsetse flies affect livestock in much of West Africa, except for less fertile Sahelian regions, though they are less common in parts of East Africa. In addition to trypanosomiasis, there has also been a reduction in draft animal use, even in areas where it was common, due to droughts, disease, theft, and poverty forcing households to sell off their assets (Bishop-Sambrook 2005). Climatic and market factors may also help explain the scattered adoption of animal traction. The short duration of planting periods and light, sandy soils render animal traction unprofitable in Sahelian zones in Burkina Faso and Niger (Jaeger and Matlon 1990; Williams 1996). Demand for animal traction is greater when it is used for cash crops with a ready market such as groundnuts and cotton in West Africa (Jaeger and Matlon 1990). In the Sudan savannah in Niger, adopting animal traction may require a shift from root crops to these cash crops in order to be profitable (Williams 1996).

Figure 4: Map of Cattle and Tsetse Fly Distribution in Africa



Source: Bovine Trypanosomiasis Consortium 2013

The cost components of animal traction go beyond the cost of animals and implements. They include feed costs, the costs of animal maintenance, which includes the direct and opportunity cost of grazing and fallow land and veterinary services. A significant adjustment cost may arise for households who must acquire new skills and reallocate their labor. While this may be less pronounced in communities with a tradition of cattle keeping, the adjustment period has been found to prevent the utilization of animals from reaching economic levels until up to seven years (Jaeger and Matlon 1990). Moreover, these costs apply year-round, while the benefits of plowing

are only realized a few months per year. In some historical cases, owning draft animals required greater economies of scale than tractors (Jasny 1935), though it is not known if this applies currently in Africa.

Draft work is in many cases not the primary motivation for owning animals (Lawrence and Pearson 2002); they also contribute milk, meat and organic fertilizer, serve insurance and social purposes, and appreciate in value over time. These other purposes of livestock ownership must also be taken into account, as they may affect the willingness of farmers to use livestock for draft purposes. Hiring livestock out for plowing as well as transporting goods helps to offset costs as well; in the two northernmost regions of Ghana, hiring out plowing services enabled 71% of surveyed animal owners to surpass the breakeven number of acres plowed and realize a profit on their investment (Houssou et al 2013).

Thus while the typical components of mechanization demand also apply to animal traction, there are plenty of potentially limiting factors along with broader benefits attainable from animal traction. This is likely to lead to clusters in which it is profitable, sustainable and thus widely adopted, and other areas in which it is not feasible and rarely observed. In such areas, it may be feasible, or in fact necessary, to bypass animal traction and transition directly from the hand hoe to engine-powered mechanization.

Demand for large and small tractors

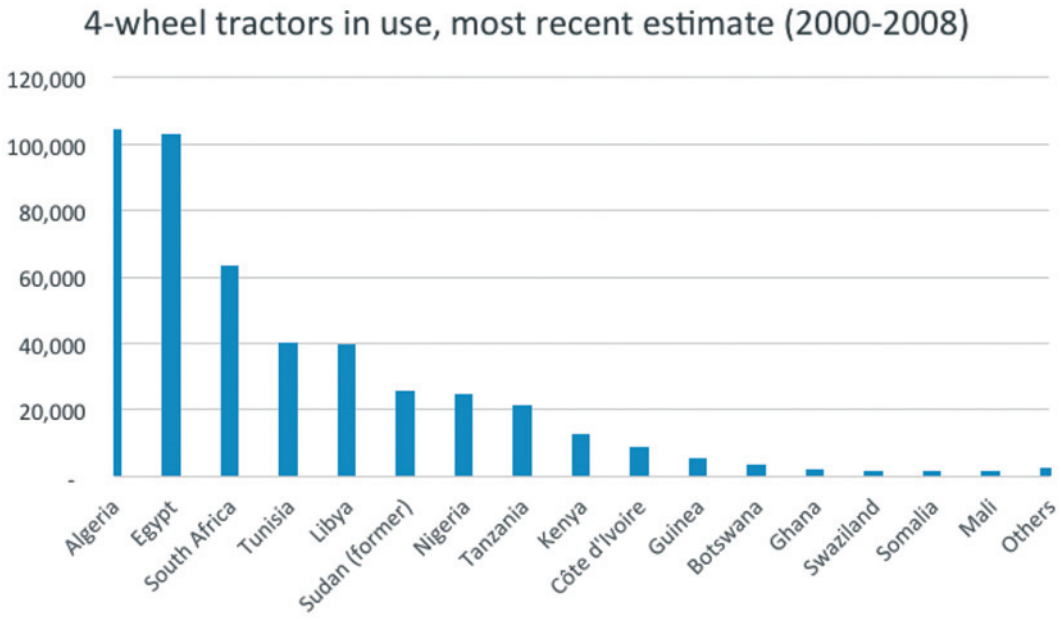
When population density rises to the level where annual cropping is needed, the adoption of tractor plowing may become profitable (Pingali et al 1987). Tractor use typically follows animal traction in areas that have adopted it; however in flood plains, valleys and treeless highlands, as well as areas not suited to keeping draught animals, tractor use may emerge directly following the hand hoe. In these treeless areas, de-stumping costs do not prevent the use of the plow and there may be more favorable production conditions, especially for irrigated rice (Pingali et al 1987). On the other hand, tractors cannot be used in areas with high slopes or other difficult terrain; these areas may favor intensive cultivation with hand hoes and increased production of dairy and tree crops (Pingali et al 1987).

FAO's definition of tractors only covers 4-wheel machines and excludes 2-wheel power tillers, which are separately (and often incorrectly) classified as "pedestrian controlled tractors" despite performing the same tasks as 4-wheel tractors (Biggs et al 2011). Demand for power tillers, which typically have 20 horsepower or less, is influenced by their lower cost compared to 4-wheel tractors, their greater maneuverability and ability to be fully utilized in systems with small landholdings, potential for off-farm use and their suitability for wet paddy. Especially due to the first three of these reasons, many proponents of mechanization have advocated for the promotion of 2-wheel tractors in Africa, although they have rarely been adopted except where directly promoted by governments (Kahan and Jaleta 2015). However, 2-wheel tractors are not suitable for conventional tillage of dry heavy soils, and are often believed to be not easily applicable in much of Africa. These factors help explain their rapid rise in Asian countries such as Bangladesh, Sri Lanka and Vietnam as well as their presence in West African irrigation schemes, as well as parts of Tanzania and Ethiopia (Biggs and Justice 2015; Takeshima 2015; CIMMYT 2015). On the other hand, 4-wheel tractors are more popular than 2-wheel tractors in other parts of South Asia, typically where rice – non-rice crop rotations are common (Pingali 2007).

Limited data is available on the number of tractors currently in use in different countries, which

only includes data on 4-wheel tractor use in 24 African countries. As can be seen from Figure 5[4], these tractors are heavily concentrated in North African countries and South Africa, followed by large countries with large commercial farming sectors such as Nigeria, Tanzania and Kenya.

Figure 5: Most recent available estimate of 4-wheel tractors in use



Source: FAOSTAT

It is also important to distinguish demand for different sizes of tractors. One might expect small and medium scale farmers in Africa to favor 2-wheel power tillers and smaller 4-wheel tractors, which are cheaper and require less land to be fully utilized. This has ocurred in much of Asia, with the rapid spread of power tillers and the tendency towards small 4-wheel tractors of 20-40 HP in India (Diao et al 2014).

Table 1: Average 4-wheel tractor horsepower in selected countries

	Burkina Faso	Ethiopia	Ghana	Kenya	Mozambique	Nigeria	Zambia
Estimated Average Tractor HP	40-60	102.3	60-80	101.4	84.9	65-80	65

Source: World Bank (2014b)

However, as can be seen from Table 1, tractors in Africa are much larger than those in Asia in all of the above countries. While farm sizes tend to be larger in Africa than in Asia, they do not appear large enough to fully explain the difference in tractor size; according to Chancellor (1986), only 16 HP of mechanical power is needed to plow 20 ha. While hiring out services is a way to

4 "Others" refers to the following countries for which data was available that had fewer than 1,000 tractors in use as of the most recent available estimate: Senegal, Madagascar, Eritrea, Mauritania, Togo, Rwanda, Cabo Verde and Djibouti

make machine ownership profitable when they cannot be fully utilized on the owner's farm, it is not typically the primary motivation for tractor ownership (Chapoto et al 2014). Therefore, it does not appear likely that the potential for hiring out services motivates farmers to purchase larger machines. Moreover in most other regions, tractor sizes were much smaller in earlier stages of mechanization and increased as farms expanded and farm households became wealthier. In Ghana and Nigeria, the initial adoption of large tractors does not appear to follow this pattern and there also do not appear to be sufficient savings in cost per horsepower attained by large tractors to explain their dominance (Takeshima 2015). Although there are no definitive explanations for this trend, farmers may prefer high horsepower tractors from observing the large sized tractors typically used on state and commercial farms before acquiring theirs. This perception effect may influence farmers when they start to invest in tractors, and the prestige of owning large machines may also be seen as a worthwhile investment. The determinants of demand for tractor size is thus a topic that merits further research.

Demand for post-harvest mechanization

According to Pingali (2007), the demand for mechanized threshing emerges in two phases. First, crops are harvested manually and then threshed using pedal or engine powered machines; once demand for mechanized harvesting emerges, combine harvesters are adopted and take over threshing operations. Demand for mechanized threshing occurs when harvested volumes increase due to higher yields and when multiple cropping creates a labor bottleneck between the harvest period and the next planting season, even when wages are low (Pingali 2007). These circumstances are especially likely to affect medium-scale farmers, who are more dependent on hired labor. When these constraints intensify and wages rise, combine harvesters may begin to be adopted and perform both harvesting and threshing operations. Significant losses of grain, to the order of between 20-35% depending on the crop and system, also arise from manual threshing compared to using a combine harvester (Hassena et al 2000). Moreover, manual threshing is one of the more arduous agricultural tasks and is typically carried out by women.

Relatively inexpensive threshing machines are often fabricated locally and are available on the market in many African countries. Owners can easily hire out threshing services when there is demand for mechanized threshing among other farmers. In the Senegal River Valley, 86% of surveyed rice producers who were exposed to the ASI thresher adopted it (Diagne et al 2009), implying not only that there is demand for mechanized threshing among farmers in high-potential rice areas, but also that locally developed technology can (to a degree) meet this demand. Tractor mounted threshing machines are also available and may be instrumental in extending the use of tractors beyond the plowing season, which may provide a further incentive for tractor owners to mechanize threshing (Houssou et al 2014).

Demand for mechanized harvesting

Harvesting of grain and root crops is a control-intensive function that also requires substantial power input. Therefore, it is always mechanized after mechanized plowing and threshing are adopted and is rarely profitable in low-wage countries (Binswanger 1986). Because of this, one would expect demand for mechanized harvesting to be quite low in Africa and only occur where wages are exceptionally high. Harvesting can be mechanized through reaper machines or through small and large combine harvesters that both harvest and thresh the grain (Rickman et al 2013). While it is rare overall, there do appear to be pockets in which demand for mechanized harvesting has emerged, mainly in cereal systems such as those for wheat in Kenya and Ethiopia as well as

in rice irrigation schemes, mainly in West Africa (Lugogo and Longmire, 1989; Hassena et al 2000; Takeshima et al 2013). In many of these cases, taking into considerations of labor cost of threshing and crop loss of manual harvesting and threshing, hiring in combine harvester services is attractive and is even cheaper than hiring labor for manual harvesting and threshing, which creates demand for hiring such services among smallholders in some areas. Nevertheless, continental demand for mechanized harvesting will likely be limited until a sharp rise in rural wages is observed and/or large farmers that can afford to invest in a machine become more common.

