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Agricultural Mechanization in Africa

Insights from Ghana's Experience

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The enormous potential of the agriculture sector to contribute to food security, economic growth, and poverty reduction in Africa south of the Sahara is gaining renewed recognition. Sustainable intensification of agriculture can provide both food and jobs for a growing population. Agriculture is expected to become increasingly mechanized in this intensification process. Mechanization can help farmers perform timely field operations amid changing weather patterns and reduce labor requirements, lightening the drudgery of farm work and allowing greater time for off-farm income generation. In contrast with other developing regions that experienced rapid increases in mechanization in recent decades, though, African agriculture still relies predominantly on human muscle power. State-led efforts to promote use of tractors and other forms of mechanization have largely failed.

Recent experiences in both Asian and African countries suggest that the private sector is best positioned to meet the emerging demand for mechanization throughout the supply chain—from manufacturing or importing machinery, to hiring services for farmers, fabricating and distributing attachments and spare parts, and providing machinery repair and maintenance services. Rather than promoting mechanization through direct government interventions, which often lead to market distortions, the public sector can play an important role in addressing key market failures by promoting private ownership of agricultural machinery and spurring development of farmer-to-farmer service-hiring markets to meet growing demand from small farmers. This brief explores recent developments in Ghana that lend insight into the drivers of mechanization and the appropriate role of government policy in supporting this transition.

EMERGING DEMAND FOR MECHANIZATION

Agricultural intensification is largely driven by growing demand for agricultural products, itself a result of population growth, improvements in market access and urbanization, and rising household incomes (Boserup 1965; Hayami and Ruttan 1970, 1985). However, for agricultural intensification to lead to mechanization—from tractors for land preparation to other machines for threshing and harvesting—additional factors that increase farmers' demand for such equipment, such as sufficient farm size and rising labor costs, are required.

In Africa south of the Sahara, adoption of mechanization—both engine-powered machinery and animal traction—was quite limited until recently. Animal traction has not been adopted in tropical areas of West Africa such as southern Ghana, largely because trypanosomiasis limits the possibility of raising cattle and other large animals used for plowing (Diao et al. 2014). Adoption of engine-powered mechanization also remains low because of the predominance of subsistence agriculture and poor market access. An early study of 30 government mechanization schemes in Africa from 1945 to 1987 found that these schemes consistently failed because of lack of demand among farmers, in addition to the poor management and efficiency issues commonly associated with state-run intervention programs. As a result, publicly run tractor-hiring services quickly collapsed and machines were often left idle, scrapped, or abandoned (Pingali, Bigot, and Binswanger 1987).

Demand for mechanization in Ghana and many other African countries, however, has changed since the late 1990s. Data from a recent survey-based study in Ghana (Chapoto et al. 2014), along with other recent literature on mechanization in the region, show that three factors can explain the recently emerging demand for mechanization in Africa.

Urbanization

Urbanization is closely linked with growing market demand for agricultural products, which is a driver of agricultural intensification and consequently of mechanization. Ghana urbanized rapidly in the past two decades—as of 2010, more than half the total population was living in urban areas. Intensification as a whole and mechanization in particular in Ghana appear to be fairly correlated with market access, as measured by travel time to large towns and proximity to roads (Cossar 2015). Urbanization is associated with changes in dietary structure that lead to increased demand for cereals, which generally have higher labor requirements than roots and tubers and are more conducive to mechanization (Nin Pratt and McBride 2014). While northern Ghana is still dominated by agriculture, low population density and relatively large farm sizes enabled it to significantly increase its supply of maize and rice to urban markets across the country.

