# Agricultural Development, Mechanization, and Rental Markets: Theory and Empirics from Ghana

*Thesis submitted in partial fulfilment of the Degree of Doctor of Philosophy*

By

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## Abstract

**Agricultural Development, Mechanization, and Rental Markets: Theory and Empirics from Ghana**

Frances Ruth Cossar

*St Antony's College - DPhil International Development - Trinity Term 2018*

The subject of this thesis is the process of agricultural mechanization in the tropical farming systems of Ghana. Three original research papers are presented which explore separate research questions with different methodological approaches. All three papers draw upon detailed empirical analysis of the decisions by farm households over the use of tractor plowing in cereal-producing farming systems of Ghana. This empirical analysis informs our theoretical understandings of mechanization, its use, and its impacts.

The questions considered are: (i) to what extent can the patterns of agricultural mechanization be explained by changes in population, urbanization, and agro-ecological conditions? (ii) Given the heterogeneity of conditions and farming systems, is it right to assume that mechanization will reduce the labour requirements for production? What is the impact of mechanization on other farming decisions and productivity? And (iii) what role do informal institutions and social capital play in facilitating access to more productive technologies by farmers of all scales?

By revisiting the theories of mechanization developed in the 1960s through to the 1980s, the first paper argues that farmers' technology adoption decisions continue to be linked to system-wide drivers such as population change and urbanization. The second paper argues that farmers are taking up tractor plowing in this production system in large part because of the advantage it confers in shortening the required time for land preparation, even as mechanization has little impact on post-planting farm practices, which remain highly labour-intensive. The final paper examines the market for tractor plowing services, which is the primary mode of access to mechanized technology for farmers in Ghana. I argue that the social embeddedness of farmers in rural Ghana is key to the functioning of the market for tractor services, allowing communities to manage spatial externalities and time constraints.

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And finally, the true answer to why and how I made it to the end of this process lies in these words, and the One who inspired them.

“Speak up for those who cannot speak for themselves,
for the rights of all who are destitute.
Speak up and judge fairly;
defend the rights of the poor and needy.” (Proverbs 31:8-9)

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# Thesis Introduction

In most of the developed world, agricultural production activities, such as plowing, planting, and harvesting, are carried out using tractors and other farm machinery as the sources of power. In contrast, mechanization in South Asia and Sub-Saharan Africa (SSA) has been intertwined with oscillations in colonial, post-colonial, and more recent government objectives for agricultural development. Many farmers themselves, particularly smallholders, in these regions continue to rely upon animal traction or human physical strength as the primary power sources for agricultural production. Until recently, human power has been the sole source of power for most of SSA, with the exception of some pockets of large-scale commercial farming in southern Africa, and the successful introduction of animal traction in certain areas of both East and West Africa. Low productivity and meagre productivity growth in SSA agriculture have been well documented. International and national governments, NGOs, and research initiatives have put considerable efforts have been put into increasing the use of productivity-enhancing technology amongst SSA farmers. Attention is increasing moving towards the potential for mechanization to increase productivity, especially the productivity of labour (African Center for Economic Transformation, 2017; Malabo Montpellier Panel, 2018). However, sustained adoption of either agricultural machinery or animal traction has, until recently, been limited to a few areas in SSA.

This apparent lag in agricultural technology adoption has been explained in several ways in the literature. Some cite the incompleteness of markets for credit as a critical barrier to farmers making investments in productivity-enhancing technologies. Furthermore, the institutions which govern the intermediate markets for land, labour, other inputs, and outputs in rural agricultural economies in SSA are frequently characterized by informality and dependence upon dense horizontal family and kinship networks. The weaknesses in these markets are have been used to explain the lack of modern technology adoption, such as agricultural machinery, which is a lumpy investment requiring high upfront cost of purchase. However, these explanations often overlook the socio-economic context, technical feasibility, or underlying characteristics of the local farming systems in analyzing the constraints to technology adoption (Sumberg, 2005). The adoption of agricultural machinery by smallholders in Sub Saharan Africa has historically been very low, despite state interventions to promote it (Bigot, Binswanger & Pingali, 1987). In spite of the many barriers to technology adoption and diffusion, this thesis will focus on an interesting case: the emergence of an effective and active private market for tractor services in northern Ghana.