Spatial Variations of Mechanization Demand

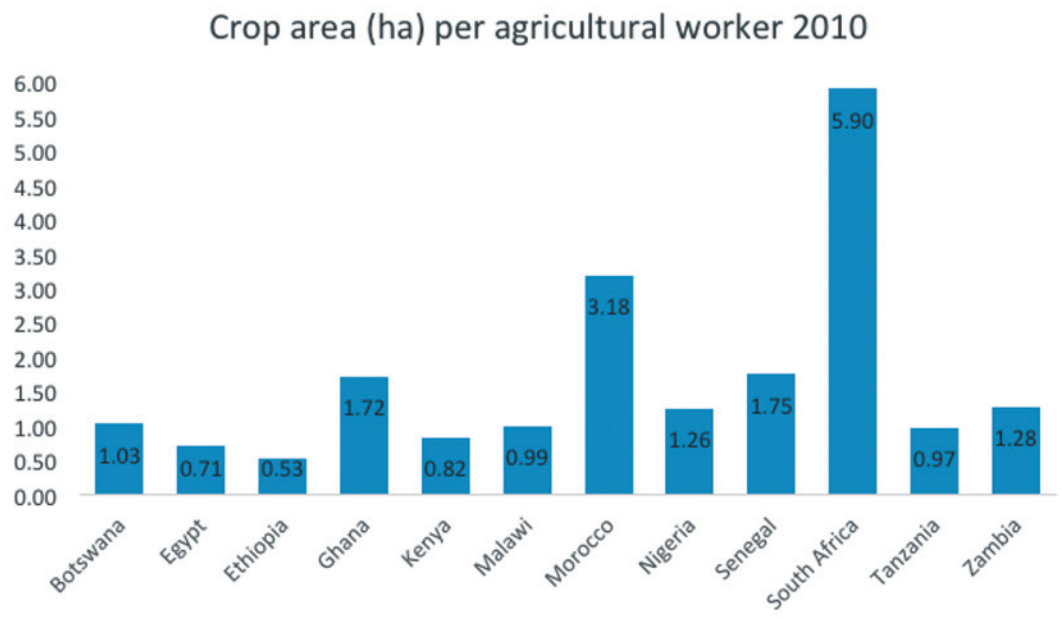
Due to the complex and diverse components of demand discussed above, both the potential demand and adoption of mechanization can be expected to exhibit much spatial variation. This is also because agricultural production is largely influenced by agro-ecological conditions that vary across regions. As such, national statistics and data cannot reveal the clear picture of the demand. The estimates below (Table 2), collected from national ministries and reported by the World Bank, illustrate the low but diverse levels of mechanization in Africa using 4-wheel tractors as a proxy. However, these figures belie the diversity of mechanization types and variation within countries. Moreover, some of the countries with very low tractor density figures, Ethiopia, Ghana, Nigeria and Tanzania in particular, appear to be making some of the most notable progress towards mechanization. The same appears to be true of national statistics on cropland available per agricultural worker (Figure 6); low availability of land per worker on a national level may obscure the presence of regions in which there is still land available for commercial production and requires labor-saving technology in order to cultivate.

Table 2: Tractors per 100 sq km of arable land

Country	Burkina Faso	Ethiopia	Ghana	Kenya	Mozambique	Nigeria
Tractors	8.9	4	11	26.9	12.7	5.7
	Rwanda	**South Africa**	**Tanzania**	**Tunisia**	**Zambia**	**Zimbabwe**
	1.3	43	7.4	143	20.7	35.6

Source: World Bank (2014b); FAOSTAT

Figure 6: Crop area per agricultural worker



Source: FAOSTAT; GGDC

For example, Ethiopia's high population density and low availability of agricultural land per worker would make it ill-suited to mechanization. With an extremely low tractor density of 4 per 100 square km, Ethiopia would be overlooked in a discussion of mechanization predicated upon national statistics, yet there is still a vibrant mechanization process going on in parts of the country. While these statistics are influenced by the densely-populated central highlands where tractor use is minimal and animal traction is popular, mechanized commercial agriculture is being vigorously pursued in the Western Highlands, where fertile land is still available (Berhane 2014). Likewise, while Zimbabwe with a tractor density of 35.6 per 100 square km appears quite tractorized relative to other African countries, over 75% of tractor use is concentrated in the A2 (commercial) farming sector, suggesting limited access to tractors among the majority of smallholder farmers (Kienzle et al 2013). Thus national-level statistics may fail to capture the full dynamics of mechanization use.

In Ghana, demand for mechanization also can vary between neighboring districts, largely corresponding to population density and market access (Cossar 2015; Houssou et al 2015). There can also be significant differences in tractor service charges across districts, which amounts to twice larger breakeven size of plowed land for tractor investment between two districts (Houssou et al 2015). Animal traction in Ghana is also concentrated in a few districts in the two northernmost regions and is barely used at all in the rest of the country (Houssou et al 2013). Similar spatial difference in mechanization trends are exhibited in Zambia, where 60% of tractors are located in two (Central and Southern) of the country's nine provinces and in Kenya, where mechanization is clustered in the high-potential Rift Valley and Western Lowlands (World Bank 2012d; 2013a). In Nigeria, adoption of both animal traction and tractors is concentrated in the Central and Northern zones, rather than root-crop based Southern zones (Takeshima et al 2013).

Bishop-Sambrook (2005) undertakes a study of 14 communities in 7 African countries which helps illustrate some of the diversity across communities. She details the evolution of manual labor, animal traction, and tractor-based systems and shows their differences between and across

countries, which provides a brief snapshot of the variations that exist in mechanization demand. For example, the figure of 34% of farmers that use tractors (along with 10% animal traction use) in Mvomero, Tanzania both belies the figures of sparse mechanization use on the national level and contrasts with the 60% of farmers who use animal traction (along with 10% tractor use) in Msingisi, which is also a maize-dominant system in Morogoro region. As a comparison, other studies in districts of Western Tanzania have placed animal traction use at over 90% (Shetto et al 2000; Starkey and Mutagubya 1992). There are also differences at local levels between the proportion of farmers obtaining services from their own animals/machines or the hiring market.

In summary, mechanization is typically adopted when farmers desire to expand their land or to overcome labor constraints, when market demand for their products is increasing (not just for cash crops but with food crops as well), and when utilization of machines through hiring market can be improved. In most cases in Africa, these factors experience much spatial variation, which requires more in-depth and localized data to accurately describe mechanization both across and within countries in Africa.

4. Mechanization Supply Chains in Africa

After reviewing factors that determine mechanization demand, this section focuses on the supply side of mechanization by providing a detailed overview of the supply chains for engine-powered mechanization in Africa.

The Supply Chain as a Framework

A supply chain refers to the processes of production and distribution of a good or service across different actors. Applying a supply chain approach to analyze mechanization is a useful framework to describe the extent and typology of mechanization processes taking place in Africa and to identify the bottlenecks where supply is not meeting demand. The supply chains for mechanization cover the manufacturing and importation of machines, mechanized service provision, and spare parts and repairs services for machinery maintenance. The supply chain for animal traction is integrated with broader livestock value chains and is therefore not discussed here in the supply chains for mechanization.

Development of Supply Chains

Important components of supply chains arise from experiences with technology inherited from past generations, exogenously introduced, or adopted through induced innovation. There is not a widespread tradition of agricultural mechanization technology from before the colonial era in Africa. While some cultures have a history of animal husbandry, the ard plow or maresha in Ethiopia is perhaps the only animal traction implement predating the colonial era known in Africa (Pingali et al 1987). Elsewhere, animal traction and engine-powered mechanization were mostly introduced by colonial governments and settlers. While in some cases, colonial and post-independence governments continued to actively promote mechanization, technology diffused more naturally in others. Induced innovation theory, as put forth by Binswanger and Ruttan (1978), suggests that farmers will invent or adopt technologies based on changes in factor endowments, with attempts to replace scarce factors with abundant ones. This appears to have been the case for the development of animal traction in many parts of East Africa, where agricultural intensification was brought about through natural population pressure and a shift towards marketable crops such

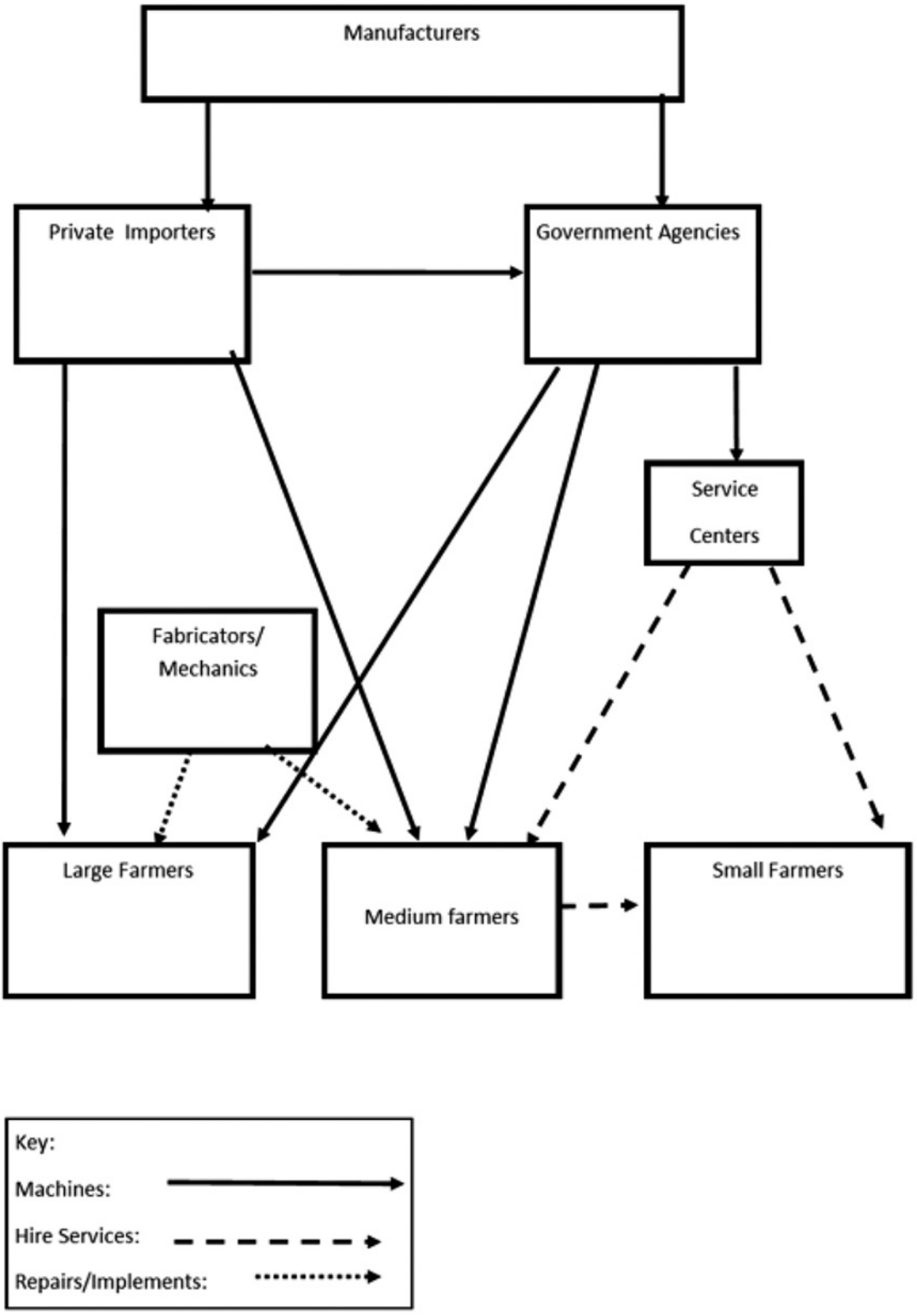
as cotton influenced by the colonial administration and the construction of railroads (Pingali et al 1987).