Rising farm size among medium-scale farmers

While the average farm size has fallen—or at least not increased—in many African countries among smallholders, both the number of medium-scale farmers and their average farm size increased recently (Jayne et al. 2016). In northern Ghana, medium-size farms now account for 60 percent of all farms, while the number of small farms has decreased (GSS 2014). Large farmers in Africa historically used tractors for land preparation, but medium-scale farmers appear to be driving the recent emergence of mechanization demand and constitute a significant share of new tractor owners in many African countries, including Ghana. The survey of medium-to-large farmers in northern Ghana found that half of tractor owners cited land expansion as the primary motivation for investing in tractors (Chapoto et al. 2014). In Tanzania, similarly, farmers who own tracts of land greater than 6 hectares are more likely to purchase a tractor than smaller farmers (Mbesa 2016). While farmers in some areas of African countries have long been aware of mechanized technology options, the increased number of medium-scale farmers who are tractor owners creates new potential for the supply of hiring-out services. In fact, many medium-scale farmers were formerly smaller farmers who used tractor-hiring services, and farmers who have used hired-in tractor services expand their land more than those who have not used tractors (Houssou, Diao, and Kolavalli 2014a). Finally, an active land market or a traditional land tenure system, like the one in Ghana, that makes it easy to obtain additional land is a key factor for raising mechanization demand, as it enables farmers to expand and consolidate landholdings for the use of tractors (Mrema, Baker, and Kahan 2008).

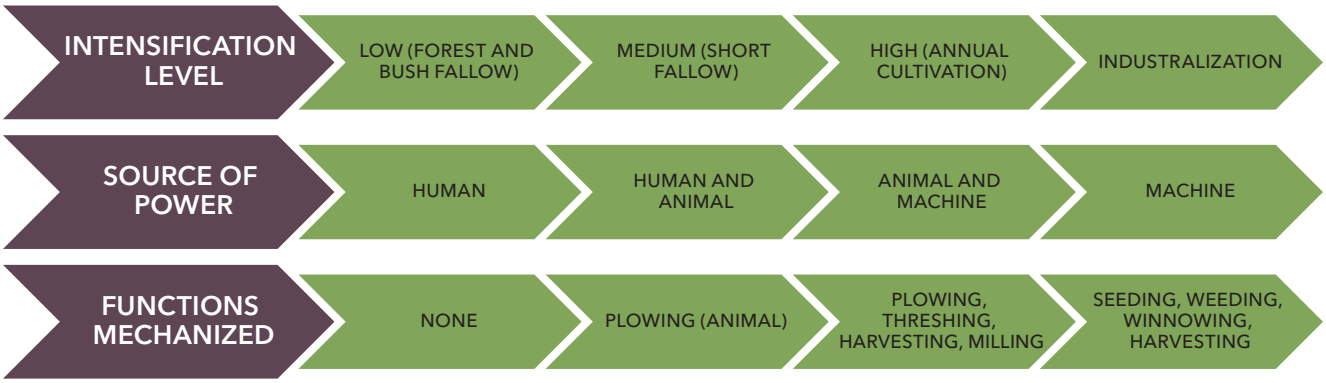
Rising rural wages and labor-saving technology

Urbanization not only increases market demand for food but also creates more nonfarm jobs in both urban and rural areas, putting upward pressure on rural real wage rates and hence creating demand for labor-saving technology like mechanization. Mechanized plowing significantly reduces the labor required for land preparation and, though to a much lesser extent, reduces the labor required for weeding and harvesting (Pingali, Bigot, and Binswanger 1987). When hired labor is a major source of agricultural labor in certain farming activities—for example, land preparation and harvesting—the bottleneck effect of seasonal labor shortages increasingly prompts farmers to switch to mechanized services where they are available. Such seasonal factors are seen in wheat-/barley-growing areas in Ethiopia because of the short window between first-season harvesting and second-season planting (Berhane et al. 2017).

Demand for mechanized services is further boosted when hired labor represents a large share of production costs and becomes more expensive. Under such circumstances, even small farmers begin to demand mechanization technology. In Africa, recent structural changes have increased job opportunities in the rural nonfarm economy, and many family members from rural households are participating in nonfarm economic activities (Diao et al. 2014). This creates an upward pressure on rural wages. Ghana has witnessed substantial migration of workers from rural to urban areas, alongside substantial employment growth in the rural nonfarm economy; the share of workers remaining in agriculture fell to about 40 percent of total employment in recent years. Data from the Ghana Living Standards Surveys (GLSS) between 1991/92 and 2012/13 show agricultural real wages grew by nearly 7 percent per year over the period, and the growth rate is similar in the north and south.

