Food Policy 48 (2014) 168–181

Contents lists available at ScienceDirect

Food Policy

journal homepage: www.elsevier.com/locate/foodpol

Mechanization in Ghana: Emerging demand, and the search for alternative supply models

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ARTICLE INFO

Article history:
Available online 18 June 2014

Keywords:
Agricultural mechanization policy
Agricultural intensification
Agribusiness
Ghana

ABSTRACT

Influential studies in the 1980s and early 1990s drew on the Boserup–Ruthenberg theories of farming systems evolution to argue that African countries were not yet ready for widespread agricultural mechanization. Through applying the theories of farming systems evolution and of induced innovation in technical change, this paper shows that demand for certain mechanized farming operations particularly plowing has emerged even among smallholders, suggesting that supply issues may now be the main constraint to successful mechanization. We therefore adopt a supply chain approach to analyze two types of mechanization practices in Ghana, i.e., a recent state-led mechanization program and the private sector-led service hiring market, against an international perspective by drawing on three Asian supply models. We identify two major flaws in existing policies. First, the agricultural mechanization service centers that the government promotes fail to use tractors services with sufficient intensity. Second, direct importation of agricultural machinery by the government inhibits imports of appropriate and affordable machinery. In contrast, the development of mechanized service hiring market in which medium and large scale farmers who are tractor owners provide hiring-out services to small-scale farmers represents a promising model for sustainable mechanization in Ghana. This private sector-led second model is consistent with international experiences.

Introduction

Agricultural mechanization represents technology change through the adoption of non-human sources of power to undertake agricultural operations such as plowing, harvesting, shelling, and planting. Adoption of mechanization by farmers is an evolutionary process influenced or induced by a set of country specific agro-climatic factors, economic factors and social conditions for which the government's policy choices have impact. Because of this, the literature on mechanization in Africa that is dated to the 1970s and 1980s focuses on evaluating governments' early interventions in mechanization services. The consensus was that the early push in mechanization failed in Africa due to lack of economic demand from farmers and the fiscal burden of state-sponsored programs (Pingali et al., 1987; Mrema et al., 2008). Donors' and governments' appetite for mechanization policy fell considerably after the 1980s. However, with the recent emphasis on agricultural development and public investment in the sector, some African countries have started to devote public resources to promote agricultural mechanization, including through direct subsidization of machinery imports. The objective of this paper is to bring the attention of researchers to the role of mechanization in agricultural transformation and the role that governments can play in the development of the machinery supply chain. Through applying the theories of farming systems evolution developed by Boserup (1965) and Ruthenberg (1980) and of induced innovation in technical change developed by Hayami and Ruttan (1970, 1985), the paper first assesses whether mechanization demand has emerged. After providing a concrete assessment on emerging demand for mechanization, the second part of the paper focuses on the alternative supply models of agricultural mechanization for addressing such emerging demand. Based on a cross-country comparative analysis and recent development of mechanization in Ghana, the paper examines the appropriateness of mechanization strategies of the government of Ghana. We find that demand for certain mechanized farming operations particularly plowing has emerged even among smallholders. The development of the mechanized service hiring market in which medium and large scale farmers who are tractor owners provide hiring-out services to small-scale farmers represents a promising model for sustainable mechanization. On

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http://dx.doi.org/10.1016/j.foodpol.2014.05.013
0306-9192

the other hand, the specialized service provision model recently promoted by the government seems to be not viable. Continuous implementation of such model will not only increase the financial burden to the government, but also encourage more rent-seeking behaviors, a negative factor to hurt the private sector as the leader in developing mechanization supply chain.

Ghana has experienced steady economic growth since the late 1980s, and the growth is accompanied by rapid urbanization and rising nonfarm opportunities in the rural areas. During this period, the government of Ghana has adopted a market-driven agenda in which its policies and investments have been remarkably neutral with respect to the production sectors. Apart from cocoa, the "winner-picking" type of government intervention is rarely adopted in the agricultural sector. However, beginning in 2003, the Government started to reemphasize the importance of mechanization, directly engaged in tractor imports, and established subsidized agricultural mechanization service centers in the last a few years. Several African countries are considering similar mechanization policies. In Nigeria, for example, the government is the primary importer of tractors, which were sold at subsidized prices to farmers (PropCom, 2012). Similarly, the Government of Tanzania has sold more than 5000 sets of imported agricultural machinery at subsidized prices since 2009 (Lyimo, 2011). The government of Mali imported 400 tractors from India in 2006; DRC imported 920 sets of tractor and farm equipment; and Cameroon planned to import 1000 tractors from India in 2013, all at the subsidized prices (FAO, 2013a). Many of these imports and associated policies are facilitated by lines of credit from the emerging economies such as Brazil, China and India. The records of the Export-Import Bank of India show that Angola, Benin, Burkina Faso, Burundi, Chad, Guinea Bissau and Swaziland have received similar lines of credit ranging from $4 million to $50 million from India to purchase agricultural machinery (pipeline and operative, as of August 2013). China's exports of agricultural machinery have increased in value from $410,000 in 1994 to nearly $65 million in 2008, with much of the increase driven by large tractor exports and 11% of such exports going to Africa (FAO, 2013a). While exports through these credit arrangements with African countries' governments are encouraging these countries to increase agricultural machinery imports, it is a question whether it also presents potential challenges for these countries to be able to establish a private sector-led sustainable supply chain for agricultural mechanization.

Against this background in the recent development of mechanization policy among African countries, we employ a methodology that is a combination of qualitative interviews, secondary data analysis and literature review for a diagnostic analysis of demand for and supply of agricultural mechanization. We focus on Ghana and have interviewed farmers, tractor owners, government officials, importers and other stakeholders there in April 2012 – July 2013.[1] The hypotheses emerging from the field work were tested and refined by analyzing both aggregate and household survey data. A number of small-scale surveys or field studies conducted by IFPRI's Ghana Strategy Support Program, including a farm budget survey (Akramov and Malek, 2012), a study of animal traction use (Houssou et al., 2013a), a survey of input use for maize and rice production (Chapoto and Ragasa, 2013), a survey of government-supported mechanization service centers (Benin et al. 2012), and a study of cropping practices and labor requirements for farm operations (Ngeleza et al., 2011). Part of the data from a recent survey of tractor owners and medium and large scale farmers jointly conducted by IFPRI and Ghana's Savannah Agricultural Research Institute (SARI) in October – December 2013 is also used. The cross-country comparison of agricultural mechanization experiences was developed through an extensive literature review.

Very little research has examined the supply side factors of mechanization (e.g., Mrema et al., 2008), and those have usually focused on provision of services alone rather than the entire supply chain with service provision at the end. This paper tries to fill the knowledge gap by analyzing the entire supply chain both in the cross-country comparison and in Ghana's case study.

The paper begins by examining the demand side of mechanization in the next section. Using the frameworks of evolution of farming systems that was used by Pingali et al. (1987) and induced innovation in technical change developed by Hayami and Ruttan (1970, 1985), the third section provides a contemporary assessment of demand for mechanization services in Ghana. Supply issues are then examined. Three stylized models of mechanization supply based on the experiences of selected Asian countries are presented in the fourth section. The penultimate section has a diagnostic case study of Ghana's current practices in mechanization supply, which covers the model promoted by the government through Agricultural Mechanization Service Enterprise Centers (AMSECs) and the practice led by the private sector. The final section concludes.

Agriculture since 1980s: Is demand for mechanization emerging in Ghana?

Since the early 1970s, all over the developing world, power intensive operations of land preparation, threshing, pumping and transport have been largely motorized via tractors and stationary machines (Binswanger, 1986). However, Africa is an exception. The early push of tractorization by African governments and some donors largely failed, and animal traction was also processing very slowly in many countries. Applying the Boserup–Ruthenberg model, Pingali et al. (1987) have provided a formal analysis on the main reasons for the slow progress of agricultural mechanization in Africa. By examining the existing farming systems in Africa carefully, the authors argue that the slow transition from hand hoe to mechanized plow can be explained by lack of the evolution in farming systems. Only when the systems move from long fallow to short fallow or permanent agriculture does plowing become necessary to deal with grassy weeds and hardening soils which are difficult to remove with the hand hoe.

How have farming systems evolved in Africa in the last 30 years after the publication of Pingali et al. (1987)? Understanding such evolution is the first necessary step for better assessing possible changing situation of demand for mechanization in Africa in the recent years. In the following subsection we first investigate a measure of farming systems, commonly used by Boserup and Ruthenberg, for Ghana in the last five decades. We then apply the induced technical change framework of Hayami and Ruttan (1970, 1985) for an analysis of the changing characteristics of the economic environment to explain the emerging demand for labor-saving technology among farmers.