The drivers of mechanization adoption also influence the types of supply chains developed. Where private demand naturally occurs, the supply chain that emerges generally is shaped by the nature of the demand and the technologies favored by owners and users are typically either developed or imported. However, when mechanization is introduced, mainly through governments or international NGOs, the type of technologies brought in are not necessarily suited to local conditions. For example, large heavy plows designed for European oxen and soils fared poorly in most African conditions during colonial animal traction promotion efforts (Pingali et al 1987). Today, a similar case is observed between the parallel private and government market channels for tractors in Ghana. Used tractors of the brands preferred by farmers, for which spares and repairs are available, are mainly imported by private traders. Meanwhile governments frequently import new tractors of the brands to which they has preferential access through concessional loans, with which mechanics are less familiar and spares parts are not widely available (Diao et al 2014). Nevertheless, private supply chains do not always have the capacity, at least in the short term, to deliver the full range of machines and services demanded by farmers, and thus may require technical, policy or coordination support in order to perform efficiently.

Key Players and Their Functions in Mechanization Supply Chains

The supply chain for new machines used in Africa originates with manufacturers, almost all of whom are large multinational companies based in the US, Europe or Asia. The heavy reliance on foreign multinational companies as suppliers of tractors contrast with smaller machines such as threshers and other simple implements, which are often fabricated locally in a number of African countries. There are three main importation channels in African countries, which includes direct government importation of new machines, and the private importation of new and secondhand machines. In some cases, a government may also import machines through a private company. There are then three main models of service provision: (1) direct government service provision, which offers plowing services to farmers from public hiring stations, often at a subsidized price, (2) specialized private service provision models, which are ostensibly private enterprises that hire out mechanization services without their own cultivated farms (in Ghana and Nigeria, they have been established through a government credit scheme), and (3) private farmer-to-farmer service provision. The end users of mechanization technology are large, medium and small farmers, who exhibit distinct usage patterns under different circumstances. The supply chain is supported by retailers of imported and second-hand tractors, spare part dealers, fabricators and mechanics. The layout of the supply chain is illustrated in Figure 7 and is described in greater detail in the following sections.

Figure 7: A Supply-Chain Diagram for Mechanization in Africa



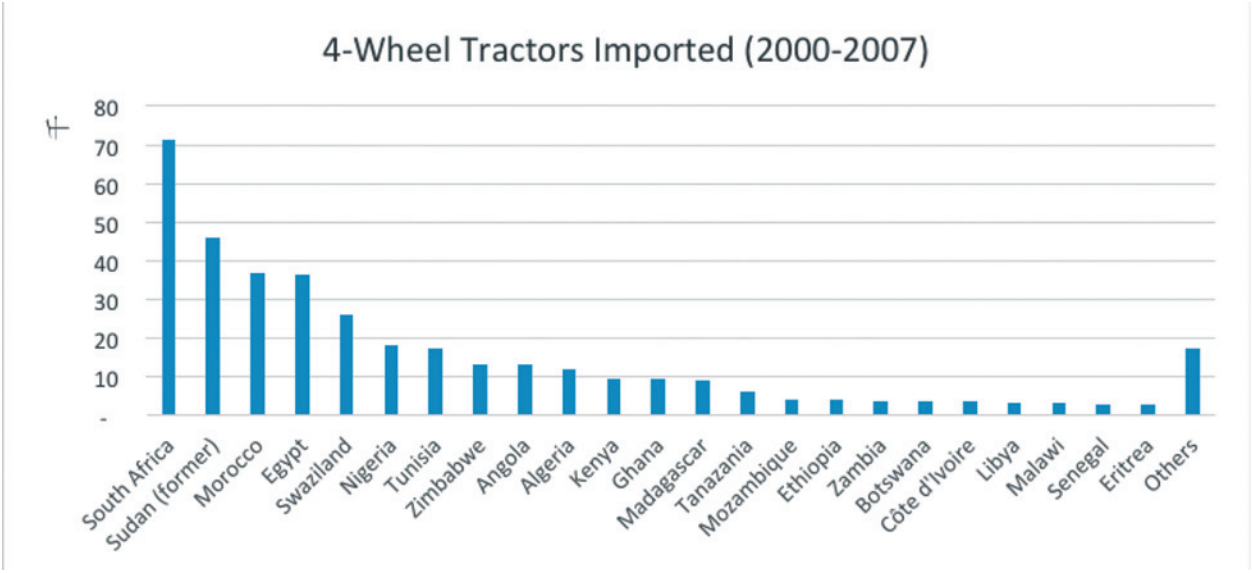
Source: Authors' Illustration

Importation

The tractors, power tillers, and combine harvesters used in Africa are almost exclusively manufactured outside the continent, as local manufacturing capacity is virtually non-existent. Mechanization trends in Africa are responsive to the global manufacturing industry. While in the past, machinery was typically imported from Europe and Japan, an increase in imported machinery from India and China, along with Brazil, Korea, Thailand, Turkey and the Czech Republic, has followed the rise of these countries' agricultural equipment manufacturing sectors. India is now the world's largest tractor manufacturer, outpacing Japan and European countries (Mandal 2013). China has been the largest exporter of power tillers since 2000, followed by Thailand and Japan (FAOSTAT). Manufacturing of tractors, combine harvesters and other mechanization equipment is often subsidized in China and in India by substantial public R&D or consumer subsidies (India Ministry of Agriculture 2008; Zhang et al 2015).

Figure 8 shows available data on 4-wheel tractor imports by African countries. Unfortunately, 2007 is the most recent year for which data on tractor imports are available from FAOSTAT, meaning that this data may fail to capture more current trends. Moreover, these figures are only available for 4-wheel tractor imports, as 2-wheel tractors are not included in FAO's definition of agricultural tractors. Nevertheless, the data shows that tractor imports are concentrated in North Africa, South Africa, and countries in Africa South of the Sahara with large commercial farming sectors.

Figure 8: Agricultural tractor imports by African country, 2000-2007



Source: FAOSTAT

Africa now accounts for 11% of Chinese large tractor exports (FAO 2013), while Africa and ASEAN only represent a combined 5% share of Indian exports (Jain in Ashburner et al 2009). However, such figures may fail to capture the rapid growth of Indian tractor exports to Africa, which are being driven by concessional loans to African governments. In recent years, India has provided concessional loans for tractors to countries including Angola, Benin, Burkina Faso, Burundi, Cameroon, Chad, DRC, Guinea Bissau, Mali, and Swaziland (Diao et al 2014). This is establishing

Indian brands as the dominant ones on the market in a number of these countries.

While there is a general consensus that Japanese and European machines are of higher quality than those produced in emerging economies, there has been a historical preference towards cheap but "good enough" machines, at least in early stages of mechanization. This trend has been most pronounced in Bangladesh, where the removal of import restrictions on cheap Chinese power tillers led to their rapid adoption, to the extent that they are now used on 80% of cultivated area (Ahmed 2011). The preference for "cheap but good enough" is also present in Africa among owners obtaining their machines from private market channels (Agyei-Holmes 2015). However, this appears to be largely limited to large 4-wheel tractors, as 2-wheel tractors and small 4-wheel tractors are still much less commonly imported in Africa. While the imports of Chinese power tillers are concentrated in only a few countries, such as Ethiopia and Tanzania, the preference for "cheap but good enough" appears to apply to the preference for secondhand 4-wheel tractors as well (Kahan and Jaleta 2015).

Direct government promotion appears to be important for the introduction of 2-wheel tractors. In Tanzania, where there are about 6,000 power tillers currently in use, the government has made a concerted effort to encourage adoption of 2-wheel tractors, including distributing machinery through the District Agricultural Development Programs (DADPs), providing affordable credit through the Agricultural Inputs Trust Fund (AGITF), and establishing an agricultural window at the Tanzania Investment Bank. This has been accompanied by the removal of import duties and the overall liberalization of the agricultural sector, in the hope that the private sector can take over after government has stimulated demand. Meanwhile in Ethopia, about three-quarters of the 4,100 2-wheel tractors in use were imported by a parastatal, with programs also being operated by the Ministry of Agriculture and the Rural Job Creation Agency. Meanwhile, in Kenya and Zimbabwe, where governments have not been actively promoting 2WTs, it is likely that only a few hundred are in use (Kahan and Jaleta 2015).

In many countries, donors and NGOs are also involved in the importation and distribution of tractors and other mechanization equipment. This may occur through support to government mechanization schemes or direct distribution to beneficiaries. Other donors and organizations also provide technical support to mechanization, including training and capacity building for government stakeholders in the sector, technical training on machinery operation and repair, demonstration of new and more appropriate technologies, and other support across the supply chain.

The Japanese government has long supported mechanization around the world through its development aid agency, JICA (Japan International Cooperation Agency). Unlike other bilateral donors, JICA is relatively flexible with the types of machines that can be purchased using its 2KR (Food Security Project for Underprivileged Farmers) grants; the only condition is that the manufacturer's headquarters must be based in an OECD country, though the tractors themselves can be (and are) manufactured or assembled elsewhere. The design of Ghana's AMSEC program was partly influenced by JICA's 2KR grants, which require a 70% down payment and a payback period of three years, though forming a registered company is not required as it is for AMSECs. (JICA 2014). Interactions with ministry officials from Ghana suggest that the payback rates for 2KR tractors are much higher than those for AMSEC loans. Other examples of recent projects that have addressed mechanization in Africa include the ADVANCE Project in Ghana, which supported 255

mechanization service providers with machinery, requiring small down payments from farmers, as part of a holistic value chain approach.

Since the capacity to manufacture mechanization equipment locally in Africa remains limited, mechanization will likely continue to depend on imported machinery. Where there is demand for mechanization, private dealers develop import and distribution channels while demand is in turn influenced by the types of machines the market is able to supply. However, governments may step in and attempt to meet demand where private channels are unable to do so or where there are political motivations for involvement in mechanization. Government imports comprise a substantial share of total imports in a number of countries and exert significant influences on the supply chain, especially when imports are financed by concessional loans, which dictate the country of origin or specific brand/type of machinery that is imported. Consequently, the responsiveness of private supply channels to the demand is reduced and imports become driven by government orders. As a result, the market for sales, spares and repairs becomes dominated by brands determined by the terms of concessional loans rather than farmer demand and it becomes more difficult to introduce such brands through private channels (Diao et al 2014). Governments' distribution of tractors to farmers at subsidized prices or employing them on state farms or hiring stations may also have influenced the adoption of high horsepower tractors. This may have developed a supply chain built around these larger tractors and stifled demand for smaller, potentially more suitable tractors.