While mechanization for land preparation is not necessarily a productivity-enhancing technology (Pingali, Bigot, and Binswanger 1987), reduced dependence on hired labor improves farmers' control over the timing of agricultural operations. In semi-arid areas with few days of rainfall and in areas with bimodal rainfall that practice multiple seasons of cropping, seasonal labor bottlenecks can impact productivity. For example, in northern Ghana a two-week delay in planting can lead to a 30–55 percent loss of yield (Houssou, Diao, and Kolavalli 2014a). Reducing harvest losses, hence increasing actual returns from crop production, creates demand in turn for mechanized threshing and harvest services. In this case, demand for mechanized services can rise even for farming activities that depend on family labor, as observed in Ethiopia (Berhane et al. 2017).

Figure 1 Overview of sequential adoption of mechanization



Source: Adapted from Pingali, Bigot, and Binswanger (1987).

Adoption of mechanization in Africa

Demand for mechanization typically emerges sequentially (Figure 1). Farm tasks that are power-intensive—beginning with plowing—are usually the first to be mechanized (Pingali, Bigot, and Binswanger 1987). Limited data are available on the number of tractors in use in Africa. While Asia has widely adopted two-wheel tractors, four-wheel tractors account for a much larger share of tractor ownership in Africa (possible reasons are discussed below). These are heavily concentrated in North African countries and South Africa, followed by countries with large commercial farming sectors such as Kenya, Nigeria, and Tanzania (FAO 2015).

Typically, emergence of demand for mechanized plowing is followed by demand for mechanized threshing, and lastly for mechanized harvesting (Pingali, Bigot, and Binswanger 1987). Threshing machines are often fabricated locally and are available on the market in many African countries (Pingali 2007). While mechanized harvesting remains rare in Africa, it does appear in a few pockets, mainly in wheat/barley cereal systems and rice irrigation schemes (Longmire and Lugogo 1989; Hassena et al. 2000; Takeshima et al. 2013; Berhane et al. 2017).

Because agricultural production is largely influenced by local conditions, both potential demand and adoption of mechanization often exhibit substantial spatial variation within a country. Given this variation, national statistics alone cannot give a clear picture of demand. In most African countries, existing demand for mechanization is concentrated in certain types of areas. First, demand is often high where there is a group of farmers with farm sizes larger than the national average, and in areas that have been highly urbanized but where farm sizes remain small. For example, Ethiopia is known as a relatively land-scarce economy. There, both tractor services for plowing and combine-harvester services are emerging in mid-altitude lowlands; the machines are owned by medium- and large-scale farmers who provide hiring-out services to smaller farmers (Berhane et al 2017). In northern Ghana, which comprises the savannah and transition zones, the mechanization level is higher than in the south. The recent Labor Force Survey conducted in 2015/16 in Ghana shows that while countrywide one-third of crop-growing households practice mechanized agriculture, primarily for plowing, the adoption rate is as high as 88.5 percent in the Upper West Region and 76.9 percent in the Greater Accra Region (GSS 2016).

Second, demand is strong where agroecological conditions are suitable for mechanization. In most countries, mechanization is concentrated in areas that are semi-arid but with sufficient rainfall for developing agriculture. Tropical forest areas are often much less mechanized, with an adoption rate in the range of 2–10 percent in Ghana's forest zone regions, for example (GSS 2016). The southern forest zone in Ghana is more suitable for permanent tree crops than annual crops. Stumps remaining in cleared fields also contribute to the low level of mechanization. On the other hand, lower demand for mechanization in some areas within a country is commonly associated with strong animal traction traditions and extremely small farm sizes. In Ghana's Upper East Region, the adoption rate of mechanized agriculture is only 18 percent (GSS 2016), mainly because of a tradition of using animal traction (Houssou et al. 2013b) and the predominance of smaller farms. In Ethiopia's highlands, the adoption rate is also extremely low as a result of these factors.

Because the demand for mechanization and the suitability of available technologies vary significantly not only across regions in a country but also within regions (Houssou et al. 2015), a nationwide push for mechanization by the government would be inappropriate. However, some market failures and existing government-induced distortions may hold back the expansion of mechanized agriculture even in areas in which it is suitable.