Long term drivers of agricultural evolution

Farming system evolution

The fundamental contribution of Boserup–Ruthenberg theory in farming system evolution is to interpret agricultural technological changes and practices as endogenous rather than exogenous to the economic system, that is, such endogenous progress is influenced by agro-ecological conditions and induced by changing characteristics of the socio-economic environment with which the farmers are confronted (Binswanger, 1986). According to Boserup and Ruthenberg, and further formalized and tested by Pingali et al.

[1] In April 2012, 44 interviews were conducted in Central and Northern Ghana, and in July 2013, 35 interviews were further conducted in two districts, Ejura and Savelugu Nanton.

(1987), Binswanger and McIntire (1987) and McIntire et al. (1992), the main driving force of the evolution of the farming systems towards higher intensification are population density and market access. To assess such evolution of farming systems in a stylized way, the *R*-value, which is used both by Boserup and Ruthenberg in slightly modified form, is used as an indicator to measure the intensity of the farming system. In Ruthenberg (1980), *R*-value takes account of both cultivated and fallowed land, as well as the number of cropping seasons per year. According to Ruthenberg, animal traction appears only at the short fallow[2] stage when *R*-values rise to above 33% (i.e., the average fallow period is shortened to less than two years for each year of cultivation, Ruthenberg, 1980 p. 18). Pingali et al. (1987) further argue that animal traction started to be used when some stumps remain in the fields under the short fallow system, but for tractor to be able to operate for land preparation, stumps have to be completely removed, meaning that it may appear later in the agricultural intensification sequence.

This stylized measure of land use intensity is used here to assess farming system evolution in Ghana. The *R*-values for Ghana are calculated using the Food and Agriculture Organization's data on harvested area and available agricultural land, which is the sum of arable land and permanent meadows and pastures, and is presented in Fig. 1 (FAO, 2013b).[3] Ghana is known as a relatively land abundant country in Africa, which is captured by a low *R*-value in most years until the late 1990s (Fig. 1).[4] This is consistent with the argument of Pingali et al (1987), i.e., the farming systems characterized by the low *R*-values for Ghana indicate that at this stage farmers in general did not have enough demand for plowing nor tractorized land preparation.

From the late 1990s onwards, however, the *R*-values have permanently risen above the threshold of 33, reaching 40–43 in the late 2000s. While this highly aggregated data fails to capture regional and spatial variations, rising *R*-values at the national level nevertheless suggest that farming systems have changed significantly in Ghana since the late 1990s, compared with the periods covered by Pingali et al. (1987).

Case studies done over the years and in different parts of the country also suggest the progress of farming system evolution. They indicate the shortening of fallow periods over time, and the move to annual cultivation recently in the 2000s. For example, Nye and Greenland (1961) find that relatively long-fallow systems with cropping for 3–4 years followed by fallowing of 7–10 years was a common practice in Northern Ghana before the 1960s. A 1972 study done by Rourke (1974) in Begoro in the Eastern Region showed that land was prepared using hoes only during the first year, but was cropped for three more years without land preparation and left fallow for six years. The dramatic reduction in forest area in the southern Ghana transition zone seems to begin in the 1970s.[5] The study done by Gyasi et al. (1995) shows that in 1993 34–42% of the studied area was under fallow compared to 40–57% in 1974. In Wuripe, Northern Ghana, cultivated area increased by 14% and open woodland area decreased by 13% between 1992 and 1999 (Braimoh, 2004). In the dry and derived savannahs of Ghana, there is a transition to annual cultivation (Codjoe and Bilsborrow, 2011).

While the Boserup–Ruthenberg model and the *R*-values calculated based on this model emphasize the endogenous change in farming systems in responding to the changes in economic and social conditions, if the evolution is only characterized by land use intensity, agriculture has yet to transform from a natural resource-based to a science-based system (Ruttan, 2002). Thus, most agricultural economists refer to this type of evolution through land use intensity as agricultural extensification instead of intensification. Obviously, land use intensity measured by increased *R*-values is only a necessary but not sufficient condition for assessing the demand for mechanization. Once African farmers have moved beyond the long fallow farming system, the economic decisions at farmer-level for technology adoption, including mechanization, become more diverse and are influenced by many factors beyond population density and agro-ecological conditions.

Induced technology adoption

Beginning in the early 1970s, Hayami and Ruttan (1970, 1985) and Binswanger 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 regarded as "labor saving" and is designed to substitute power and machinery for labor, 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 adoption of biological technology.

Armed by the induced technology change theory, we focus on changing economic factors that are relevant for inducing demand for labor-saving technology, and specifically mechanization. We start with the rural population density. Rapid population growth in Africa is a well-known fact and declining farm sizes in many African countries particularly in relatively high population density areas is a theme for this special issue. Has farming system evolution characterized by the increased *R*-values in Ghana also been accompanied by a declining land-labor ratio such that labor-intensive farming practice would been preferred and adopted in Ghana? This is a question we need to address in order to understand the recently emerging demand for mechanization. If farm sizes are getting smaller and smaller, and if rural labor supply is abundant, the relative prices of labor to land are unlikely to rise, and hence, the incentives for farmers to adopt labor-saving technology such as mechanization would be limited even under the short-fallow or annual cultivation farming systems.

We calculate the land-labor ratio at the national level based on two sources of data. Data for crop cultivated areas from FAO is used to represent agricultural land, and the data for agricultural workers is from Groningen Growth and Development Center (GGDC), which covers employment data of 10 sectors including 9 nonagricultural sectors, and provides a more complete picture of labor mobility

[2] Long fallow or shifting cultivation is when the period of cultivation is much less than the time land left uncultivated. This gives enough time for forest or bush vegetation to regrow. Short fallow is when the period of cultivation is more than half of the fallow period. Under this system in sub-humid and humid areas, regrowth is primarily grasses (Ruthenberg, 1980).

[3] Without fallow land information and using pasture land instead, it may cause the *R*-values to be underestimated. Moreover, 50% of Ghana's land area was forest in 1960s and only after early 1990s has the forested area fallen to less than one-third of total area. The exclusion of forest fallow land from FAO's measure of agricultural land may further lead to an underestimation of the *R*-values.

[4] Interestingly, the government's investments in agricultural development including the creation of large scale state farms under Operation Feed Yourself (Agyeman-Duah, 2008) in the early 1970s may explain the temporary rise of *R*-values between 1970 and 1976.

[5] The transition zone as a major food production region covers parts of the Ashanti and Brong-Ahafo regions of Ghana and lies between humid forest and dry savanna with area approximately 6200 km^2.

within a country than the agricultural worker data in FAO.[6] We report the land-labor ratio averaged by decade between 1970 and 2011 in Table 1. To provide a cross-country context, we also include the four African countries with data available in GGDC and are classified as part of the high population density group in Headey and Jayne (2014). We also include South Africa as a reference, a country with highly mechanized agriculture and much more developed economy than all other African countries.

As shown in Table 1, crop cultivated area per agricultural worker is similar for Ghana and Nigeria until 1990s. Except for South Africa, Ghana is the only country in Table 1 to show a rising trend in the land-labor ratio from the 1980s onwards.[7] This is particularly true in the 2000s when crop area per worker increased by more than 30% in Ghana, consistent with the rising *R*-values in this period in Fig. 1. In contrast, the land-labor ratios of the four high population density African countries demonstrated declining trends into the 2000s.

A land-labor ratio for the country as a whole overlooks the regional heterogeneity since population density differs significantly across regions in Ghana. Without available agricultural worker and agricultural land data at the regional level, we use rural population and total cultivated areas for the 10 major food crops to analyze the regional agricultural land-labor relationship in Table 2.[8] The first panel (upper-left) of Table 2 reports rural population density at the regional level in Ghana and is calculated based on the recent three rounds of population censuses. The second panel (upper-right) of Table 2 reports the share of regional rural population in national total rural population in these three years and annual growth rate in regional rural population in 1984–2010. The third panel (lower-left) of Table 2 reports regional share of cultivated area for the 10 food crops. We do not have crop data in 1984 and the closest year with available crop data is 1992. The last panel (lower-right) of Table 2 reports the cultivated areas of these 10 food crops per rural person at the regional level in 2000 and 2010.

We focus on the three regions, Brong Ahafo, Northern, and Upper West, the three regions that have population density much lower than the national average and also are most likely to be mechanized as discussed in the later section. In 2010, the three regions together account for 45% of country's food crop cultivated areas with 30% of national rural population. Their food crop areas per rural person are not only higher than national average, but also increased in 2000–2010.[9] To supplement the previous discussion about rising land-labor ratio at the national level, the most important message of Table 2 is that the national trend in land-labor ratio is primarily driven by more rapid land expansion in the three low population density regions. While rural population growth rate has been equal to or higher than the national total in the three focused regions over 1984–2010, their rate of land expansion has been much higher than population growth rate in two of the three regions in 1992–2010. This leads to rapid change in cultivated area per rural person in these regions.