Private tractor importers are present in most African countries, though their share in total imports ranges from 10% in Tanzania and Nigeria, where government is very active in tractor imports, to 100% in Ethiopia, Ghana, Kenya and Zambia (World Bank 2014b). However, these figures reflect that governments channel their imports through private companies; governments are actually quite involved in tractor purchases and distribution in Ethiopia, Ghana and Kenya (World Bank 2012a; 2012b; 2013a). In Zambia, about 15% of tractors are also imported by private firms through project-backed loans (World Bank 2012d). Therefore, importation of tractors is even less private-sector driven than would appear from national statistics. Moreover, the vast majority of new tractors are imported by government in most African countries, with private importers focusing more on secondhand machines.

Table 3: Percent of private 4-wheel tractor imports in selected African countries

	Burkina Faso	Ethiopia	Ghana	Kenya	Mozam-bique	Nigeria	Rwanda	Tanzania	Zambia
% Private Imports	59	100*	100*	100*	60	19	42	10	100

* indicates significant government imports through private channels

Source: World Bank (2014b)

Private importers typically consist of both large dealers who establish franchises for major brands and importing companies who deal in used tractors as part of a diverse enterprise portfolio (Diao et al 2014). In many cases, private importers also provide after-purchase services and repairs and also stock spare parts for the brands they distribute. In most countries, there are typically between

8-12 large firms acting as agents for the specific brands that they import and competing amongst each other (World Bank 2014b). Much of their business comes from government agencies and government/donor-funded programs, though their clients also include large-scale commercial farms and plantations (Takeshima et al 2014). The cost of new imported machinery is often prohibitive to individual farmers, especially with the lack of attractive credit terms.

Limited access to favorable credit terms for both private importers and potential buyers constrains the private import of new machines and keeps private importers and customers concentrated in the secondhand machine market. However, some manufacturers are beginning to work with their local distributors to attract customers with financing options, as John Deere and its local distributor, AFGRI, are doing in Zambia with support from USAID and the Zambia National Farmers Union (World Bank 2012d). The cotton company Dunavant is also engaging in a similar scheme in Zambia, where it provides credit to lead outgrowers to purchase machines and provide services to other farmers. (World Bank 2012s). Future research should investigate if there are similar collaborations in Africa that are purely led by private sector, without support from donors or government.

Meanwhile, used tractor importers tend to cater to medium and large individual farmers, importing preferred brands (typically from Europe) that farmers value due to familiarity and the availability of spares and repairs (Diao et al 2014; Takeshima et al 2014). Most of these businesses do not solely focus on imported tractors, for which demand is quite seasonal, but nevertheless maintain stable import channels. Even in countries such as Ghana, whose governments imported large numbers of new tractors at subsidized prices, used tractors have constituted the majority of imports in recent years (Diao et al 2014).

Farmers also tend to find used machines more cost effective, as there is often no significant drop-off in performance and lifespan; they may even be cheaper than even government-subsidized new tractors and may also cost less to maintain, especially when the market for spares is more developed for the second-hand brands (Houssou et al 2014; Diao et al 2014). These may hold even when ages of tractors are considered. Many machines currently in operation appear to have surpassed their expected useful lives of 5 to 12 years. For example, 85% of tractors operating in Tanzania are 11 years or older (World Bank 2012c). However, among the surveyed tractors in Nigeria, both new and used tractors are similar ages (Takeshima et al 2015). Moreover, the farmers in Ghana and Nigeria obtaining their machines through private channels are known to achieve greater utilization rates by hiring out services than by farmers obtaining them through government channels (Takeshima et al 2015; Diao et al 2014). The import-reliant structure and growth of secondhand tractor market channels in some countries may cause older tractors to be more common.

Governments do not generally encourage the importation of secondhand tractors. The growth of used tractors import in some African countries uniquely attests to the ability of private sector supply chains to emerge in responses to farmers' demands and changing availability of various brands of second-hand tractors in foreign markets with relatively little government support. However, appropriate government support, as described later, can help create incentives that strengthen private import channels.

Manufacturing of Agricultural Machinery

Although a broad range of imported machinery is used in Africa, very little of it is specifically designed for the continent's conditions, as manufacturers do not perceive that there is sufficient demand in Africa (Mrema et al 2008). A few efforts have been made to pursue tractor manufacturing in Africa through joint venture schemes, including a recent joint venture between AGCO and Algeria Tractors Company to produce Massey Ferguson tractors (AGCO 2012). In some cases, past joint ventures have attempted to adapt tractor designs to local conditions. The machines that were produced, such as the Kabanyolo tractor in Uganda and the Tinkabi tractor in Swaziland, were not competitive and eventually abandoned (Holtkamp 1991 in Mrema et al 2008). Likewise, substantial investments were made in locally designed animal implements that were never adopted by farmers (Mrema et al 2008). These experiences have demonstrated the difficulty of designing and manufacturing equipment that can successfully compete with imports on both quality and cost. Throughout Africa's mechanization history, there have been a number of efforts to establish tractor assembly plants, many of which have failed. Government assembly plants in Nigeria, Tanzania and elsewhere have long been shuttered, as the domestic plants lacked the technical capacity and managerial efficiency to compete with imports (Houmy et al 2013). However, the Nazareth Tractor Assembly Plant, established during the Derg regime, is still operating in Ethiopia and is able to assembly roughly 300 tractors per year, which accounted for 46% of tractors entering the Ethiopian market between 2005 and 2010 (World Bank 2012a). Other assembly facilities have been established by foreign manufacturers, often in joint ventures with local governments or companies, though it is unclear if they will be able to compete with new and secondhand imports. Based on the experience in India, South Korea and China, joint ventures with foreign manufacturers in the first years are typically needed to successfully launch the domestic manufacturing (Rijk 1986 p14). Nigeria had similar joint ventures in the past (for example with Fiat); however, these attempts failed because governments requested foreign firms to use locally produced parts which were usually of poor quality (Adubifa 1993). A number of Indian and Chinese companies are currently establishing joint and private ventures in Mali, Nigeria, Chad, and Cameroon. However, markets for tractors may still not be large enough in many of these countries, creating skepticism over the feasibility and motivation of these programs (Kienzle et al 2013).

Overall, manufacturing of tractors and other large machinery does not appear to be a major player in Africa, though mechanization markets in Africa respond to changes in the global manufacturing sector. While the capacity for the assembly of mechanization equipment in Africa appears limited and scattered, there are some areas where it may be worth further pursuing. In these cases, the demand for the technology being pursued and local industry's capacity to compete with imports must be ascertained before any substantial investment can be made. Although most countries have eliminated import duties and VAT for imported tractors, completely- and semi-knocked down (SKD/CKD) parts are still widely subject to the full tariffs (World Bank 2014b). If there is potential for locally assembled tractors to compete with imports, then governments could help encourage this by removing or lowering duties on CKD parts and providing training programs to develop the technical capacity required by assembly plants. When pursuing local manufacture or assembly, attempts should also be made to court private investment; if such investments are not attractive to the private sector then they are not likely to be feasible.

Ownership and Service Provision

Owners of tractors and other agricultural machinery consist of individual farmers who frequently hire out services to other farmers, and specialized hiring enterprises which do not engage in

farming. These hiring enterprises are often subsidized by government, as are the AMSEC program in Ghana and the AEHE program in Nigeria. Despite the continent-wide failure and collapse of the majority of government hire schemes, there are also still cases of direct government service provision currently provided in some countries.

Farmer-ownership characteristics

Mechanization equipment is owned by both individual farmers and commercial estates. These estates may own multiple tractors and combines and rarely hire out machines to nearby farmers, making them less significant for adoption of mechanization by smallholders. Such large-scale commercial ventures are often owned by foreign investors; they are common in Kenya, Tanzania, Zambia and Zimbabwe and are beginning to emerge in countries such as Ethiopia, Ghana, and Nigeria (Jayne et al 2014).

As expected, individual farmers who own mechanization equipment are typically relatively large scale farmers and are wealthier than average farmers. According to the IFPRI/SARI survey in Ghana, tractor owners have larger farm sizes and higher uncultivated portions of their landholding, suggesting that they have more room for further expanding their farm size. While many tractor owners are larger farmers, their currently cultivated land is not large enough to fully utilize their tractors, and therefore, they have incentives to hire services out to non-owner farmers. Only a few very large farmers typically own combine harvesters while some smaller farmers may own threshing machines; and hiring services seems to be a pre-condition for these farmers to invest in combine harvesters or threshing machines. On the other hand, the potential for tractor owners to supply plowing services is dependent on the presence of nearby demand from local farmers, because most owners typically prefer to serve local customers, and the mobility of machines, particularly of large tractors, is generally low in Africa (Takeshima et al 2015).

These owners obtain tractors from both private and government (often subsidized) channels. According to the IFPRI/SARI survey conducted in eight northern districts of Ghana, the majority of tractors owned by individual farmers are purchased secondhand tractors from private importers. 80% of tractors in the survey were purchased secondhand and only 13% were new tractors purchased with government subsidy (Chapoto et al 2014). Even the subsidized prices of many new tractors are still higher than those of most secondhand tractors in Ghana. Moreover, relatively few of these tractor owners in the IFPRI/SARI survey favor the subsidized brands imported by the government, as in most cases, the brands imported by the government are limited to those manufactured in the countries whose governments provided the concessional loans to the Ghanaian government (e.g., Farmtrac and John Deere are imported under the Indian government provided concessional loans and are manufactured by the Indian companies). A majority of tractor owners prefer second-hand Massey Ferguson tractors, which are imported from European countries by the private sector (Diao et al 2014; Chapoto et al 2014). In some other African countries however, more farmers obtain their tractors from government channels. Total subsidies on tractors were greater than 60% in some Nigerian states, due the combination of state and federal subsidies, although the federal subsidy was withdrawn in 2012 (Takeshima et al 2014). In Nigeria, private tractor owners achieved annual utilization rates of over 400 acres compared to 250 acres for tractors obtained from government sources. This suggests that farmers who are willing and able to use tractors more efficiently may obtain their own tractors from the private supply chain, a potentially important consideration for government distribution programs to take into account (Takeshima et al 2014).

Individual farmer-owners purchase tractors from private channels primarily without credit or loans involved. In the IFPRI/SARI survey in Ghana, 84% of medium-scale farmers purchased their tractors using solely personal savings and only 3.4% used any loan for their purchase (Chapoto et al 2014). This is similar to surveyed tractor owners in Kaduna and Nasarawa states in Nigeria, where for privately purchased tractors, 82% of total finance was from owners' personal savings, 4% from bank loans and 3% from government loans (Takeshima et al 2015). This appears to be because credit markets are almost non-existent for farmers' machinery investment, with both owners and non-owners reporting access to credit as the most significant constraint to tractor purchase. A tractor is a high cost investment for its buyer, while the domestic financial sector is unlikely to provide loans easily to famers if farmland cannot be used for collateral under customary land tenure systems. Thus, the constraint faced by potential tractor buyers who are farmers and hence seems to go beyond a standard credit market failure issue. This constraint is unlikely to be effectively addressed without further reform in the land market.

Combine harvesters are typically owned by a few very large private farmers who either purchased them or inherited them from abandoned state farms, the latter of which is especially common in Tanzania and Ethiopia (Kienzle et al 2013). Other farmers rarely find it feasible to own such a large machine and will thus rely on hiring services where they are available, though these areas may still be rare (Longmire and Lugogo 1989). Reaper machines, which can typically harvest less than 1 ha of rice per day, making them suitable for medium-scale farms, are commonly used in northern Senegal and the Office du Niger in Mali, although they are not common elsewhere (Rickman 2013).