The thesis, through three individual papers, will explore the following questions:

1. To what extent can the patterns of agricultural mechanization be explained by changes in population, urbanization, and agro-ecological conditions?

2. Given the heterogeneity of conditions and farming systems, can we assume that mechanization will reduce the labour requirement for production? What is the impact of mechanization use on other farming decisions and productivity?

3. What role do informal institutions play in facilitating, or hindering, access to more productive technologies by farmers of all scales?

The key arguments of the thesis are that the emergence of the tractor services market in northern Ghana reflects the specific characteristics of agriculture in this region. Machinery use has considerable consequences for the crops farmers cultivate, as well as the distribution of agricultural activities between men and women in smallholder households. The thesis also makes the case that the tractor service market depends critically on the effectiveness of existing social structures and informal institutions at solving problems of coordination across farmers.

This introductory chapter is structured as follows. Section I gives the background on agriculture and economic development in Ghana including aspects of economic and demographic trends, the farming systems and agricultural productivity, land and social institutions, and government policies related to agricultural mechanization. There is also an overview of the history of mechanization in developing countries. Section II will then discuss the theoretical literature and concepts on agricultural intensification and mechanization, farming systems research, and the role of social capital in technological change. Finally, the research questions, methodological approach, and key findings of each thesis paper will be discussed in Section III.

# I. Development, Agriculture, and Mechanization

### *a. Ghana's development*

Ghana achieved GDP per capita of over $1,500 in 2016, after several decades of steady economic growth.[2] In 2011, it was classified as a lower-middle income country by the World Bank. The absolute poverty rate (population living on under $1.90 a day) was recorded at 4% in 2012.[3] As well as halving extreme poverty, Ghana successfully met other Millennium Development Goals to improve access to safe drinking water and to improve access to universal primary education with gender parity (Government of Ghana, 2015). The success of Ghana's development has been attributed to the establishment of stable democratic institutions and state capacity, combined with economic growth fueled by the export of gold, cocoa, timber, minerals, and more recently, oil. However, this dependence on commodity exports has led to concerns over 'Dutch disease' and inflationary pressure. In fact, there is evidence of high labour costs influencing the production decisions of farmers (Nin-Pratt & McBride, 2014). Rapid growth of non-agriculture economic sectors has led to a decline in the share of GDP attributed to agriculture from over 40% in the 1990s to 20% in 2016[4].

Through these decades of progress, the population has become increasingly urbanized. Total population growth in Ghana has been steady over 1960-2010 at 2.4-2.7% annual growth.

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[2] World Development Indicators, 2018. Accessed at: http://databank.worldbank.org/data/ , February 2018.

[3] Ibid.

[4] Ibid.

This growth has been concentrated in the transition and southern areas of the country, driven by rural-to-rural and rural-to-urban migration (Van der Geest, 2011). This trend has been explained by the push factor of poor environmental conditions in the north, combined with the draw of available fertile land further south, and growth in non-agricultural economic activity in urban areas (Van der Geest, 2011; World Bank, 2011). Ashanti, an important cocoa-producing region, is the second most common destination for migrants, after Greater Accra (World Bank, 2011). The proportion of the population residing in urban areas increased from 42% in 1998 to 55% in 2016[5].

### b. Ghana's food and agricultural systems

Sub-Saharan Africa is characterized by considerable heterogeneity in agro-ecology, soil conditions, relative land-labour abundance, and market demand, which have shaped the structure of farming systems. Furthermore, some economists have argued that resource-rich economies of SSA have labour costs which are higher than of Asian countries (Kingdon et al., 2006; Bigsten et al., 2005; Eifert et al., 2008). This heterogeneity affects the demand for different technological interventions that have the potential to boost agricultural incomes and output (Kaplinsky, 1990; Ruthenberg, 1980). Despite the higher profitability found in horticulture and non-traditional cash crops, cereal and root crop production is the mainstay for producers in African economies. According to FAO statistics for 2016, 69% of the

[5] Ibid.

harvested area in Sub-Saharan Africa was allocated to cereal and root crops.[6] Agricultural productivity growth in staple crop production has lagged despite decades of efforts to promote the use of fertilizers, high-yielding seeds, and other technologies through national extension systems and development initiatives. For example, maize yields in Africa and Asia were comparable in the early 1960s at around 10,000-11,000 hg/ha. By 2016, maize yields in Asia were over double that of Africa.[7] This leads to questions of whether these technological interventions themselves adequately reflect the challenges facing farmers, or whether the technologies are effective but farmers in some way lack knowledge and access to such technologies.