The most rapid increase in the land-labor ratio has been in Brong-Ahafo region. A major part of Brong-Ahafo region is located in Ghana's transition zone, where agricultural land has yet to reach its frontier. The land expansion has been driven mainly by the expansion in maize production. The region is now the most important for maize production region and contains 25% of the national maize cropped area in 2010 (Ghana, MOFA, 2013), while in the early 1990s, it produced less than 10% of national maize. When the expansion of cropped area is mainly used to produce marketed cereal crops such as maize, the induced demand for labor-saving technology is likely to start early due to labor being relatively scarce and demand for the agricultural output is elastic (Binswanger, 1986). This is often the case in other early mechanized countries, as discussed in Binswanger (1986) for the cases of India's Punjab State and Central region in Thailand.

A national land-labor ratio also overlooks the heterogeneity in farm size. At the micro level, that whether labor becomes a limiting factor in technology adoption depends critically on farm size. As Binswanger argues, for larger farmers mechanization can start much earlier when wage rate is still low (1986). Thus, we assess the farm size by different holding groups in Table 3, based on the two rounds of national representative living standard surveys in 1991/92 (GLSS3) and 2005/06 (GLSS5).

The first message of Table 3 tells us that, while Ghana is dominated by smallholders with land less than 2 ha per household, there is a significant number of farmers with land more than 2 ha. In 1991/92 there are more than 40% of total farmer households with holding size more than 2 ha, while this fraction in total farmer households increased to almost 50% in 2005/06. The second message is that, considering farmers with land more than 5 ha only, there is still a significant number of such rural households. In 1992, 12.3% of farmers belong to this group, while in 2005/06 the fraction for this group of farmers in total farmer households rose to 17%. The third message is that, over time the number of farmers with relatively larger holding size grew more rapidly than

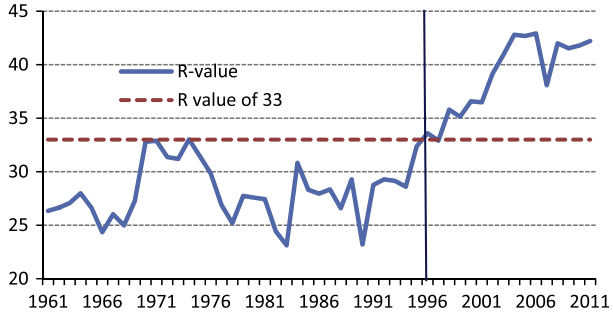

Fig. 1. *R*-value measure of farming system evolution in Ghana. Source: Compiled from FAO data. Note: *R*-value = 100× (harvested area/agricultural land).

Table 1
Crop area per agricultural worker (hectare per worker). *Source:* Authors' calculation based on FAO for land and GGDC for agricultural labor.

	1970s	1980s	1990s	2000s
Ethiopia	1.1	0.8	0.5	0.5
Kenya	1.1	1.0	0.9	0.8
Malawi	1.2	0.8	0.7	0.9
Nigeria	1.9	1.5	1.3	1.3
South Africa	5.1	5.6	5.5	6.0
Ghana	**1.6**	**1.2**	**1.3**	**1.7**

[6] In FAO data, agricultural worker is defined as economically active population in agriculture, including engaged in or seeking work in agriculture, whether as employers, own account workers, salaried employees or unpaid workers assisting in the operation of a family farm or business. This classification may cause an overestimation of agricultural worker if agricultural worker is not classified together with number of workers in the other nonagricultural sectors. Part of the employment information used in GGDC is collected from various survey-based data sources including censuses and labor force surveys.

[7] Footnote 3 provides a reason to explain the relatively high *R*-values in Fig. 1 for the early 1970s, the same reason that can also explain why land-labor ratio is high in the 1970s in Table 1 for Ghana.

[8] According to FAO data, these 10 crops accounted for 60% of total cultivated areas in Ghana. The 10 crops are maize, rice, millet, sorghum, cassava, yam, cocoyam, plantain, groundnuts, and cowpea.

[9] There are another four regions in which the ratio of food crop areas to rural population rose between 2000 and 2010.

Table 2
Regional rural population density and food crop areas per rural person. Sources: Authors' calculation using data from population censuses (GSS, 2013) and crop assessment (Ghana, MOFA, 2013).

	Rural population density (person/km^2)			Share in national rural population (%)			Annual growth rate
	1984	2000	2010	1984	2000	2010	1984–2010
Western	37	51	57	10.7	11.5	11.3	1.6
Central	83	101	118	9.7	9.4	9.6	1.4
Greater Accra	75	110	117	2.9	3.4	3.1	1.7
Eastern	63	71	77	14.5	13.0	12.3	0.8
Volta	47	58	68	11.5	11.2	11.6	1.5
Ashanti	58	72	77	16.9	16.5	15.5	1.1
Brong Ahafo	22	29	32	10.6	10.7	10.6	1.4
Northern	12	19	25	10.4	12.6	14.3	2.7
Upper West	21	26	32	4.7	4.5	4.8	1.6
Upper East	76	88	94	8.1	7.3	6.8	0.8
National	35	45	51				1.4
	Share in national food crop areas (%)			Annual growth rate	Crop areas per rural person (ha)		Change in
	1992	2000	2010	1992–2010	2000	2010	2000–2010
Western	6.4	8.2	6.7	2.2	0.20	0.18	−6.7
Central	4.9	6.8	7.0	4.0	0.20	0.23	12.3
Greater Accra	1.7	0.7	0.3	−6.8	0.06	0.03	−38.8
Eastern	13.9	16.0	14.1	2.0	0.34	0.35	4.0
Volta	4.9	5.5	5.9	3.0	0.14	0.16	16.2
Ashanti	11.9	14.2	12.8	2.4	0.24	0.26	7.7
Brong Ahafo	14.0	13.7	18.5	3.5	0.35	0.54	52.5
Northern	18.6	14.8	16.1	1.1	0.33	0.35	7.0
Upper West	8.8	9.3	10.6	3.0	0.58	0.68	16.8
Upper East	15.0	10.9	8.0	−1.6	0.41	0.36	−12.6
National				1.9	0.28	0.31	11.8

the number for total farmer households. In fact, the larger the average holding size for a farmer group, the faster increase in the number of farmers. The fourth message is that, in contrast with the countries in the high population density group discussed in Headey and Jayne (2014), not only has the average holding size at the national level increased in Ghana, but also the size for each group of farmers including the smallholder group did not fall.

Putting all of these messages together, it is reasonable to think that the agro-ecological factors and economic and social conditions in Ghana have enabled many farmers to increase agricultural production through expanding their holding size. For these farmers with relatively larger farm size or being able to expand their holding size, with rising land-labor ratio, the cost of labor relative to land will be increasing. These dynamics will create demand for labor-saving technologies to be developed and adopted as predicted by Binswanger and Ruttan (1978).

Opportunities in nonfarm sector, relative input costs, and emerging demand for mechanized plowing

Urbanization

Focusing on agriculture alone is unlikely to fully capture the emerging demand for mechanization, as rising labor cost and expanding market size for agricultural products are often the outcome of urbanization. Ghana has been known to be more urbanized than most African countries since the mid-1900s (Jedwab, 2010). For the purpose of this study, we are more interested in the dynamics of urbanization since the late 1990s when the *R*-values passed the threshold for the farming system evolution discussed above. The data from World Development Indicators shows that after a stagnant period of urbanization in the late 1970s and entire 1980s, urbanization regained its speed in the 1990s. By the mid-1990s, urban population reached more than 40% of total population (World Bank, 2013). The 2010 population census further shows that the urban population surpassed the rural population by the end of 1990s (GSS, 2013). At similar per capita income level to Ghana, there are only three other African countries, Cameroon, Cote d'Ivoire, and Nigeria, with urban population more than 50% of total population in 2012.[10]

Jedwab (2010) argues that urbanization in Ghana, and in the other rapidly urbanized African countries, is driven by exports of primary goods – cocoa and gold in the case of Ghana, which leads to the emergence of consumption cities, where services and other non-tradable activities are dominant employment creators and sources of nonagricultural income. Ghana's national statistics shows that in the process of transforming to a middle-income country, reduced shares of agriculture in the economy have been filled by services, while manufacturing has stagnated and even declined in its contribution to the economic growth (Kolavalli et al., 2012). One reason that manufacturing, particularly labor-intensive manufacturing has not developed in Ghana is the relatively high labor cost, which is a typical outcome among resource-rich African countries where growth in income is an outcome of natural resource (or primary good) exports (Gollin et al., 2012).