Ownership of threshing machines is more widespread, since threshing is a function that is mechanized earlier than harvesting (Pingali 2007), and machines are usually much cheaper than tractors or combine harvesters, and can be relatively easily manufactured by local fabricators. However, depending on crops and cropping systems, threshing is less time-bound than plowing, creating less of a timeliness benefit for owning a thresher compared to hiring on the market. Threshing machines are commonly owned in some cereal systems, especially in wheat, maize and irrigated rice systems where the use of combine harvesters have not yet emerged.

Success Story 2: Farmer to Farmer Service Provision

Where demand has emerged in much of Asia, as detailed in Success Story 1, the small proportion of farmers owning machines has been able to successfully service the large proportion of farmers using machines. For example, according to a nationally representative survey in Bangladesh, the 2% of farmers owning power tillers are able to service the 72% of all farmers who have mechanized primary tillage operations (Ahmed 2013). Similar observations have been made for Sri Lanka, Nepal and parts of Thailand (Biggs and Justice 2015). While most of these countries use small 2-wheel tractors, the hiring market for 4-wheel tractors appears even stronger in Tunisia, where 90% of farmers in rainfed areas use tractors and 90% of tractor users hire in from the rental market (Hopkins 1990).

Farmer to Farmer Service Provision

Farmer to farmer service provision has been increasingly noted in recent years as an important mechanism to promote mechanization among small farmers in Africa (Diao et al 2014). We consider it as an important supply model of mechanization, as it is often able to overcome the administrative and technical inefficiencies associated with other service provision models while enabling tractor and other machinery owners to fully utilize their machines – improving the incentives for some farmers to invest in machinery. In order for the hiring

market to function effectively, sufficient demand for mechanization among small and medium farmers must exist, as well as there being enough large and medium farmers capable of making the investment in tractors and hence supplying services. While data constraints preclude quantifying the scale of hiring markets at country level or throughout Africa, private farmer to farmer service provision has been observed in many African countries by IFPRI staff. In both Ghana and Nigeria where more in-depth research has been conducted, this supply model appears to be vibrant in a number of locations in these countries (Houssou et al 2014; Takeshima et al 2014). Such a model has also been present in Tunisia and studies conducted for Asian countries (Thailand, Indonesia, Vietnam, India, Bangladesh, Nepal and China) by other researchers have captured the similar patterns of farmer to farmer service provision (See Success Story 2). Such services include plowing, harvesting, carting, and post-harvesting threshing (Biggs and Justice 2015).

Table 4: Summary of tractor ownership and services from 2013 IFPRI/SARI survey in Northern Ghana.

	Small (<5 ha)	Medium (5-20 ha)	Large (>20 ha)
% owning tractor	3.8	25.1	71.1
Land owned (ha)	5.3	16.5	61.6
Area cultivated (ha)	2.9	9.5	38.4
% of total owners	7.2	53.0	39.8
Tractors per owner	1.1	1.1	1.3
% of owners hiring out services	88.9	87.6	89.0
Mean area plowed on own farm (ha)	4.1	10.8	33.6
Mean area plowed on others' farms (ha)	188.2	167.4	199.6
% of farmers hiring in any services	48.6	59.4	43.5
% of farmers hiring in first plowing services	44.3	48.2	22.2
% of farmers hiring in maize shelling	17.2	30.5	28.9

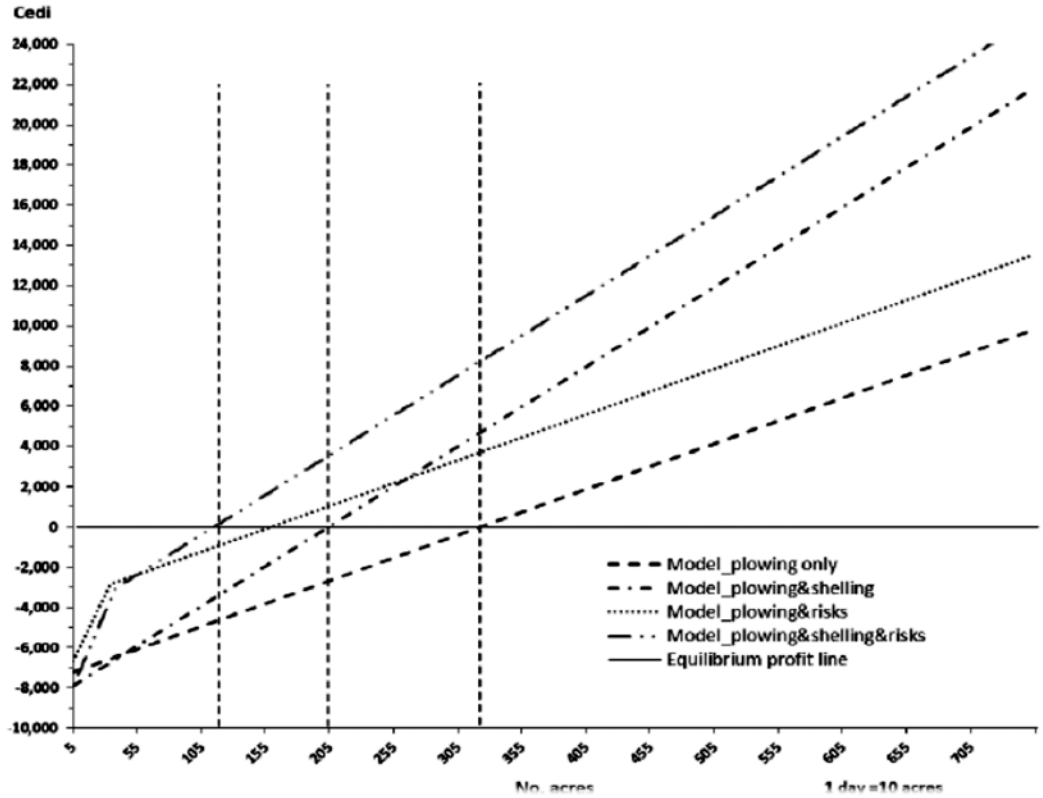
Source: Chapoto et al 2014

Although this model has been observed in a number of countries, Ghana perhaps provides the most suitable illustration of its dynamics due to the in-depth mechanization-focused research that has been conducted there. Table 4 provides an overview of tractor ownership, service provision and hiring from the IFPRI/SARI survey in Northern Ghana. As can be seen, even relatively large farmers (> 20 ha) have incentives to hire out their tractors, hiring out at equal rates to other farmers, as they do not cultivate enough area on average to meet the seasonal utilization capacity of a tractor. Provision of plowing service constitutes an important source of profits for all three categories of owners, although overall profitability rises with a mix of providing plowing services in addition to other services such as maize shelling and transport and the timeliness benefits attained by avoiding the delays associated with hiring in services, relative to owning a tractor. For example, in a JICA survey in three communities in Northern Ghana, 16% of rice farmers who requested tractor services accessed them in the first week after rain, 47% had accessed them after two weeks, and 82% had after three weeks (Nakamura 2013). However even when delays occur in the hiring market, tractor hire is still likely to be attractive due to its labor-saving benefits and may still allow plowing to be carried out more timely than it could be using manual labor or animal traction.

Evidence from primarily rainfed areas in Ghana suggests that tractors were profitable investments for 54% of surveyed owners when considering plowing service provision alone, and profitable for 85% of surveyed owners when taking all of these factors into account (Houssou et al 2014). Hiring out services is often necessary for owners' investments to become profitable, particularly for medium size farmers. This implies that the number of owners is constrained by whether the potential owners enable to find enough other farmers as consumers of their services, an indication that the service market is rather competitive and service prices are mainly determined by the market instead of monopolistically determined by the service providers. Figure 9 shows the differences in profitability of tractor ownership between providing plowing services alone and also account for benefits from providing shelling services and avoiding the risk of delays. With these additional considerations, the breakeven acreage required becomes much more easily attainable and profits rise, explaining some of the advantages of farmer tractor ownership compared to ownership by specialized tractor service enterprises.

In addition to the prevalence of tractor hiring services under rainfed agriculture, the significant growth of mechanized land preparation and harvesting under irrigated farming systems has been observed in Africa including both land preparation and harvesting. In Ghana, privately hired tractors or power tillers now provide plowing for more than half the areas within three out of five major largest irrigation schemes (Takeshima et al 2013). Power tillers in Kpong Irrigation Scheme, which are mostly used for rice cultivation, exhibit similar usage patterns to 4-wheel tractors studied in other areas. While roughly half (46%) of surveyed owners obtained their power tillers from the private sector, major differences were observed in profitability between machines from private and government channels. Surveyed owners who obtained their machines from private channels earned average profits of $542 per year, compared to a loss of $311 per year for those obtaining power tillers from government or NGOs (IFPRI 2014). This large gap suggests that more efforts are required to target subsidies to owners who could utilize machines profitably. Combine harvester hiring services have also started to gain popularity in West African irrigation schemes very recently. Similarly, tractors and mechanized threshers, mostly through private service providers, cover more than 70 percent of the area in Bakolori irrigation scheme, the largest scheme in Nigeria (Takeshima & Adesugba 2014).

Figure 9: Net used tractor mechanization service profits under four scenarios, Ejura District, Ghana



Source: Houssou et al 2014

A general consensus drawn from the recent research is that in Ghana, Nigeria and potentially other parts of Africa, the current supply of tractor services in plowing does not appear to be enough to meet existing demand for such services. Nearly half (45%) of service providers surveyed in Ghana believe they are unable to meet demand, while only about half of them thought that their tractors were being used to full capacity. Frequent breakdowns and long distances to customers are also quoted as important constraints for tractor owners to reach their tractors' utilization capacity (Chapoto et al 2014). In Nigeria, it is also hypothesized that medium and large farmers owning tractors are too few and sparse to meet smallholder demand (Takeshima 2015). The differences in plowing charges between countries as well as across districts within countries may help illustrate that the hiring markets for tractor services are very localized, exhibiting price disparities across different locations. The significant regional and even district-level variation in service charges within countries can reflect localized differences in demand for mechanization services and tractor densisty. Indeed countries with higher overall tractor densities exhibit lower hiring costs on average, with the exception of Zambia, where tractors are more widely used on isolated commercial farms (World Bank 2014b). Such trends are especially observed in Ghana, Nigeria and Mozambique, where stark contrasts in tractor use have been observed across agro-ecological zones and between regions with different economic development levels between Northern and Southern regions (Table 5).

It is likely unnecessary for there to be many tractor owners in an area, given that in most Asian countries, almost all land preparation has been mechanized through a very small group of owners hiring out services (e.g., in China and Vietnam). While the existence of enough tractor owner-

operators may help make service charges more affordable for smallholders, there is little evidence to show that the current hiring market is not competitive enough at the given level of tractor owners. It is also unclear to what extent service charges reflect the costs facing tractor owners, such as the investment, fuel, maintenance and operator wages, and to what extent they reflect farmer demand.

Variations in plowing service charges and the difficulty of accessing such services in some areas may arise partly due to the constraints for tractor mobility. While cross regional migration has been seen for a few owners in some areas of Ghana, Nigeria and Ethiopia, increasing profitability for owners and improving the overall efficiency of hiring service markets, the size of tractors (that are often large), the road network and road condition, and the development logistics of shipping tractors across regions are all important constraints affecting migration. Migration appears to be profitable overall for the service providers who do so, though it is not yet attractive to many tractor owners.