MARKET FAILURES IN MECHANIZATION

"Supply" of mechanization covers manufacturing and importation of machines, mechanized service provision to farmers, fabrication and distribution of attachments and spare parts, and machinery repair and maintenance services. While demand for mechanization appears to be growing among farmers in Africa, such demand does not necessarily lead to adequate supply responses, particularly when the demand is from many small-scale farmers. Market failures could slow the private sector's response to the increased demand for hiring services for mechanization. Although some of the possible government interventions related to mechanization may not be ideal, government policy can play an important role in mitigating the effects of market failures. To develop an effective government policy to support mechanization, it is important to both identify market failures in mechanization and recognize the risk that inappropriate government interventions—"government failures"—may create market distortions that disincentivize the private sector's role in developing mechanization supply chains.

Risk and uncertainty of private investment in agricultural machinery

Even where demand for mechanization is high among farmers, few smaller farmers can afford tractors or other large agricultural machinery, which require a large upfront investment. As for other indivisible lump-sum investments, the uncertainty about the returns to investment increases the risk for private investors and can lead to underinvestment in agricultural machinery and unmet demand for mechanization services. Investment in tractors and other large machinery depends on farmers' confidence in achieving profitable utilization rates; farmers are constrained by both uncertainty in the hiring market and the uncertainty of opportunities for multifunctional tractor use.

HIRING MARKET RISK: In Asia and Africa, medium-scale farmers who own tractors typically rely on hiring-out services to achieve profitable utilization rates, since their landholdings are too small to make full use of a tractor. In some countries, mechanized hiring services are also provided by nonfarmer entrepreneurs, both for tractor plowing and combine harvesting, as in the Itaya/Assela areas of Oromia Region, Ethiopia.[1] In Ghana, few farmers owned tractors until the early 2000s, and most of those who did were large farmers. Since then, many medium-scale farmers have acquired tractors. Many of these farmers mentioned demand for machinery-hire services among smaller farmers as a key reason for owning machinery (Houssou, Diao, and Kolavalli 2014a). In addition to meeting local demand from small farmers, in some locations with good rural roads or less fragmented farmland, owners also migrate with their machines to other areas for plowing and harvesting.

However, the hiring-service market is still in an early stage in most African countries, and both medium-scale farmers and nonfarmer entrepreneurs face uncertainty about whether sufficient demand exists for hiring services to make investing in a tractor or a combine harvester profitable. Indeed, the survey conducted in Ghana shows that 85 percent of tractor owners were first consumers of hiring services for about 10 years on average before they purchased tractors (Houssou, Diao, and Kolavalli 2014b). Their early experiences provided a learning period for better understanding the service market. Despite the expansion of hiring services, migratory service provision in plowing is rare in Africa. While Ghana has different agricultural seasons in the north and south, only about one-fifth of surveyed tractor owners in Ghana migrate between the two regions. Most of these tractor owners are clustered in just one district (Chapoto et al. 2014). Possible explanations for the failure to take advantage of the different seasons include uncertainty over demand, insufficient transport infrastructure, lack of local agencies to connect with farmers in unfamiliar areas, and other information asymmetries. The risk and uncertainty will likely decrease as the hiring-service market becomes more established with more private owners participating; however, at present, the supply response is expected to lag behind demand as long as individuals providing hiring services require a period of learning by doing. In China, for example, county-level governments set up communications platforms among service providers and provide harvest calendars and other information across the whole country to help machine owners overcome the information asymmetries that increase the risks of migratory service provision (Yang et al. 2013).

The market failure caused by the uncertainty in the hiring-service market is magnified by lack of access in the financial market to credit for machinery investments. In Ghana, as in many other African countries, tractor owners depend on their own savings for such investments. Only 3.4 percent of surveyed medium-scale farmers in Ghana who owned tractors obtained any loans for their purchases (Chapoto et al. 2014). Accumulation of the large amount of money needed to purchase a tractor takes time. Land tenure traditions also contribute to this problem. In Africa, land has historically been communally owned.

[1] Observed by the authors in the course of a field trip, November 2017.

Such customary land tenure systems help many African countries avoid land concentration in the hands of a small number of large owners, but these systems prevent the use of land to secure loans for investment. In addition, interest rates for existing commercial loans are too high to attract borrowers for agricultural machinery investments. Consequently, the supply of hiring-out services tends to be concentrated in areas with large and medium farmers who can afford the investment in machines; the supply response in other areas has been slow to meet rapidly growing demand for mechanization.