The rapid urbanization characterized here has two relevant implications for agriculture and for technology use. First, urbanization leads to changes in food demand patterns. Determined by job and life styles, urban residents prefer more easy-to-cook food than rural residents, which often leads to increased demand for cereals – maize, rice and wheat and their products instead for root crops. It is known that cereal production is generally more labor intensive than root crop at given land size (Nin-Pratt and McBride, 2014), indicating that agricultural labor demand could increase led by increased demand for cereals as an outcome of changes in food consumption patterns. Moreover, urbanized consumption patterns are often more diversified, particularly when per capita income grows

[10] With about 2 million population, urbanization rate of Gambia is also more than 50%, while its per capita GDP is only one-third of the level in Ghana (2012). There are another four African countries with urban population more than 50% of total population, and all these four countries have per capita GDP more than twice of Ghana's in 2012.

Table 3
Distribution of rural farm households by holding size. Sources: Authors' recalculation from Table 1 in Jayne et al. (2014), in which the original data is from GLSS3 and GLSS5.

	% in total farm households		% change in # of farm households	Average landholding size (ha)		% change in holding size	% in total land holding	
	1991/92	2005/06	1992–2006	1991/92	2005/06	1992–2006	1991/92	2005/06
0–2 ha	56.9	50.3	25.9	0.8	0.9	7.2	17.0	12.8
2–5 ha	30.8	32.9	52.0	3.0	3.1	2.0	33.6	29.0
5–10 ha	7.8	10.4	91.1	6.9	7.0	0.7	19.3	20.8
10–20 ha	3.0	4.1	95.5	13.3	13.1	−1.9	14.3	15.3
20–100 ha	1.5	2.3	117.8	28.8	33.3	15.7	15.7	22.1
National average			42.5	2.8	3.5	25.9		

Notes: GLSS5 survey sampled 8 households with holding size more than 100 ha, while farm households with similar sizes were not sampled in GLSS3. Considering the small number of samples with land more than 100 ha, we capped the holding size at 100 ha for better comparison between the two rounds of surveys.

Table 4
Non-agricultural employment opportunities for rural Ghanaian household. Source: Authors' calculation using data of GLSS5-2005/06 (GSS, 2013).

	Rural households with nonagricultural employment				
	% of rural households with any family member primarily engaged in non-agriculture	% of nonagricultural employment in total number of employment	Number of total workers per household	Number of agricultural worker per household	Number of agricultural worker per household, for households without nonagricultural employment
Western	44.0	74.3	1.74	0.45	1.76
Central	38.1	71.6	1.94	0.55	1.42
Greater Accra	68.1	67.8	1.96	0.63	1.53
Volta	37.6	62.1	2.13	0.81	2.02
Eastern	48.9	61.2	2.24	0.87	2.03
Ashanti	37.1	64.5	1.98	0.70	1.85
Brong Ahafo	27.3	58.8	1.98	0.81	2.02
Northern	25.9	48.4	2.89	1.49	3.36
Upper East	22.9	42.7	3.24	1.86	3.22
Upper West	15.1	28.6	4.90	3.50	4.18
National	34.4	58.1	2.28	0.96	2.50

Notes: Employment is defined according to the primary work in the last 12 months during the survey time and each working family member only counts once in the calculation. Many agricultural workers may have non-agricultural work as secondary jobs. However, we consider them as agricultural workers only.

rapidly in the urban area. More vegetables and fruits are demanded as well as more livestock products. Vegetable and other horticultural production are also much more labor intensive than staple crops.

The second implication of consumption-led urbanization for agricultural production is the rising non-farm opportunities for rural households and cost of hired labor. When growth is driven by natural resource exports, it is common for prices of nontradables and hence labor costs to rise without productivity gains (aka Dutch Disease). Under this situation, most nonfarm activities are self-employed and are in informal services with low barriers for entry, resulting in rising wage rate and increased opportunity cost for rural labor. In addition, the attraction of the urban life style is pulling more rural youth into urban areas and away from the drudgery of agricultural work.

Opportunity costs for agricultural production

The easiest way to show the impact of urbanization on rural wage rate is to display trends for changing urban and rural real wage rate over time. Unfortunately, such data does not exist in Ghana as the country has never systematically collected both labor and wage data. With such data constraint, we apply micro level data to indirectly measure the impact of urbanization on agricultural labor cost. The first indicator is a measure of rural households' nonfarm employment opportunities, which would lead to increased opportunity cost for agricultural labor (Table 4). Percent of rural households with family members primarily working in the non-agricultural sector either for paid jobs or as self-employed is presented in column one of Table 4. We then report the percent of non-agricultural employment in total employment, considering only the rural households with nonagricultural income. Numbers of total and agricultural workers (which is reported as self-employed or family workers primarily working in agriculture in the survey) per average rural household are also reported in the table, and we report the numbers separately for the two types of households, i.e., with and without nonagricultural employment opportunities. All the calculations are reported at regional and national levels.

In 2005/06 there were about 40–45% of total households residing in the rural areas, of which more than one-third with at least one family member primarily engaging in nonfarm activities. The share is lower than the national average in the north and in the regions with higher land-labor ratio (e.g. Brong Ahafo,), and is higher in Greater Accra and other regions in the south. Among such rural households almost 60% of working family members primarily worked in the nonfarm sector, and the share can be as high as 74% in Western region. The number of agricultural workers per household, for the rural households with at least one family member primarily engaged in non-agriculture, is much smaller than that for the other group of rural households without such nonfarm opportunity. Obviously, labor opportunity costs for rural households already engaging in nonagricultural activities are much higher than those without such engagements. Thus, labor-saving technology, especially the technology substitutable for power-intensive activities and activities that can become bottleneck for farming is expected to be attractive to rural households with nonagricultural activities as part of family employment portfolio.

Cost of hired labor in total agricultural production cost

An analysis of the cost of hiring labor for agricultural production in total input cost is crucial for understanding the demand for labor-saving technology. Hiring labor (paid in cash or in kind but excluding family labor exchange) has become a standard practice

Table 5
Labor hiring and fertilizer costs. Source: Authors' calculation using data of GLSS5 for 2005/06 (GSS, 2008).

	Cost of hired labor as% of total paid input cost	Cost of fertilizer as% of paid input cost
By region		
Western	31.7	31.0
Central	42.8	13.9
Greater Accra	46.2	22.6
Volta	59.9	10.6
Eastern	41.0	11.7
Ashanti	46.6	16.7
Brong Ahafo	51.8	18.1
Northern	57.6	24.6
Upper East	22.0	45.6
Upper West	26.2	29.8
0–2 ha	48.3	15.5
2–5 ha	43.9	22.1
5–10 ha	42.4	20.1
10–20 ha	41.9	31.9
20–100 ha	41.6	23.3
National	44.5	20.8

Notes: The government did not have any large scale fertilizer subsidy program in the survey years.

across agro-ecological zones in Ghana. The three rounds of Ghana Living Standard Survey (GLSS) between 1991/92 and 2005/06 indicate that, 45–64% of smallholders (with holdings less than 2 ha) hired labor, while 64–84% of the households with more than 10 ha of land hired labor. The World Food Program (WFP) survey of 2008 indicates that more than 50% of surveyed households report hiring labor but it was more common in the richer regions such as Brong Ahafo (76%), Ashanti (65%), and Eastern region (62%) (World Food Programme, 2009). Most recently, the Ghana Agricultural Production Survey for 2011/12 finds that 56% of surveyed households used paid labor for at least one agricultural operation.

When hired labor becomes a common practice and the cost of hired labor relative to other input cost is high, farmers are likely to begin to adopt labor-saving technology. Table 5 presents the cost of hired labor as a percentage of total paid input cost in GLSS5 for 2005/06. Cost of fertilizer use, a technology identified as a "land-saving" one is also presented in the table for a comparison. As shown in the table, hired labor is the most costly input for farmers and accounted for 45% of total paid input cost for an average farmer, while fertilizer, the second most costly input, accounted for only 21%.[11] The labor hiring cost is more than 40% of total input costs for an average farmer in 7 of the 10 regions, and is more than the fertilizer cost in 8 of the 10 regions. In particular, for Northern and Brong-Ahafo regions, the regions with more observed emerging demand for mechanization, the labor cost is over 50% of total costs.