Table 5: Plowing Costs in Selected Countries and Regions

	Burkina Faso	Ethiopia	Ghana	Kenya	Mozam-bique	Nigeria	Rwanda	Tanzania	Zambia
Cost of plowing 1 ha (USD)	51	81.25	46	31.25 gov; 50 private	62	60	163	68	125

Ghana	Ejura	Gushiegu	Yendi	Sissala East
Cost of plowing 1 ha (USD)	53.97	41.36	43.83	60.35

Nigeria	North East	North West	North Central	South East	South West
Cost of plowing 1 ha (USD)	93.75	42.75	44.53	74.38	42.58

Mozambique	Masssingir	Chókwè	Manica	Sofala	Zambezia	Gurue	Nampula
Cost of plowing 1 ha (USD)	45-55	61-91	61	55	62-75	70	55

Source: World Bank (2012b; 2013b; 2014a and 2014b); Houssou et al (2014)

The majority of tractor owners provide services within their own districts both in Ghana and Nigeria. With one crop season in the north and two crop seasons in the transition zone that is not too far from the north in Ghana, the IFPRI/SARI survey shows that roughly one fifth of tractor service providers migrated to between north and transition zones to provide plowing services, and the vast majority of the migratory service providers are clustered in one district (Ejura). Similarly, the surveyed tractor owners in both Kaduna and Nasarawa states of Nigeria may travel to provide services but are unlikely to migrate across agro-ecological zones. Most owners operate within 25-30 km of their home districts during peak plowing season, and only about 12% of plowing takes place outside of the owner's home state.

The Asian countries' experiences seem to indicate that the migration model is crucial and more appropriate for mechanized harvesting, which also requires smaller machines and good roads (Zhang et al 2015), though it is less common throughout Africa. Improving the profitability of tractor owners may come from other sources including enabling multi-functional uses of tractors. The natural limitation of full utilization of tractors services in plowing also indicates that lowering the investment cost is the most important mechanism to encourage tractor ownership. The policy dilemma here is whether policies to lower tractor investment costs are sustainable and are not "winner picking," an important topic we will further discuss in the policy section of this report later.

Farmer to farmer service provision is also seen for combine harvesters. However, given that there are very few very large farmers that own such costly machines, there is not enough evidence to assess this model's efficiency. For example, only 2% of farmers in the Ghana survey of medium-to-large farmers reported using combine harvesters, though 30% reported the desire to own one (Chapoto et al 2014). Miniature combines, which have been successfully introduced in Asia and could be suitable to smaller farm sizes in Africa, though it is more effectively used in wheat-barley systems thanthe maize systems common to most of Africa. Combine harvesters are commonly hired out in wheat systems in some areas of Kenya, where there is demand for mechanized harvesting among smallholders as it is cheaper and faster than manual harvesting and there is excess machine capacity among owners for them to hire out services (Longmire and Lugogo 1989). Where conditions are met, combine harvesters served a significant share of farmers in the locality; for example in 1995, in Asasa and Etheya districts of Arsi region, Ethiopia, 78% and 59% of farmers, respectively, used combine harvesters, mostly through private owners (Hassena et al 2000). Small scale farmers often formed groups to meet the cost and scale required to access combine harvester services, which implies that the land must be connected, without obstacles preventing the movement of a combine. Nevertheless, using a combine in these areas is about 20-30% cheaper than hiring in manual harvesting labor. Most farmers obtain services from private machine owners, though government hire services and state farms are also active in the area until recently (Hassena et al 2000). There are also vibrant hiring markets for combine harvesters and threshers in different rice irrigation schemes in West Africa, where a large cluster of market-oriented producers with demand for harvesting and threshing services helps owners overcome the constraints of traveling to service small farms but physically connected (Takeshima et al 2013). For example 48% of rice area in Kpong Irrigation Scheme in Ghana is now harvested using combines and almost all farmers in the scheme are small scale (Takeshima et al 2013).

Service provision of mechanical threshing is much more common in cereal systems, both in the irrigation schemes for rice and other rainfed cereal systems. According to the IFPRI/SARI survey of medium-to-large farmers in Ghana, where maize shelling is an important extension of tractor use, about 25% of farmers hired in tractor driven maize shelling services. In Senegal, 68% of rice is mechanically threshed in surveyed irrigation schemes (Sakurai 2015). Service provision for rice, wheat and maize threshing using locally fabricated threshers is also common in some parts of Ethiopia, as demand for mechanized threshing emerges, although prices are considered to be high due to limited access to threshing technology (Moges and Alemu 2014).

Specialized Service Provision

Nonfarm enterprises as specialized service providers can be home-grown private enterprises, private entities established with the government's support through subsidies or public agencies.

In all the three models, the key to make such service provision as a viable business is the level of machinery utilization. If these enterprises are specialized in plowing services, they face natural disadvantages because of relatively short season for plowing and difficulty of migrating with tractors. Moreover, unlike farmer owners who usually own one or two tractors, specialized nonfarm enterprises, particularly those subsidized by the government or the public agencies tend to have more tractors to begin their business. This makes them less likely to be profitable in operation even with government's subsidies on tractor purchases. There is little evidence in Asia and Africa that suggests the specialized nonfarm enterprise in plowing service provision can be a viable model (Diao et al 2014).

A successful model of specialized service provision is often seen for harvesting. This has been observed in the United States for combine harvesters following the harvest from Texas and Oklahoma to northern states where the harvest occurs much later (Binswanger 1986). Similar stories are seen in India's Punjab state (Singh et al 2013) and recently in China, where combine harvesters are small and individually owned by nonfarm businessmen who form clusters to provide harvesting services by migrating across agro-ecological zones operating 8 months a year (Yang et al 2013; Zhang et al 2015). In the China case, the farms that hire in services are typically one ha or less. Similar models are also emerging in Thailand and Vietnam (The Economist 2014). Certain types of government support (including some subsidies) might be involved to promote such specialized service provision at the beginning. In China, however, the most important support from the government is in business coordination. It is the local (county level) governments that have played such role in helping private service providers overcome coordinating failure and information asymmetric that are typically associated with long distance traveling, in addition to the public investment in road infrastructure which is often done by the central and provincial governments (Yang et al 2013).

There is little evidence for the existence of this home-grown private nonfarm business model in mechanization service provision in Africa. Most nonfarm mechanization service enterprises are established under the promotion of specific government programs such as AMSEC in Ghana and AEHE in Nigeria. In the past, there were numerous examples of African governments' failed attempts to establish the public service provision centers, while this model currently still exists in a few countries without apparent success. For example, a recent audit report of the mechanization program in Sierra Leone revealed low utilization and poor maintenance of machines operated by the public service centers (Sierra Leone Audit Service, 2012). Similar cases of poor management, maintenance and low utilization are also reported with government tractor hiring services in Swaziland (Kienzle et al 2013). In Ethiopia, the number of government AMSE hiring stations has reduced to four, with government attempting to privatize the program (World Bank 2012a).

Nevertheless, the model of specialized nonfarm private enterprises supported by the government or publicly operated centers seems to have gained popularity in recent years, as shown in Table 6. Some African countries' governments see the Ghana's AMSEC attractive and sent delegations to Ghana with an intention to adopt this model, although little evidence suggests this model can be sustainable (Diao et al 2014 and Houssou et al 2014). In fact, few specialized service providers in Ghana and Nigeria that received the subsidized tractors from the governments as part of mechanization promotion programs (AMSEC in Ghana and AEHE in Nigeria) made profits. Still, neither country's government intends to stop such programs. African governments have justified subsidizing mechanization services by citing the high cost of tractor investment. The potential for

a demonstration effect is also used to justify the subsidies, though there is no evidence to show that more demand for the services can lead to more investment in tractors by already established specialized businesses after the subsidies are removed. Moreover, there is no clear evidence that machinery subsidies lead to lower service charges to farmers. While AMSECs are possible to be more reliable in providing timely hire services than private farmers as service providers, they have not enabled farmers to plow significantly more area or adopt fertilizers and other complementary technologies (Benin 2014). Many AMSECs have been defaulting on their loans, bringing further doubts that this is a sustainable program. Moreover, there are concerns that such specialized businesses crowd out non-subsidized private investment and distort private hiring markets when many such entities were established through the government programs, an issue that will be discussed in the following section.

Table 6: Countries with active government run or supported mechanization equipment hire schemes

Country	Type of program	Name of program/agency
Benin	Government tractor hire	
Cameroon	Government tractor hire	
Ethiopia	Government tractor and combine hire	AMSE
Gambia	Government tractor hire	
Ghana	Subsidized Specialized Service Provision	AMSEC
Kenya	Government tractor hire	ADC
Malawi	Government tractor hire	PVHO
Nigeria	Government tractor hire (some states)	Different state-level programs
Nigeria	Subsidized Specialized Service Provision	AEHE
Sierra Leone	Government tractor hire	MAFFS
Swaziland	Government tractor hire	RDA Mechanization Section

Sources: Tokida 2011; Mijinyawa and Kisaiku 2006; Hassena et al 2000

Agricultural cooperatives and farmer groups can also jointly own tractors and other mechanized equipment that are used to serve members. Collective ownership seems to be attractive to help smallholder farmers overcome the cost and scale constraints that prevent individual farmers from owning tractors. However, the problems related to collective action typically arise with joint ownership of productive assets that often impede the performance of cooperatively-owned tractors. According to Seager and Fieldson (1984), Egyptian cooperatives achieved dramatically lower utilization rates and higher costs per acre compared to government and privately owned tractor enterprises. According to a more recent study in Nigeria, cooperative-owned tractors performed better on utilization and cost than government-owned tractors, but worse than privately owned tractors (Oluka 2000).

In Ethiopia, which has one of the largest cooperative movements in Africa, cooperatives provide the majority of tractor hiring services; cooperatives also commonly provide services in Mozambique and Burkina Faso, where they are supported with subsidies and credit from donor projects and government (World Bank 2013b; 2013c). It remains to be seen if these projects can

overcome the limitations of collective ownership and become an efficient and sustainable solution to increasing access to mechanization services.

Fabricators, Spare Parts and Maintenance

Rural repair services

Timely and quality repair services, along with a reliable supply of spare parts, are imperative to keep machines functioning during peak plowing seasons. Under a rainfed agricultural system, which is common in Africa, even a short delay from waiting for a relatively minor part to arrive can result in missing the crucial period suitable for plowing, which ends up to have potential yield effect when farmers are forced to plant their crops without proper land preparation. The profit loss is also significant for tractor owners that provide hiring services in plowing. In Ghana, frequently broken down in tractors during the peak plowing seasons were seen as the largest constraint by the surveyed tractor owners meeting their full capacity for hiring out services (Chapoto et al 2014).

Repair services are fully operated by the private sector in almost all African countries. Few private dealers provide after-sales services, and repairs are typically done locally by specialized mechanic shops or individuals, while many dealers also imports spare parts in addition to machinery to supply to the repair shops. Many such shops are located in the rural towns in the districts or regions where tractors and other machinery owners are concentrated, while mechanics of such shops often travel to the villages to meet the demand for rather simple repair jobs by tractor owners. In Kaduna and Nasarawa States, Nigeria, for example, over 80% of repair jobs for surveyed tractor owners took place in the owner's village (Takeshima et al 2014). Repairs and maintenance are also provided by part retailers that are often small-scale businessmen, as such activities can be important sources of business incomes to them (Takeshima et al 2014). While rural mechanics are often able to provide basic services without formal training, improving their technical skills through additional training would help them deal with more serious repairs, and hence prevent further breakdowns and reduce the time machines spend out of commission. However, rigorous empirical evidence of such impacts in Africa is scarce.