For Ghana, the nature of domestic food demand has evolved during its economic development since the 1990s. Rising household incomes and changing urban diets have placed pressure on the agricultural sector to respond. Although 29% of domestic cereal supply is imported - relatively high for SSA - this ratio has not increased as urbanization and economic growth have advanced.[8] Figure 1 shows the growth in Ghana's cereal production since the 1980s. In particular, production of maize has increased relative to other cereals. Particularly in the northern Guinea savannah, maize production has increased whilst millet and sorghum production have declined (Ellis-Jones et al., 2012; Ngeleza, Owusua, & Jimah, 2011). In these areas, under favourable conditions, maize cultivation with improved seeds

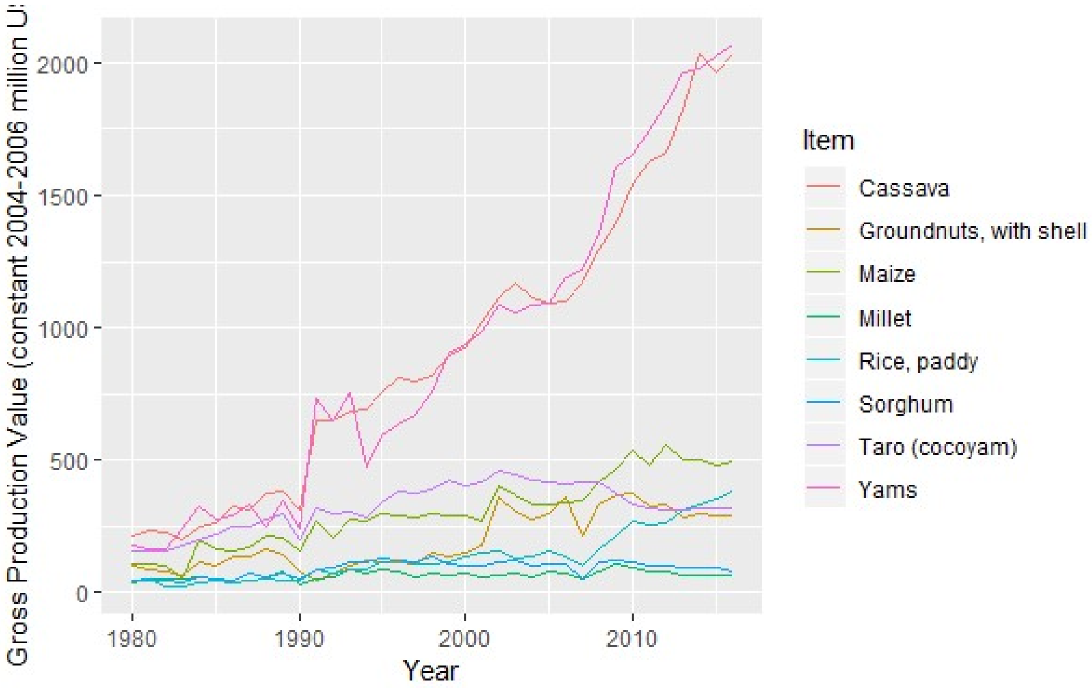
[6] The main cereal and root crops grown in SSA include (in descending order of harvested area): maize, sorghum, millet, cassava, rice, cowpeas, groundnuts, yams, sweet potato, plantain, wheat, potato, barley, and other roots and cereals. FAOSTAT (2018), accessed online, March 2018.