UNCERTAIN OPPORTUNITIES FOR MULTIFUNCTIONAL TRACTOR USE: Tractor use can also be extended beyond land preparation, including using tractor engines to power threshing machines or water pumps. This multifunctionality is often an important factor in achieving profitable utilization rates. In fact, in developing Asian countries, the wide dissemination of hiring services is strongly associated with the multifunctionality of tractor use, especially in the early stages of mechanization (Diao et al. 2014). In Bangladesh, for example, the removal of import restrictions on small, cheap, diesel engines from China led to the rapid development of mechanized small-scale irrigation, and when the restrictions on Chinese-made power tillers were later lifted, power tillers were immediately put to use to power shallow tubewells for irrigation in addition to plowing and transportation. Researchers argue that the synergy between power tillers and irrigation is one of the important factors driving rapid mechanization in Bangladesh (Biggs and Justice 2015).

However, in many parts of Ghana and other African countries, irrigation options are limited by the lack of suitable and affordable small-scale irrigation technology as well as knowledge needed for utilizing available water resources such as ponds, creeks, and shallow water for irrigation. This lack of technology and information significantly restricts opportunities for utilizing a tractor's power. Tractors are also commonly used for transportation. When Asian countries started to adopt power tillers for land preparation, the machinery was also the lowest-cost transport equipment available in rural areas. While farmers in Ghana and some parts of other African countries occasionally use tractors for carting crops from the field, motorized tricycles, both imported and locally assembled, are much more popular than tractors today in Africa's rural areas for transporting goods and people; they also cost less and use less energy than most large tractors. As a result, tractors are largely used solely for plowing in Ghana, with some owners also using the engine for maize shelling. The survey shows that 90 percent of the revenues generated from tractor service provision in Ghana are from plowing services (Houssou et al. 2013a).

Additionally, lack of knowledge of good land preparation practices in areas without an animal traction tradition further limits tractor use. Farmers often prefer just a one-time plowing and are reluctant to pay additional fees for a second plowing or for leveling and harrowing, which are common practices in East Africa where animal traction is used. The survey in Ghana shows that only a small fraction of tractors are used for a second plowing or for harrowing, although the harrowing attachments are imported by the government at subsidized prices. The limited opportunities for multifunctional usage further increase the risk of investing in tractors, discouraging would-be owners from purchasing tractors and providing services to other farmers.

Lack of knowledge and availability of appropriate smaller agricultural machinery

Tractors come in a wide range of sizes and horsepower as well as prices in developing Asian countries. Power tillers and small, low-horsepower, four-wheel tractors are manufactured in China, India, Thailand, Viet Nam, and some other Asian countries and are affordable for many small and medium farmers. In many African countries, however, smaller agricultural machinery—including small tractors that are relatively affordable and suitable for African soil conditions—is not readily available. Farmers in Africa commonly favor large and powerful tractors; the average horsepower of tractors ranges from 60 to 80 in Ghana, and is over 100 in Ethiopia and Kenya, while the smaller tractors popular in Asian countries range from 20 to 40 horsepower (World Bank 2014). While power tillers have been widely adopted throughout Asia, the low level of irrigation in many African countries reduces the potential for adoption of power tillers. Some African governments recently tried to introduce power tillers to farmers outside of irrigation schemes under subsidized prices, but outcomes are generally disappointing because of lack of demand and lack of knowledge about their proper use (Mrema, Kahan, and Agyei-Holmes 2017; Kahan and Jaleta 2015; Takeshima et al. 2015). Smaller tractors and power tillers combined with ripper/seeder technology can be introduced under conservation farming with minimum tillage, which reduces the need for deep plowing. However, the experience in Tanzania shows that most smallholders who are exposed to conservation farming still prefer to plow their soils, a job difficult for smaller machines with limited horsepower (Bymolt and Zaal 2015).

Further research is needed to fully understand why smaller tractors have not been widely adopted in Africa, and why tractors' utilization efficiency is generally low. The next section explores a few possible market failures that may explain the relative absence of smaller machinery in Africa south of the Sahara.