Emerging demand for mechanized land preparation

With diversified agro-ecological conditions, population density and nonfarm opportunities across regions in Ghana, demand for mechanization, particularly for land preparation, would first emerge locally in the places where agro-ecological conditions are suitable for tractor use, labor-saving technology is more attractive to farmers, and some farmers are able to invest in tractors at affordable prices. With such pattern of mechanization demand, the national statistics is unlikely to fully capture the changing trends, and thus, we turn to available surveys for the assessment. The most recent national representative survey of which the data is available publicly was done in 2005/06 when the demand for mechanization is still relatively modest. However, compared with the survey done in 1991/92 (GLSS3), it still shows an increased trend in the use of machinery through rental services. This is particularly true in a few regions in the transition zones and in the north, which influences the national average to be up from 1% of rural households using rented equipment in 1991/92 to 8.2% in 2005/06 (Table 6).

Table 6
Percent of rural households using rented equipment in Ghana. Source: Authors' calculations based on the two rounds of Ghana Living Standards Survey (GLSS3&5).

	1991/92	2005/06
Western	0.3	12.8
Central	0.3	2.1
Greater Accra	7.9	5.2
Volta	2.5	2.8
Eastern	0.5	4.2
Ashanti	0.5	9.0
Brong Ahafo	1.7	8.0
Northern	1.9	5.2
Upper East	0.0	1.9
Upper West	0.0	7.1
National	1.0	8.2

In the areas with a tradition of animal traction, plowing can be undertaken by animal power, which is still cost-effective in part of semi-arid northern areas of Ghana, e.g., Upper East region. However, in the transition zone of Ghana, where more land has been brought under cultivation in the recent years, there is no such tradition due to tsetse infestation and the presence of trypanosomiasis disease. Moreover, in part of the northern Ghana with animal traction tradition, lack of feed, implementation design and animal stealing issues constrain the development of draft livestock sector (McIntire et al., 1992; Bobobee et al., 2007; Houssou et al., 2013a). Animal husbandry is also relatively labor and land intensive, making it an unfavorable choice in the locations where labor is already costly. Furthermore, policies that have encouraged the use of tractors often neglected the promotion of animal traction (Houssou et al., 2013a). Therefore, both in transition zones and northern Ghana more and more farmers prefer to plow using a tractor.

Indeed, quite a few non-national representative surveys have captured increases in mechanized plowing. A 2008 survey of WFP shows that in Northern Ghana 44% and 46% of households reported using tractor services or animal traction, respectively. Of 219 maize farmers interviewed nationwide in 2009 (including farmers in forest zones where plowing is almost impossible), 35% reported to have hired tractor services (Ngeleza et al., 2011). In the Northern region where tractor services have been adopted more widely than in the South, the survey indicates that 77% of interviewed farmers reported the use of tractor services for plowing. The 2010 survey conducted by IFPRI's Ghana Strategy Support Program in four districts of the three northern regions indicates that about 95% of 173 interviewed maize farmers used hired tractor services for land preparation (Akramov and Malek, 2012). A survey jointly conducted by IFPRI and SARI in November 2012-February 2013 for 630 maize and rice growers in 30 districts of 9 regions shows that 25% of maize farmers used tractor for plowing. Among fertilizer user farmers, which are about 45% of sample households, 46.5% of them used tractor for plowing (Chapoto and Ragasa, 2013).

Large scale farmers are often the first-adopters of mechanization as profitability is possible for them based on preparing their own large land area (Binswanger, 1986). The incentive for medium-scale farmers to invest in machinery is less if it is only used for their own farm (tractors will be underutilized). However, the tractor utilization rate can increase if medium-scale farmers are able to provide hiring services to other medium and small scale

[11] The broad fertilizer subsidy program was adopted after GLSS5 (2005/06) survey in 2008. Therefore, the cost for fertilizer reported in Table 5 is calculated more or less at the market prices in 2005/06.

Table 7
Tractor and animal traction users vs. owners. Source: 2013 IFPRI/SARI Survey on medium and large-scale famers and mechanization survey, 2013.

			Farmers who use tractor plowing		Farmers who use animal traction for plowing	
District	Region	Total sample	Non-tractor owners	Tractor owners	Non-bullock owners	Bullock owners
Ejura Sekye Dumasi	Ashanti	253	108	119	0	0
Techiman	Brong Ahafo	217	14	1	0	0
Kintampo North	Brong Ahafo	221	58	9	0	0
Yendi	Northern	269	135	112	0	1
Gushiegu	Northern	300	172	91	1	5
Kasena Nankana East	Upper East	160	99	10	11	31
Bawku Municipal	Upper East	195	36	5	54	79
Sissala East	Upper West	228	131	45	19	17
Total		1843	753	392	133	85

farmers. A 2013 survey jointly conducted by IFPRI and SARI in 8 districts of five northern and central regions captures this pattern of mechanization by specifically asking farmers about tractor ownership, hiring service provision and service recipients. In the survey, more than 60% surveyed farmers reported the use of tractor for plowing. Among the tractor users, two-third of farmers (who are all medium and small scale farmers) do not own tractor and they get access to tractor services through hiring market. Furthermore, almost 50% of surveyed small-scale farmers hired services from tractors owners. Indeed, among the medium and larger scale farmers who are tractor owners, 78% reported to provide tractor hiring services for plowing in the survey year. The detail information about tractor use for plowing can be found in Table 7. As will be discussed further in the next section, the majority of tractor owners purchased second-hand tractors without any government subsidy.

The 2013 IFPRI/SARI survey also covers animal traction. As we discussed above, Table 7 confirms the strong regional patterns of animal traction. Only farmers in the two most northern regions – Upper West and Upper East do use animal traction for plowing.

We end this section by authors' own observations from multiple field visits in 2012–2013. During these field visits, we interviewed many farmers, small and relatively large; tractor owners and recipients of hiring services; tractor dealers and repairing shops. Everywhere we visited, we heard about the complaints from farmers for lack of tractor services to meet their demand and there was no single case in which a tractor owner complained of a lack of adequate demand for his/her services. Farmers who hired-in services reported that they often had to approach more than one tractor owner before securing services to plow their field. Farmers who hired out services reported that they never have any concern for lack of consumers and during land preparation season, they are often inundated with requests for services. Transactions between service providers and recipients are not governed by any contract and there was no need expressed by those we interviewed. With evidence that tractor ownership has increased in the recent years, farmers who are hiring-in services reported that it is becoming easier in some locations to secure plowing and maize threshing services now compared with the past.

In summary, data drawn from various surveys and observations from authors' field visits suggest that demand for agricultural mechanization has indeed been emerging in Ghana. The long term trends in the evolution of farming systems and in rising land-labor ratio and average farm sizes have led farmers' demand towards labor-saving technology. Urbanization is another driver in this process by increasing market demand for food and creating more opportunities to rural labor in nonfarm sectors. Current mechanization demand concentrates on tractorized plowing (also maize threshing that has not been discussed here). Demand for agricultural machinery is more prevalent in the Northern and Brong-Ahafo regions of Ghana where land is still available, cereal crops dominate and land-labor ratios have been increasing. Demand for mechanization of other operations, such as planting, seeding, and harvesting, is only expected to emerge with improving agricultural land productivity and increasing farm profit. This pattern of mechanization development will pose challenges for viable supply models, which will be the focus of the next two sections of the paper.

Agricultural mechanization: alternative supply models

Demand for mechanization does not always lead to an adequate supply response, particularly when such demand comes from small-scale farmers. While many small-scale farmers in Ghana are ready to pay for hired services at the market price, they are still unlikely to pay the prices for full ownership of tractors. Purchasing a tractor is an investment decision, and returns to it are unlikely to cover the cost of the investment for many small farmers, i.e., for small-scale farmers, it is not just an issue of lack of financial support. Governments in Africa, including Ghana, often use this as an argument to justify a subsidized mechanization program. However, there is a risk that a subsidized program can restrain the machinery supply from the private sector, which makes the program often unsustainable. Indeed, the literature provides overwhelming evidence that public sector-led early efforts in Asia and Africa in the 1970s and 1980s failed to facilitate sustained adoption of mechanization. Reviewing 38 public mechanization programs in 21 countries across Asia and Africa, Seager and Fieldson (1984) found that only 2 programs were deemed to have been successful and they were for land rehabilitation and leveling using bulldozers, rather than provision of tractor services. Under most programs, the service charges were often set to cover only the operating costs, undercutting private providers and resulting in weak capacity along the supply chain.