Locally fabricated implements and small machines

Tractor-mounted maize shellers are manufactured locally in many countries. In Ghana such small machines are an important part of post-harvesting mechanization, which also creates off-season use for tractors and improves the capacity for tractor utilization (Houssou et al 2014). Other types of tractor-drawn implements and threshing machines are commonly manufactured in a number of African countries (Tokida 2011). Fabricators in cities and even rural areas manufacture animal drawn implements such as carts and are often able to repair tractors and tractor-drawn implements to some extent. In Kenya, local manufacturers of equipment such as treadle pumps and hammer mills have become common in Nairobi and have even emerged in smaller towns such as Nakuru (Sims and Kienzle 2009). In the 1980s, there have also been a number of threshing machines for maize, wheat, rice, sorghum and multiple crops developed in partnership with government research and engineering agencies in Ethiopia (Moges and Alemu 2014). Such models appear to remain in use, though they are more concentrated in a few regions.

A second wave of attempts to design and manufacture smaller equipment tailored to local conditions has also begun to take place. Many of these designs are attempted to adapt machines developed in Asia. One of the more successful instances of this is the ASI thresher. The ASI thresher

is an adaptation to a Vietnamese design developed by AfricaRice and partners with a capacity of 1,000 to 1,500 kg of paddy per hour. It is now being embraced in Senegal with regional spillover to Mauritania, Mali, Burkina Faso, Cote D'Ivoire, and Ghana (Rickman et al 2013). A similar attempt has been made to adapt a mini-combine harvester for rice from the Philippines. The adapted model can harvest between 1.5 and 2 ha per day, requiring half the labor that manual harvesting with ASI threshing does. Nevertheless, it remains to be seen how successfully such a machine can be produced and whether it can be more widely adopted than the large imported combines that failed to gain widespread use.

In addition to smaller conventional machinery, conservation agriculture (CA) equipment is also being developed, especially in Eastern (Kenya and Tanzania) and Southern (Zambia and Zimbabwe) Africa (Sims et al 2012). Conservation agriculture is by no means a panacea for non-mechanized smallholder farming in Africa, (Pingali 2007); its spread has been limited despite significant donor interventions and there are still debates over its benefits and appropriateness for smallholder farmers in Africa (Giller et al 2009). Despite this uncertainty, the push towards conservation agriculture has pursued the local development of mechanization equipment.

Table 7: Locally developed mechanization equipment in Africa

Function	Machine	Description	Developer	Country
Land preparation	Kabanyolo and Tinkabi tractors	Mini-tractors locally designed in Uganda and Swaziland, respectively		Uganda; Swaziland
	Magoye and Palabana rippers	Animal drawn ripper that creates 10 cm deep rip lines, easily adjustable; Palabana 25 cm	Magoye and Palabana research stations	Zambia; Zimbabwe
	Groundnut seeder	Developed by local company to directly seed groundnuts, which cannot be seeded with a Fitarelli seeder	Grownet Investmnets	Zimbabwe
Harvesting	Mini-combine	Able to harvest >2 ha of rice per day but low cost may make it more appropriate for African rice farms than some machinery that had been introduced from Asia	AfricaRice adapted from import from the Philippines	Senegal
Threshing	ASI thresher-cleaner	1-1.5 tons of paddy per hour, can be fabricated locally, does not require winnowing after threshing	Africa Rice, IRRI, ISRA, SAED adapted Vietnamese extension to MVT model	Senegal with regional spillover to Mauritania, Mali, Burkina Faso, Ivory Coast, Ghana

Much of the push towards CA equipment stems from the successful experience of local design and development of rippers and seeders in Brazil (Casão et al 2012). However, the uptake of conservation agriculture has been slower in Africa, where smallholder farmers face additional biophysical and socioeconomic constraints. In Zimbabwe, conservation agriculture actually increased requirements for labor and fertilizer (Ndlovu et al 2014). Moreover, CA in Africa did not arise through an organic process stemming from farmers' own innovations but began with donor interventions that mostly focused on R&D at research stations before being rolled out to farmers and utilizing their participation (Johansen et al 2012). CA equipment designed and adopted in Africa includes animal-draw rippers and direct seeders as well as two-wheel tractor-drawn strip tillers and seed drills, though these are much more common in Asia than in Africa. Some machinery developed in Africa includes the Magoye and Palabana animal-drawn rippers, which were developed in Zambia and Zimbabwe, respectively, but have spread to a degree throughout Southern Africa. An animal-drawn tine ripper creates rip lines in the soil, which must be then sown by hand. Like much other CA equipment, direct animal drawn seeders are imported from Brazil, but a Zimbabwean company has developed a direct seeder for groundnuts, a crop for which the common Fitarelli model does not work (Johansen et al 2012).

5. Roles of Government in Promoting Mechanization

As has been demonstrated, demand for mechanization has been emerging in a number of areas within African countries, and the private sector channels for machine purchases and mechanized service provision have grown in recent years. Nevertheless, there are many ways for governments to play a supportive role in the mechanization process, through investing in public goods, developing a favorable policy environment, and providing capacity building and technical support where needed.

Providing Public Goods to Create an Enabling Environment for the Private Sector

Many African governments have often to seen direct involvement in mechanization as an effective way of promoting mechanization. Governments commonly believe that while private sector led mechanization does occur in their countries, the scale of such operation is often too small and the pace is too slow for the majority of smallholders to adopt mechanization technology. Without considering the full comparative advantage of the private sector along the supply chain of mechanization, it is unlikely for a government to refocus its roles in promoting mechanization truly led by the private sector.

Focusing on the role in the creation of enabling environment for the private sector to lead mechanization, the governments can play a greater role in generating and providing public goods that are urgently needed by the private sector. Such public goods include spreading knowledge of machinery, the operation of machinery and farming practices that can maximize the benefit of mechanization, and to facilitate the development of suitable institutions for providing such public goods.

Research on Mechanization Demand and Adoption

One such public good would be strengthening research on the extent and nature of mechanization adoption. As discussed in Section 3, demand for mechanization is often quite localized and existing data are not rich or specific enough to make useful inferences on where mechanization is

most feasible. It is necessary to intensify research to better understand the nature of demand for mechanization services, based on different farming systems, labor dynamics, and socioeconomic factors. Governments could overcome this lack of data through conducting tractor censuses, and household surveys that fully capture the dynamics of equipment ownership, use and service provision across different regions and climatic zones. Soil maps can also provide information on the types of tractors demanded and the effects of plowing. This can help identify priority areas for mechanization to be pursued as well as those areas where population and market dynamics have not yet made mechanization feasible.

Support to R&D

In addition to collecting and analyzing data on the use of mechanization, government support to R&D will be important in countries in which the manufacture of machines, implements, and spare parts is being pursued. Such support can also address the issue of appropriate technology, by developing locally available equipment perhaps more suitable for African farmers than the large 4-wheel tractors that currently dominate the market (Baudron et al 2015). There have been instances of successful collaboration between government research agencies and international organizations, such as with the ASI thresher in Senegal (Rickman et al 2013). Such collaborative efforts may be necessary if the technologies developed are to be better suited for local conditions while still competitive with imports. Governments can further strengthen R&D efforts by increasing funding, liaising with manufacturers from Europe and especially Asia to learn from and adapt equipment developed there, and by facilitating South-South knowledge exchanges for agronomists and agricultural engineers. Such efforts would mirror the extensive research being invested in the seed sector. Lessons can be drawn from India and China, which have stimulated manufacturing of agricultural machinery through public support along with subsidies that cover a wide range of equipment (Diao et al 2014). Such efforts should be pursued in ways that complement existing private sector research on machinery design improvement often undertaken by local fabricators (Ajibola & Zalla 2007).

Success Story 3: Prudent Use of Government Subsidies to Promote Mechanization

The Indian government provides substantial support to the agricultural and manufacturing sectors, including subsidies on mechanization equipment. These subsidies appears to have supported mechanization while avoiding some of the distortions that befell African governments' subsidies. India's subsidies covered a wide range of machinery, including tractors of different sizes, power tillers, reapers, transplanters, and animal-drawn equipment to ensure that the types of machines being adopted were driven by choice rather than by the subsidy. Recent subsidies have covered smaller tractors, which enables smaller-scale farmers to purchase tractors and provide hiring services. Moreover, these subsidies have been supported by the extension of long-term credit, mostly for the purchase of machines, and substantial public investment in R&D. Thus African countries have models to look to for both stimulating private importation and making public importation constructive rather than restrictive.

The experiences observed in Asian countries repeatedly show that multi-functional tractor use is important for its broad adoption in agriculture. Innovation is required to create more practical multi-functional use of tractors relevant to Africa today, which likely can only come from the private sector. The public sector's support to encourage multi-functional tractor use could give the private sector incentives to develop both proper machinery and technology that can significantly improve the use of tractor beyond just for plowing. However, efforts may be required to enable

farmers to put tractors and power tillers to multiple uses.

Technical training for basic tractor operations as well as adapting tractors under different soil and agro-ecological conditions for different crop systems and on machine maintenance and repair would also be useful for owners and mechanics. In Ghana, for example, most operators have not received formal training and do not have driver's licenses; rather, they learned from assisting other tractor operators. Most mechanics are roadside mechanics without formal training, who often attempt repairs using improvised spare parts on a trial-and-error basis (Daum 2015). However, aid agencies such as JICA and tractor manufacturing companies have emphasized training programs for tractor owners, operators, and mechanics, which will be important for improving operating efficiency (JICA 2014). Additionally,, operators who do not own the machinery but are paid on commission often do not have incentives to maintain machines well and instead overuse them. However in Ethiopia, tractor operators are required to undergo specialized training in order to receive licenses. Such a requirement could prevent operators from misusing machines.

In addition to technical skills training, business-development services could enable owner-operators to improve the efficiency of their hiring out enterprises. FAO has conducted such training programs, mainly for conservation agriculture equipment in East Africa (Sims et al 2011). Where local extension networks have proven effective, they could be well equipped to include such trainings for tractor owners.

Infrastructure Investments

Government investments in rural and national road networks can also support mechanization service provision. Better road infrastructure within rural areas will help machines cut down time spent travelling between fields and thus increase the area that they can plow. Improvements to national road networks would help facilitate-cross regional migration. Additionally, better rural and feeder roads will make it easier for tractors to provide transportation services for carting both agricultural and nonagricultural goods in the rural areas year round. Better rural roads may also enhance labor mobility (which may induce further labor movement away from farming), and improve market access, possibly leading to an environment where mechanization is more profitable and increasingly demanded.