LIMITED KNOWLEDGE AND INFORMATION ABOUT SMALL MACHINERY: The early push for mechanization through state-run mechanization service centers in the 1970s and early 1980s exposed farmers only to large tractors; in fact, many large tractors imported during that period are still operated and owned by large farmers today. Farmers and would-be-suppliers of mechanization services possess little knowledge about different types of mechanized technologies, including returns to tractors of different horsepower, the merits of small machinery such as hand tillers, or the appropriate use and handling of different machines. Similarly, would-be importers need to be aware of variously sized engines and equipment and their potential uses to be able to assess potential demand and business opportunities related to smaller mechanized equipment. Farmers may not know the proper plowing depth for their fields and often prefer deep plowing, which requires high-horsepower tractors.[2] Thus, second-hand tractors currently imported from Europe by private traders and new tractors imported by the government are all large, and the existing supply chains for spare parts tend to cater to the few brands of large tractors already popular. While knowledge about small-scale machinery's availability and performance will increase as information and evidence spread, until then, importers, farmers, and potential tractor owners will be unlikely to change their preferences for larger machinery.

LACK OF SMALLER-SCALE AGRICULTURAL MACHINERY SUITABLE FOR AFRICAN CONDITIONS: Different soil types require tractors of different sizes and horsepower, and different farming systems and traditional practices also affect the adoptability of different types of machinery. It is not clear whether the smaller-scale engine equipment widely adopted in Asian countries is suitable for African soil conditions. In most areas of Africa dependent on rainfall for crop production, the tropical soils are heavy and highly compacted. Available smaller-scale tractor engines are reportedly not powerful enough for land preparation before the rains when soils are very dry. However, the necessary knowledge about soil types is not available in many countries, as soil types are location-specific and few African countries have recent soil maps. Soil research is needed in addition to research and development (R&D) in designing smaller engines for locally appropriate equipment. While soil research is clearly a public good, investment in designing locally appropriate smaller equipment can be made by the private sector. However, the social returns to such investments are often greater than the private returns to private firms if the technology can be easily copied by other firms. The existence of this potentially positive externality may require government intervention to incentivize private investment.

GOVERNMENT FAILURES IN PROMOTING MECHANIZATION

To address the market failures in agricultural mechanization, African countries commonly try to promote hiring-service provision by mechanization service centers through government support and subsidized machinery. In Asian countries, subsidies are also used to develop domestic agricultural-machinery industries, such as in India (Singh 2000), or as part of direct agricultural support programs, as recently done in China (Yang et al. 2013). These subsidies go directly to farmers and other private owners who provide the hiring services, often cover different types of machines, and are available for all potential buyers of the equipment—this helps to minimize the possible market distortions from subsidies (Diao et al. 2014). In contrast to this Asian model of universal subsidies, subsidies in African countries are often much more selective. Currently, governments in at least nine African countries are providing subsidies to tractor owners in hiring-out schemes (Diao, Silver, and Takeshima 2016). While these recent government programs largely avoid the use of state-run mechanization service centers and subsidized machines are mainly in the hands of private individuals, governments often select these individuals directly and import and distribute subsidized machinery. In recent years, some governments (for example, Nigeria in 2014 and Ghana in 2016) tried to move away from this type of subsidy, although as with other subsidized programs, public financial constraints often threaten the financial sustainability of these efforts.[3]

Ghana is a good example in this regard: about 90 agricultural mechanization service centers (AMSECs)—which provide professional hiring-out services—were established between 2007 and 2013 with government subsidies. The selection process for recipients of subsidized machinery lacks transparency, which invites rent-seeking activities. The subsidized machinery is largely imported from donor countries using concessional loans, which gives the Ghanaian government little control over the brands and models of imported machinery. Beyond the issue of the fiscal unsustainability of such subsidy programs, brands and models of imported machinery have been changed frequently because of shifts in donor countries. Moreover, selected brands may not suit local conditions such as soil texture and rainfall patterns. And when new brands or models are introduced, spare parts and knowledge about maintenance and repair services are rarely available, which could hamper the growth of mechanization supply chains. Not surprisingly, farmers prefer to purchase used tractors, mainly imported by private traders, for which spare parts and repairs are available (Diao et al. 2014).

[2] Authors' interviews with tractor-service providers in Ethiopia, November 2017.