In this and the following sections, we consider the supply side of mechanization with a focus on the conditions under which the private sector would be able to lead the development of mechanization supply. We adopt a supply chain approach and consider the following players in the analysis. The primary upstream agents, in most African countries including Ghana, are machinery importers. Importers control the type of machinery introduced into the country, directly affecting the adoptability of mechanization. The downstream of the supply chain consists of machinery owners who interact with small-scale farmers through hiring services. Market-determined prices for the services are likely to be related to costs of alternative power sources (e.g. cost of hired labor for doing similar tasks) rather than the investment cost of machinery. However, the feedback from farmers through their demand for market-determined services provides information to both potential tractor owners and importers for affordable prices and most preferred machines. Finally, machinery maintenance and repairing service

providers are also important players along the supply chain. The quality and cost of maintenance services has a bearing on the investment decision of potential machinery owners, while development of such service business is influenced by the number of machinery and number of owners in a given location.

Using the supply chain approach, we develop three stylized models to demonstrate the alternative relationships between demand for mechanization when it is mainly from small-scale farmers and supply of mechanization services that are provided by the private sector. The three stylized models are named after three Asian countries, while they represent experiences from many other Asian countries.

Small-scale farmers owning small machines: the bangladesh model

The Bangladesh model is characterized by the ownership by small-scale farmers of small and low cost machines including water pumps, power tiller and threshers. Bangladesh is a country with limited agricultural land and extremely high population density, which leads to a general perception that the country is unlikely to mechanize its agriculture. Indeed, the early push by the government in mechanization in the 1970s and 1980s largely failed, and the country was dominated by animal traction for land preparation until the late 1980s. A series of major floods and cyclone hit Bangladesh in the late 1980s, affecting significantly draught oxen population. From some points of view, this unexpected exogenous factor led to rapid mechanization among small-scale farmers in Bangladesh through importation of small Chinese-made power tillers since early 1990s. To find the most appropriate way for the quick replacement of the lost animal draught power, the president was told by his agricultural policy advisers that Chinese power tillers would be a feasible option, which led to the removal of the national standard committee who restricted the imports of such machinery (Biggs et al., 2011; Ahmed, 1995). Before this policy change, the Ministry of Agriculture permitted the imports of only certain makes and models, and a parastatal has responsibility for import and marketing of the machines (Gisselquist and Grether, 2000). While the parastatal continued to import for several more years, private traders quickly took over by importing cheaper equipment from China, which resulted in a 40% drop in the cost of imported machinery (Gisselquist and Grether 2000; Roy and Singh, 2008). The result is that Bangladesh now has a highly mechanized but still labor-intensive agricultural system. By 2007, approximately 400,000 power tillers were in use in Bangladesh and nearly 62,000 units were being imported annually (Alam and Khan, 2008; Ziauddin and Ahmed, 2010). Yet strikingly, 4-wheel tractors accounted for only 8% of the combined horsepower of all 2- and 4-wheel tractors (Biggs and Justice, 2013), and only 16% of farmers use 4-wheel tractor services (Ahmed, 2013).

A recent national representative survey shows that while only 2% of farmers in Bangladesh own power tillers, 72% of farmers used power tiller, an indication of highly developed and well functional hiring market (Ahmed, 2013).[12] A different estimation by Roy and Singh (2008) has a consistent result, which shows that 80–90% of cultivated areas for paddy rice, wheat, maize, and other crops are prepared using power tiller. Even the poorest farmers hire power tillers as they are cheaper than hiring bullocks or 4-wheel tractors (Roy and Singh, 2008). In the recent survey, it shows that 58% of marginal farmers, who are among the poorest farmers and have land less than 0.2 ha, are power tiller users, and 80% of small-scale farmers, with land less than 0.6 ha, also belong to this group (Ahmed, 2013).

[12] Only 30% of farmers still use draft animal for land preparation.

With the extremely small landholding size for farmers, the use of power tillers for land preparation alone limits their utilization and hence profitability for their owners. To overcome such limitation, farmers are innovative in their use of power tillers. In Bangladesh, and in other Asian countries, it is common to see a power tiller being used as an engine in crop threshing and water pumping for irrigation, or as a vehicle to cart agricultural and nonagricultural products to local markets and to transport people. In fact, the availability of suitable implements for power tillers has led to the mechanization of many farming activities. Planting and harvesting are exceptions to this since power tillers are not suitable and these activities continue to depend on human power. This pattern of mechanization tells us that there is no single universal mechanization sequence. Without price distortions caused by the government's subsidies on selected machines, farmers and the private sector are able to select the right machines and make their use more efficient and effective. In fact, Roy and Singh (2008) show that power tiller owners in Bangladesh can repay their investment 1–2 years after the purchase. While Bangladesh still does not have the capacity to produce power tillers, local fabricators have emerged to manufacture spare parts, basic implements, and other equipment such as threshers and trailers, which has not only enabled power tiller owners to use their machines for a broad range of activities but also induced mechanization in other agricultural activities beyond land preparation.

Medium-scale farmers owning tractors and supplying hired services: the india model

The Indian model differs significantly from the Bangladesh model in terms of who owns machines and the kind of machines which are used. As in Bangladesh, draught animals were a traditional source of farm power in India. In some areas, farmers began to mechanize much earlier than the rest of the country, following a substantial rise in real wages around 1968 (Gupta and Shangari, 1979; Binswanger, 1986). At the national level, the share of total farm power supplied by tractors and power tillers increased from 7.8% in 1970–71 to 42.5% in 2000–01 (Singh, 2000). In contrast to Bangladesh, medium-sized tractors with 20–40 horsepower (hp) dominate the Indian market, and 65% of Indian tractor sales in 2000–01 were machines of this type (Singh, 2000). The second difference from the Bangladesh model is that tractors were used by medium and large farmers before small-scale farmers: more than 60% of farmers using tractors had farms larger than 4 hectares in the early 1980s (Singh, 2000). Although the population of draught animals fell from 80 million in 1960 to 56 million in 2004, animal traction remains important for small and marginal farmers who may also use tractor hire services (Kulakarni, 2009).

The role of the state in mechanization also differs between India and Bangladesh. India is well known for government's support to both agricultural and manufacturing sectors through subsidies. The subsidy received by farmers is complemented by public investments in research and development to encourage the development of domestic agricultural machinery industry. The subsidy policy has covered a wide range of agricultural machinery and tools including animal-drawn implements, power tillers and tractors, which ensured that the choice of machinery was demand-driven rather than subsidy-driven. Since the 1980s, small-scale farmers have begun to use tractors, and in the early 1990s, 65% of farms using tractors were smaller than 4 ha (Singh, 2000). In recent years, policies have started to encourage the ownership of smaller tractors, which helps small-scale farmers to be able to purchase tractor. For example, a 2008 subsidy policy covers tractors under 40 hp, power tillers, self-propelled paddy reapers, and transplanters (India, Ministry of Agriculture, 2008). Furthermore, credit has been made available to farmers. According to Singh (2000), the financial

sector extended US$2.9 billion worth of long-term credit to agriculture, mostly for the purchase of agricultural machinery in 1998–1999. Foster and Rosenzweig (2011) show a strong link between bank proximity and farm investment in machinery in India.

The important aspect of India model is that medium to larger farmers offered hiring services and they were critical in expanding mechanization. When there is potential to hire out services, the farm size of the tractor owner has much less influence on the choice of size of the machines (Binswanger, 1986). A similar pattern of hiring service market development has been observed in other Asian countries where there is a substantial number of medium to larger farmers. In Thailand and Malaysia, for example, the vast majority of tractor owners in the survey areas are farmers whose landholdings are about twice the size of those of tractor-hiring farmers (Chancellor, 1971). In Thailand custom plowing by a 4-wheel tractor was found to bring its owner off-farm net income $400 in average per year (Pak-uthai, 1981). Contracting out rice threshing services in Thailand could bring in a net income of about US$640 to US$1,013 per unit in 1979 (Pathnopas, 1980). The 1971 agriculture census of the Philippines, cited by Binswanger (1986), indicates that harvesting and threshing equipment, tractors, and motor vehicles are used by five to seven times more farms than the number owning them. A recent study of Paman Ujang and Uchida (2012) for the case of Riau province in Indonesia found that about 85% of farmers had hired power tillers for land preparation, and 64% hired thresher for threshing rice. The role of the hiring market in mechanization adoption has important implications for Ghana and other African countries. As discussed in the previous section, Ghana has both small-scale farmers with landholding size less than 2 ha and a substantial number of medium and larger scale farmers, indicating that the country is suitable for developing tractor hiring service market as Binswanger suggested in his 1986 article.