Mechanization Credit Schemes

A number of governments, often in collaboration with donors, have initiated credit schemes designed to enable more farmers to purchase mechanization equipment and provide hiring services. These schemes are often geared to types of machinery governments believe to be more suitable to farmers. Government and donor projects in Mozambique, Tanzania, and Zambia have attempted to address this issue by offering favorable credit terms for individual farmers and cooperatives to buy tractors and provide services to smallholders (World Bank 2014b). Programs in Tanzania include the Agricultural Inputs Trust Fund, which provides funding for 4-and 2-wheel tractors along with other agricultural inputs to individual farmers, and District Agricultural Development Plans, which provide an interest free loan to farmer groups to purchase 2-wheel tractors. The agricultural window of the Tanzania Investment Bank also provides government-supported financing to importers and farmers (CIMMYT 2015). In addition to the subsidized credit provided by the AEHE program in Nigeria, the government is also pursuing the implementation of NIRSAL (Nigerian Risk-Sharing Agricultural Lending), which guarantees up to 75% of bank loans for mechanization and other agricultural investments and may allow more private tractor

imports to enter the market as the federal government hopes to scale back its involvement (World Bank 2014a). Historically, many of government mechanization credit schemes have suffered due to poor repayment rates, high monitoring costs. Therefore, they may not be a practical or sustainable solution to the lack of demand for machine purposes among potential service providers. Loan guarantees through NIRSAL in Nigeria may suffer from both banks' and borrowers' moral hazard as high monitoring costs will remain a constraint. There are also concerns that subsidies and subsidized credit with certain conditions attached will distort markets for importation. As with the AMSEC scheme in Ghana however, it remains to be seen whether or not such programs will prove sustainable or collapse due to poor management and high default rates.

Eliminating Distortions

Despite recognizing the potential distortionary effects of subsidies, governments may still feel compelled to play an active role in promoting mechanization technologies. Many governments have appreciated the viability of farmer to farmer service provision and recognized that the high cash outlays and lack of affordable credit prevent potential owners from acquiring machines. In these cases, either subsidizing tractors or credit provision may encourage more large and medium farmers to make the investment in a tractor and provide services. However, such an approach is only justified where it is certain that there is widespread demand for hiring in services and should foster a supportive environment rather than competing with, distorting or crowding out the private sector. Machinery subsidies adversely affecting private importers and artificially influencing brand selection, as well as subsidized service provision, as discussed in previous sections, are examples of distortionary effects that should be avoided.

Success Story 4: Creation of an Enabling Environment for Private-Sector Driven Mechanization

While government imports can in some cases stifle private supply chains, government can also play a facilitative role in stimulating the flow of imports. For example, the removal of restrictions on Chinese 2-Wheel tractors in Bangladesh is often credited with turning the country from a "basket case" into one with over 80% mechanization of primary tillage operations. As a series of major floods and cyclones in the late 1980s decimated the country's draught animal population, President Ershad was advised to lift import restrictions on Chinese 2-wheel tractors imposed by the national standards committee (Biggs et al 2011). This resulted in a 40% decrease in the cost of imported machinery and throughout the mid-1990s, large numbers of these tractors were imported. As a result, land preparation is now heavily mechanized, as mentioned throughout this paper, with 2-wheel tractors accounting for 92% of all tractor power (Diao et al 2014).

Trade and fiscal policy is another area in which distortions affecting mechanization can be eliminated. Most African countries have eliminated import duties and VAT for imported tractors; Burkina Faso and Mozambique are the two exceptions in the World Bank's ABI case studies, charging a 5% import duty, which can reach up to 16% in practice in the former (World Bank 2013b; 2013c). Ethiopia has a more complex process, where tractors are only exempt if they are cleared and purchased within 6 months of arriving at the port of Djibouti (World Bank 2012a). However, the imports of spare parts are still charged heavy duties, reaching 30% in many countries, which prevents adequate stocks from being built and supplied to users, leading to significant delays when a breakdown occurs during peak season.

Table 8: Import Duties and VAT for Tractors and Parts in Selected Countries

	Burkina Faso	Ethiopia	Ghana	Kenya	Mozambique	Nigeria	Rwanda	Tanzania
Import duty + VAT for tractors	16%	0%	0%	0%	5%	0%	0%	0%
Import duty + VAT for spare parts	20%	25-40%	27%	16%	25%	5%	30%	10%

Source: World Bank (2014b)

Raw materials for mechanization implements and completely- and semi-knocked down (C/SKD) tractor parts are still widely subject to the full tariffs (World Bank 2014b). If there is potential for locally manufactured implements or locally assembled tractors to compete with imports, then governments could help encourage this by removing or lowering duties on raw materials on CKD parts. Delays in import procedures can also adversely affect the timely supply of machines to rural areas. For example, all machinery imported into Tanzania must be examined and approved by CAMARTEC, the government agency in charge of machinery quality control and testing. While this helps ensure that only well-functioning machines enter the country, a number of stakeholders have cited delays in this process as a major bottleneck (World Bank 2012c). In short, import policies should not only provide an incentive to importers, and consequently users, but also ensure that customs and testing procedures are smooth in order to avoid delays.

Potential Roles of Donors in Mechanization Promotion

The roles of donors in promoting mechanization should be similar to those of governments, in that they should focus on stimulating demand among farmers and filling gaps in the supply chain through encouraging private sector development. Likewise, they should also avoid interventions such as direct subsidies that would distort the market for machinery and services. In fact, many of the iconic failed government mechanization machineries were funded by donors (Tokida 2013, in Kienzle et al 2013).

Instead, donor interventions should emphasize training and capacity building across the mechanization supply chain. This can include support to local R&D and manufacturing, as well as demonstration of potentially more effective technologies and training farmers. For example, JICA has supported training and extension activities alongside the provision of machinery through 2KR grants in order to improve the utilization of agricultural machinery, R&D efforts in African universities, facilitated South-South trainings, and a number of other technical cooperation projects, especially focusing on rice mechanization. Specific trainings have included general farm mechanization, upland and irrigated rice mechanization, appropriate technology development for small-scale farmers, machinery testing and evaluation, repair and maintenance, rice postharvest and processing technology. These trainings have long been conducted in countries such as Egypt, Morocco, Tanzania, Ghana, Cote D'Ivoire, and Madagascar, among others (Tokida 2013, in Kienzle et al 2013). The Japanese Association for International Collaboration of Agriculture and Forestry (JAICAF) is also demonstrating and training farmers on a wide variety of technologies, including tractors, power tillers, rice seeders, and rice mills in Ethiopia, Uganda and Tanzania (JAICAF 2015).

Such support increases the demand for and improves the utilization of agricultural machinery, while interventions such as subsidized machinery and service provision may distort private supply chains. Nevertheless, all types of mechanization interventions should be designed with the goal of phasing out after a stronger private supply chain has been developed.

Opportunities for Private-Sector Promotion of Mechanization

Much of this paper has discussed the ways in which the private sector- in its broad sense, covering individual farmers, small enterprises and large companies- is best positioned to respond to emerging demand for mechanization as a result of intensification processes. However, there is still a "business case" to be made for the private sector promotion of mechanization, which both depends on active attempts by governments to create public goods and on the avoidance of inefficient direct involvement. This involves companies proactively attempting to overcome two of the main market failures in mechanization: lack of information among farmers and credit market failure.

If the lack of information about the availability and use of mechanization equipment is a substantial constraint for farmers, demonstration programs may help introduce farmers to new technologies and expose them to existing ones where they have not been widely adopted. As with the case of John Deere in Zambia mentioned in the previous section, manufacturers have not only offered affordable financing to customers, but invested in training centers and other programs that will make farmers aware of different types of machinery and train them both on the technical and business skills required for effective ownership. These business-oriented trainings focus on farmer to farmer service provision, as tractor manufacturers have begun to recognize that such a model can enable more farmers to invest in their machines. Demonstration of the full range of machinery on the market could also help correct for the distortions introduced by subsidies or concessional loans that limited farmers' exposure to certain brands, assuming supporting supply chains for spare parts and repairs could also be developed. However, this is an area where empirical evidence is scarce. It should not be simply assumed that many farmers are unaware of the benefits from various modes of mechanization. More pilot studies combined with rigorous assessments may be needed to see when demand for mechanization can be stimulated by informing farmers of the potential benefits. Likewise, it remains to be seen whether the financing provided by dealers and manufacturers will be successful in the long run.

6. Main Messages and Conclusions

Making agricultural mechanization more accessible and effective is likely to contribute to African agricultural and economic transformation. Nevertheless, mechanization must overcome a past littered with poorly-planned programs that failed to assess demand, relative neglect by researchers and policymakers, and misconceptions about what mechanization is and is not. This background paper has attempted to define mechanization clearly and broadly, identify the conditions that drive demand for mechanization, and use a supply-chain approach to describe the patterns of mechanization that have begun to emerge across Africa, and summarize key roles of government in promoting mechanization.

The debate surrounding mechanization has suffered from a number of misconceptions. Mechanization often conjures an image of large tractors operating on large farms or commercial

estates. However, African farmers of all types and sizes may use mechanization equipment in many farming systems, whether by owning machines or hiring in services from other owners. Moreover, mechanization is essential to a wide variety of agricultural functions, most significantly land preparation, harvesting and threshing, as well as non-agricultural functions such as rural transport and road construction. There are also misconceptions about the appropriateness of mechanization. On one hand, it was at times promoted indiscriminately during the 1960s and 70s, even in areas where farming systems had not yet evolved enough to generate demand amongst farmers. On the other hand, forced mechanization is often associated with the displacement of tenant farmers and rural labor along with, sometimes, environmental degradation. There is limited evidence of either of these occurring in Africa; mechanization is more likely to increase aggregate labor demand when it enables more land to be cultivated and is often accompanied by other practices meant to maintain soil fertility.

Demand for mechanization depends on farming system intensity, market access for agricultural products, labor and wage dynamics, the availability of complementary technologies and the capacity to fully utilize machines. As Boserup theorizes and as a number of past mechanization initiatives failed to realize, mechanization is a component of the agricultural intensification process and cannot be used to initiate it where it is not already being driven by population pressure and market demand. Intensification processes in Africa may be similar in principle from those that occurred during the Asian Green Revolution. The processes are, however, quite diverse both across and within countries, depending on population density, market access, agro-ecology, and other factors. Thus, there is significant spatial variation in mechanized demand across Africa, for which more information and better data are required to capture. Nevertheless, there do appear to be a number of pockets where vibrant demand from smallholder farmers has emerged.

Where mechanization demand exists, private market channels have demonstrated their ability to meet such demand. Private importers are able to import lower cost machinery of the brands preferred by farmers, for which spare parts and repairs are more widely accessible. Farmer to farmer service provision also possesses inherent advantages compared to other models, as owner-operators can achieve own-farm benefits in addition to revenues from hiring out, without the administrative costs and other inefficiencies faced by specialized hiring services, even when they are subsidized. However, these supply channels are still imperfect, and the supply of services to more smallholders depends on demand from large and medium farmers for owning tractors that can also be used in service hiring market. Many factors affect such farmers' incentives to invest in tractors; interest rates are often prohibitive for many potential-owner to access credit, and spare parts and repair service networks are still incomplete.

The supply of mechanization through inappropriate government intervention is often inefficient, which can also have adverse effect on the private supply chain development. While subsidies may be necessary under certain conditions, they can crowd out private hiring services and limit the availability of technologies/brands more suitable for the countries. If subsidies are deemed necessary by governments, then they should be targeted to reach farmers who are capable of using machines efficiently and providing services, cover a wide variety of machines and brands to suit farmers' needs and preferences, and have a plan to phase out after stimulating private demand.

Governments can support mechanization by creating an enabling environment for private supply chains to continue meeting the demands of farmers for mechanization. Some actions governments

can take include provision of public goods such as key knowledge and R&D, encouraging innovation in multi-functional tractor use, capacity building activities such as training and study tours, creating incentives for private importation and service provision, and making any involvement coherent and transparent through an effective national strategy. There is also a need for governments and international agencies to conduct in-depth, localized research that captures not only the dynamics of mechanization use but effectively evaluates demand for mechanization equipment and services in each farming system.

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