[3] Authors' informal discussions with government officials, November 2017.

The tractor models imported through concessional loan agreements between African governments and donor-country governments are those available in donor countries, which may discourage manufacturers from developing affordable and suitable smaller-scale machinery or other new products for African conditions. Investment in appropriate technology is unlikely if these firms do not perceive African markets to be large enough to justify additional R&D investment, and if their current products can be easily sold in the African market through government programs.

In sum, the AMSEC model has not overcome the market failures discussed above, and in fact, these state-supported professional hiring services seem to make less efficient use of tractors than do nonsubsidized farmer-to-farmer hiring services (Oluka 2000; Kienzle, Ashburner, and Sims 2013; Takeshima et al. 2015). There is no evidence that AMSEC programs reduce service charges for plowing, enable farmers to plow greater areas and adopt more modern inputs, or encourage them to acquire similar tractors through a demonstration effect (Benin 2013). Many of the entrepreneurs who obtained government-imported machinery using AMSEC loans have defaulted because their operations were not profitable (Diao et al. 2014; Houssou, Diao, and Kolavalli 2014a).

In recent informal discussions, a government official asserted that the Ghanaian government, learning from past failures, lately improved the process of importing and distributing tractors under concessional loan agreements. More attention is being paid to improving multifunctionality of imported tractors; small harvesters and planters attached to tractors are imported as a package under a recent concessional loan arrangement with the Brazilian government. Supply of spare parts and maintenance service provision by the manufacturers are also included in the agreement. Buyers must undergo training facilitated by the government and provided by experts from the donor country as a condition of purchasing tractors. While more than 70 new AMSECs were established under this concessional loan arrangement with the Brazilian government in late 2016, imported tractors and the attachments in the package are open to all potential buyers on a first-come, first-serve basis. Most buyers are individual farmers purchasing single tractors with attachments. The minimum number of tractors required for an entrepreneur to qualify as an AMSEC was also reduced. While these policy improvements are encouraging, it is still too early to know their outcomes.

RECOMMENDATIONS

The evidence of market failures and government failures affecting agricultural mechanization in Africa suggests that the following government policy changes could facilitate the process, particularly in the early phases of mechanization before hiring-service markets become well established.

- Encourage both farmers and nonfarmer entrepreneurs as hiring-service providers, with similar attention and support to both groups.
- Focus R&D on affordable, smaller agricultural machinery suitable for local conditions. R&D, informed by soil research, should be a primary component of agricultural technological innovation programs supported by African regional organizations, country governments, and development partners. R&D activities that aim to generate knowledge on the benefits of different types of mechanized technologies can be conducted jointly with researchers from other countries.
- Ensure that concessional loan arrangements with donor countries consider the suitability and affordability of different types of agricultural machinery. Governments and donors can facilitate technological development and knowledge transfer from abroad under such agreements, including promoting multifunctional tractor use through various affordable, smaller attachments for activities other than plowing and by promoting the importation of smaller agricultural machinery. Supply of spare parts, maintenance provision, and technical training in operating and managing newly introduced equipment should be part of the loan arrangements.
- Reform subsidies to avoid arbitrary selection of recipients and of machinery and to increase transparency to eliminate rent-seeking behavior. Subsidy design should also take care not to crowd out private importers. The effectiveness of different modalities of temporary subsidies, including direct subsidies to farmers and interest rate (rather than price) subsidies on equipment to encourage lending by private financial institutions for agricultural machinery, should be thoroughly analyzed.
- Experiment with conservation farming that includes minimum tillage requirements tailored to African conditions to facilitate the use of smaller machinery. While opportunities exist for technological leapfrogging in some areas of Africa, substantial R&D is needed to expand conservation agriculture—from data collection and analysis of detailed soil maps to location-specific recommendations for proper practices.
- Encourage engineering departments in universities and polytechnics to provide technical support for design or adaption of simple machinery suitable for local conditions. Collaboration with experts on such agricultural machinery from other developing and developed countries should be promoted by both governments and donors.
- Provide low-cost outreach courses to mechanics and tractor owners in rural areas to improve their knowledge of tractors and other machinery and repair skills. These courses could be provided by local or international technical institutes as part of donor-supported training programs.

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