Professional service enterprises: The China model

The China model is used to represent the pattern of specialized service provision for control-intensive farming activities. While there is a similarity between China and other Asian countries in the progress of power- intensive mechanization, rapid industrialization has significantly raised the rural wage rate in China in the recent years, which has led to increasing demand for mechanizing agricultural operations beyond those which are power-intensive. When mechanization advances to include control-intensive operations, individual farmers, including most medium- and larger-scale farmers, are unlikely to own such specialized machinery. Consequently, specialized businesses of service provision for control-intensive operations starts to develop, which we refer to as the China model. In this model, non-farmer entrepreneurs provide professional services to farmers for harvesting. Service provision through migration is a necessary condition for this model to be viable. Indeed, with China's vast farmland across different agro-ecologies, the same crop can be harvested at different times which allows service providers to be able to operate up to eight months per year through migration (Yang et al., 2013).

The specialized service through migration described here is not unique to China. A similar contract-hire system for combine harvesters existed in the United States in the 1970s. By migrating to follow the harvest from Texas-Oklahoma to the northern states, where harvesting takes place months later, contractors achieved higher rates of machinery utilization (Binswanger, 1986). Specialized suppliers providing wheat and rapeseed harvest services were seen in Punjab, India since 1990s, where almost all crops are harvested by such specialized service providers currently. In all these countries, the necessary condition to enable suppliers to migrate is that harvesting time for the same crop (maize, rice or wheat) differs in different parts of the countries. However, for long-distance service provision to become a reality, many other economic conditions exist, particularly the existence of a sufficiently high quality road network. Coordination difficulties also exist when serviced farm sizes are small and fragmented. As documented by Yang et al. (2013), the local government in China has played a facilitating role in this process to help clusters of private service providers overcome the coordination failure caused by many unexpected geographic, institutional, and technical barriers.

The key message from the China model is that the ability and opportunity to move services across locations is critical for the private sector to participate in a specialized mechanization service business. The innovations from the manufacturing side can be a facilitator in this model. For example, the design and production of a small-size combine harvester by a Chinese manufacturer enables the machine to be transported easily on a pick-up truck. This innovation made it profitable for private service providers to service very small plots across provinces.

Key lessons learned from the three models

We use the three stylized models to demonstrate that there are various pathways for the private sector to lead development of a supply chain for mechanization under different economic and social conditions. Table 8 summarizes and compares the stylized facts drawn from the three models.

Mechanization supply in Ghana: AMSECs vs. the private sector-led supply chain

The government's involvement in mechanization is not a new phenomenon in Ghana. In the 1960s, the Ministry of Agriculture owned and operated an estimated 1500 tractors in its 32 district mechanization stations in the savannah zone (Seager and Fieldson, 1984). Low service charges for the provision of plowing services, which were estimated to be 50% of real costs in 1973, made the scheme unsustainable. From then until 2003, supply of mechanization was left largely to the private sector, while the creation of AMSECs represents a re-emphasis of the government's role in mechanization. Thus, applying the similar supply chain approach used in the previous section, we start with the AMSEC model for the Ghana case.

The AMSEC model

State-influenced tractor importation

The main financial source for the establishment of AMSEC is through concessional loans received by the government from various emerging economies such as Brazil, China and India. Such concessional loan agreements require that Ghana import tractors from the lender country.[13] Therefore, different loan agreements have brought in different brands of tractors from different countries. In theory, the government does not directly conduct the imports, and a Ghanaian company selected as an agent does. However, as an agent, the selected company is not in the position to determine the type of machinery imported or to negotiate the price. These are determined as part of the loan agreement. We use imports of Farmtrac tractors as an example to illustrate the process and its problems. After receiving a concessional loan from the Export-Import Bank of India in 2007 and 2008, a Ghanaian company was

[13] With the Japanese grant to the Ghanaian government, machinery is supplied by companies based in countries which belong to the OECD's Development Assistance Committee.

Table 8
Comparison of the three supply models of mechanization. Source: Authors' creation based on model summaries.

		Bangladesh model	India model	China model
Service provision	Ownership	Small-scale farmers	Early stages: medium to large farmers Currently: increasing ownership by small-scale farmers	Individual persons as private enterprises
	Type of machinery	Power tiller	Medium-size tractors: 20–40 hp	Small combine harvesters
	Type of operation	Self and paid services in land preparation, and multifunctional operations	Self and paid services with well-developed hire market	Migration across country to provide specialized service in harvest
Machinery supply	Market players	Private sector in importation and domestic trade	Early stages: private sector in importation and domestic trade Currently: Private manufacturers producing for domestic markets and exports	Private manufacturers producing for domestic market
Supply of attachments	Market players	Private sector; some basic attachments produced domestically	Private sector; most manufactured domestically	Private sector; most manufactured domestically
The key role of the government	Policy instruments	Trade liberalization and deregulation	Broad-based subsidies across many mechanical power sources	Facilitative role in overcoming coordination difficulties

Table 9
Summary of Ghana's current supply models for agricultural mechanization. Source: Authors' creation based on fieldwork interviews and review of policy documents.

		AMSECs	The private sector
Service provision	Who owns machinery	Nonfarm private enterprises	Medium and larger farmers
	Type of machinery	New tractors (50–80 hp)	Used tractors and some subsidized new tractors
	Type of main operation	Hiring services: mainly plowing	Self-service and hiring services: plowing, carting, and maize shelling
	Scale of operation	5–7 tractors	1–2 tractors
Machinery supply	Key supplier	Government	Private importers for used machinery, and government for new tractors
Supply of attachments	Market players	Government for imported attachments and private sector for imported spare parts	Private sector; some basic implements manufactured domestically
The key role of the government	Policy instruments	Direct importation and distribution of new machinery; heavy price subsidy and no interest charge on outstanding payment	Duty-free imports of new and used machinery; some new tractors received from MoFA at the subsidized price
Source of financing		Concessional loans from foreign countries' government	Cash transaction in used machinery and no financial support to the private importers

selected by the government as an agent to handle the imports. The company brought in 500 Farmtrac tractors over two years from India. The Farmtrac brand and which types of Farmtrac are not determined by this company, nor the import prices. Expecting the business to continue with the government, the company constructed a large warehouse and built up stocks of spare parts with its own money. However, when John Deere machinery, instead of Farmtrac, was decided under a new concessional loan by the government in the following year, a new local company was selected as the government's agent to conduct John Deere tractor imports. The company that imported Farmtrac tractors was adversely affected not only because it did not secure the new business opportunity but also because it used its own money to invest heavily in spare parts for Farmtrac brand, with an expectation for more Farmtrac tractors to be imported. Similar one-time arrangements have been made to import Mahindra tractors from India and other brands from China, Brazil, and other countries recently.

Government-selected "private" entities as AMSECs

The AMSEC program is one of four initiatives recently introduced by Government of Ghana that originated from the country's agricultural development strategy (Ghana, MoFA, 2007), which represents an important shift in recent government policy. In the case of mechanization, AMSECs are designed for promoting mechanization, as the government believes that without the state support and subsidy, private-led mechanization supply would be too slow to develop and to meet the demand from smallholders (Ghana, MoFA, 2003). In order to avoid direct government management of mechanization services, AMSECs are designed as private entities, while their selection was done by the government. The first group of 12 AMSECs was established in 2007/08 and each center was given a package of seven tractors with basic attachments by the government. The centers paid only 20% of the subsidized prices with the outstanding payment to be paid off over the subsequent four years without interest. A further 77 AMSECs were established in 2009–2010 through a similar process and under the same payment arrangement.

As part of the agreements with the lending countries, prices for the machinery imported by the government are often lower than their market prices, which are further subsidized by the government. Together with a down payment of only 20%, it makes AMSECs a lucrative and attractive business. Unsurprisingly, the number of applicants far outpaced the supply of available tractors, and only a limited number of AMSECs were selected by the government. Thus, transparency in the selection process is unlikely to be established.

Unfeasible operational model for AMSECs

The AMSEC scheme was designed to establish specialized services in mechanization without consideration of whether it is profitable. The design is alike the China model discussed in the previous section. However, in the China model, the profitability for the private providers becomes possible by across spatial operation, resulting in high utilization rates of specialized equipment. In Ghana, the AMSECs are mainly to provide plowing services locally and demand for other mechanized operations is yet to

develop. The recent survey by Benin et al. (2012) shows that in 2010 only 38 firms among 136 surveyed provided services other than plowing and even for such firms 80–90% of revenue came from plowing. It is not surprising that many AMSECs are unable to follow the repayment schedule, and some have been allowed to default on repayment, leaving the government responsible for the repayment of concessional loans.

Houssou et al. (2013b) assess the reasons for poor performance of most AMSECs. Based on subsidized tractor prices, actual operational costs in Ghana, and an assumption of 10% capital depreciation rate, the authors calculate that a minimum of 287 hectares per tractor must be plowed in order for the net profit from plowing services to be comparable to the interest earnings from a similar savings deposit in a bank account—a necessary condition for tractors to be a private investment for specialized services only. Recent survey data are then used to compare individual providers' profits and actual acres plowed against the profitability curve for this investment business model. The result shows that even at the subsidized price, the low utilization of tractors in Ghana makes tractor purchase an unprofitable investment if service provision alone is the only means for the investors to earn money.

In Ghana, like China, there are opportunities to increase utilization by migration across regions. South Ghana has two cropping seasons and the north has one, which, in theory, can lead the increase in the number of operational days through migration and hence makes it possible for tractor investment profitable (Houssou et al., 2013b). However, experience from China shows that the risk from the coordination failure is high for individual entrepreneurs in migration when farmers are small. In practice, there is little evidence of AMSECs doing it (although there evidence of this practice by private tractor owners).

The AMSEC model also comes with managerial challenges. In all the three models discussed in the previous section, machinery is usually operated by its individual owner, a family member, a trusted relative or individual. An AMSEC that receives 5–7 tractors needs to hire up to 7 operators. As operators are paid by the number of hectares plowed, they have no incentive to take good care of machines, which leads to frequent tractor breakdowns.

A quiet revolution in Ghana: private sector-led mechanization supply chain development

Parallel to the heavily subsidized AMSEC model in which the state has directly engaged in decision making on tractor imports, prices and distribution, the private sector has operated in Ghana's mechanization business for more than two decades. Besides the import tariff exemption applied to all agricultural machinery imports, there is no other government support to the private sector operating independently along the mechanization supply chain. While the government has imported about 3000 new tractors and 300 power tillers in the past 10 years, a similar or even larger number of used tractors were imported by private importers in the same period (Ghana, CEPS, 2012). The share of used tractor in the imports has increased substantially since 2010, suggesting considerable and increased demand for affordable tractors.

Private importers are predominantly small businessmen. However, they often have developed stable import channels. In many cases, importing tractors is not the only business for them, and they have a diversified business portfolio to complement the strong seasonal pattern in tractor demand. Their clients are mostly medium- and larger-scale farmers. The 2013 IFPRI/SARI survey shows that the majority of tractor owners own secondhand tractors and purchased their tractors through this private channel. A tractor owner census conducted in the three northern regions also shows that the majority of tractors operated and owned in the country are secondhand ones (USAID/ACDI-VOCA, 2013). As in the automobile market, secondhand tractors have a great price advantage compared with the same brand new tractors. According to authors' interviews in 2012, prices for used tractors are between US$5,000 and US$10,000, which are comparable to or even lower than the prices of subsidized new machines (but are different brands) imported for the government. The life cycle for used tractors is less related to their age or mileage, a reason to explain why used tractor market is popular globally.

The secondhand tractor is attractive to farmers not only because of affordable price, but also because of preferred brands. Since the private sector has operated in tractor import business for many years, the spare parts for the brands imported by the private sector are available in most locations at reasonable prices and those brands are the most popular among farmers. On the other hand, brands of the new tractors imported by the government have changed frequently driven by the concessional loans received from different countries. This has made the maintenance services and the supply of spare parts for the new brands to be underdeveloped. In addition, the new tractors are received at discounted prices by the Ghanaian government who further subsidizes these prices, but there is no such subsidy on the prices for spare parts, leaving the spare part suppliers have no intensive to build up their stock without adequate new brand tractors in stock.

The medium- and large-scale farmers are not only the main buyers of secondhand tractors through this private channel, they are also the main providers of mechanized services to other farmers. As we have mentioned in the previous section, in the 2013 IFPRI/SARI survey, almost 50% of surveyed small-scale farmers hired tractor services for plowing. The survey also suggests that almost all farmers who hired services accessed these services from within their home districts. A different survey conducted in 2012 shows that fewer farmers received services from AMSECs than from private tractor owners (Benin et al., 2012). Because of the dominant role of medium- and large-scale farmers in service provision, a competitive mechanization service market has developed. According to Benin et al. (2012), as well as from the authors' own observations, farmers reported similar service prices in each location, i.e., AMSECs and unsubsidized service providers face similar market prices and they compete openly in serving farmers for plowing.

The observations from our recent survey and field interviews suggest that the investment of medium- and large-scale Ghanaian farmers into tractors is leading mechanization development. This echoes the Bangladesh and India models, but deviates from the China model, the one similar as the AMSEC program. So, what are the fundamental factors resulting in the development of this farmer-to-farmer supply model even without the government's direct support?

Our field interviews and 2013 IFPRI/SARI survey both show that, with relatively larger holding size for medium- and large-scale farmers, the own needs for plowing is listed as the first consideration for tractor owners in making their investment decision. Thus, the first key factor for facilitating the adoption of mechanization technology is the presence of a substantial number of medium- and large-scale farmers. However, the risk associated with purchasing a tractor is still high particular among medium-scale farmers. Apart from the financial constraint that is common to farmers for any lumpy investment, the benefits of timely land preparation may not be able to justify the cost of the tractor for a medium-scale farmer when tractor's utilization is limited to plowing own land only. Thus, the second key factor is the presence of a service hiring market and the possibility for a tractor owner to hire-out services to other farmers. The 2013 survey shows that before buying a tractor, 90% of medium-scale farmers had participated in this market as hired-in clients, and the average number of years for which they had hired-in services for this group of farmers is 10 years. Such

experience not only allows medium-scale farmers to fully appreciate the benefit of owning a tractor for their own use, but also provides them enough time for learning how to hire out services once they become owners. While medium-scale farmers participate in this market first as hiring-in clients and then as service providers, if demand for such services is limited to medium-scale farmers only, there is not enough space in this market to attract more medium-scale farmers to become tractor owners and to increase service supply. Thus, the third key factor is the growth potential of this market through increased service demand from small-scale farmers also. The 2013 survey seems to indicate such potential. The survey data shows that the ratio of service providers to service users is 1 to 100–120 in 2012, i.e., in average, a tractor owner provided hiring-out services to 100–120 farmers, of which 45–51 are small-scale farmers (with land less than 2 ha). There are more than 50% of small-scale farmers in the survey who still do not hire-in mechanization services and are potential clients in the future, thereby allowing for further market expansion and development of mechanization.

In conclusion, the emergence of the three key factors discussed here reveals a viable model through which the private sector can lead the sustainable development of mechanization – the hiring service market in which medium- and large-scale farmers are both tractor owners and service providers. On the other hand, the model of specialized service provision promoted through AMSEC program is unlikely to be sustainable without heavy subsidy of the government. Corresponding to Table 8 in the previous section, Table 9 is developed to summarize this two models in the case of Ghana.

Conclusions

This paper first examines the demand for mechanization of agricultural operations in the context of the evolution of farming systems and induced technology adoption. Ghana's farming systems have undergone significant changes in the last 30 years. Land expansion in responding to increased market demand for agricultural products has led to rising land-labor ratio and increased numbers of medium- and large-scale farmers. In combination with the rising wage rate and increased opportunities for rural workers in nonfarm sectors, it has induced the demand for labor-saving technology and demand for certain mechanized farming operations, particularly plowing, has emerged even among small-scale farmers.

The paper then employs a supply chain approach to analyze the supply side of mechanization. The three stylized models based on Asia's experiences display that private-sector led supply chain models vary according to different economic and social conditions. In the countries without capacity of manufacturing tractor, such as in Bangladesh, the private sector has brought in appropriate machinery at affordable prices. While a "smart" subsidy policy can be used to encourage private investment, such as in the case of India, there is a crucial difference between subsidies applied across an extensive range of machinery and those applied only to the tractors imported by the government. The subsidy policy has to avoid winner-picking in types and sources of machinery, as it can distort the incentives for both importers and tractor owners and encourage rent-seeking behavior.

Two different supply models in Ghana are discussed in the paper and have communicated a similar message as the three stylized Asian models do. In the case of Ghana, the development of the hiring service market led by tractor ownership among medium- and large-scale farmers seems to be a promising model for sustainable mechanization to reach farmers of all sizes. On the other hand, the AMSEC model recently promoted by the government seems to be not viable. Continuous implementation of such model will not only increase the financial burden to the government, but also encourage more rent-seeking behavior and diminish the role of the private sector in developing mechanization supply chain.

Most tractors imported by the private sector are secondhand at much lower prices than the new ones, indicating the price sensitivity for tractor buyers, while such lumpy investments have yet to receive any financial support from either the government or private financial sector. India's experience shows that through government support to financial institutions, domestic banks (particularly development banks) can provide longer-term lending to enable the private sector to invest in agricultural development, including in mechanization. Policies and interventions to assist the private sector in overcoming market failures in credit markets have been documented for other Asian countries too. Will Ghana's government be able to indirectly promote mechanization through the engagement of the financial sector instead of establishing AMSECs? This is a policy option that deserves more research.

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