[7] Maize yield for Africa in 2016 was 19,272 hg/ha, for Asia it was 51,076 hg/ha. FAOSTAT (2018)

[8] FAOSTAT 2017, Cereal import dependency ratio.

and fertilizer affords higher yields – and maize typically fetches higher market prices than other coarse grains. There is also evidence of expansion of farming into poorer quality land, associated with declining soil fertility and increased weed problems (Braimoh & Vlek, 2005; Ellis-Jones et al., 2012). More efficient farms are combining use of fertilizer with mechanization, larger farm sizes, and herbicide use (Nin-Pratt & McBride, 2014).[9]

**Figure 1: Crop production over time (million US dollars)**




Source: FAOSTAT 2017

Most farmers in Ghana would be classed as smallholders, and yet mechanization for some operations has become widespread. The average farm size in Ghana is 2.83 ha. Especially

[9] These 'larger farms' are still relatively small. Average farm size of farms in this study range from 0.8 ha to 5.5 ha across levels of population density and agro-ecological zones of Ghana.

pertinent to a discussion of mechanization is to understand the distribution of land sizes across Ghana. Table 1 shows the average farm size by quintile for both the whole country, and for the northern regions only. Farm sizes are slightly bigger in the north, but the data confirms that most farm land is being cultivated by small-scale farmers. Even with relatively small land sizes, over 80% of households in the north across land size quintiles were using tractors on at least one plot in 2009. Mechanization use is more common for cereal production in the transitional and savannah zones of northern Ghana.

**Table 1: Land size distribution and tractor use**

| | All regions | | Northern regions only | |
|---|---|---|---|---|
| Quintiles of total land area | Mean area (ha) | Proportion of hh using tractor on at least one plot | Mean area (ha) | Proportion of hh using tractor on at least one plot |
| 1st | 0.37 | 12.84% | 0.79 | 83.85% |
| 2nd | 0.99 | 23.38% | 1.59 | 94.06% |
| 3rd | 1.73 | 22.33% | 2.42 | 88.82% |
| 4th | 2.91 | 26.40% | 3.58 | 95.86% |
| 5th | 8.20 | 30.01% | 8.11 | 96.60% |
| Total | 2.83 | 22.91% | 3.22 | 92.00% |
| Gini coefficient | 0.52 | | 0.45 | |

Source: EGC-ISSER Socioeconomic Panel Survey, 2009-10. Northern regions include Upper West, Upper East, and Northern region. Estimates are weighted using household weights.

This relatively equitable distribution of land, particularly in the northern regions, can be explained by the traditional land tenure system in Ghana (Toulmin 2009). The Gini coefficient for land area owned by households is comparable with those of other SSA countries, which range from 0.40 to 0.59 (Deininger et al. 2017)[10]. Households are entitled to use rights over agricultural land through family inheritance and through community land administered by local chiefs. Their tenure rights are dependent upon the history of acquisition, ethnic and cultural background, as well as the agricultural practices and investments of the farmer (Lambrecht & Asare, 2016). Under the traditional tenure system, which dominates for agricultural land, ownership of land is communal. Individual farmers hold use rights over their plots and own the crops produced on the land. Where population pressure has risen, and where more commercial farm structures are emerging, the traditional tenure system has adapted to the changing needs of smallholder farmers and larger scale commercial farm enterprises (Gyasi, 1994). Markets for land ownership and rental are emerging in some urban and peri-urban areas. However, increasing competition over land rights can also create incentives for farmers to reduce fallowing and make land investments in order to improve the security of their traditional land tenure (Goldstein & Udry, 2008).

With increasing urbanization and economic growth, government policy has been focused on supporting farmers in rural areas both to increase agricultural output and to attempt to share the benefits of economic growth with rural communities, especially in the poorer north of the country. In particular, the Ministry of Food and Agriculture has revived state-sponsored agricultural mechanization since the early 2000s, with the motivation of modernizing the agriculture sector and reducing the drudgery of agricultural work. To some extent, this

[10] This study used six countries included in the World Bank's LSMS-ISA surveys: Ethiopia, Malawi, Niger, Nigeria, Tanzania, and Uganda. In contrast, the Gini land coefficient for South Africa in 1970 was 0.70, and 0.80 in Brazil in 1985 (Frankema 2005).

represents a continuation of policies that were attempted and abandoned in failure fifty years ago.

Farmers undertake cereal production across Ghana's diverse regions. Even areas which specialize in cocoa production, also produce maize and other staple crops. In the most part, farmers face similar pressures in relation to sparse and highly seasonal rainfall for cereal production, as these areas lie within the broad agro-ecological zone defined as semi-humid guinea savannah.[11] Ngeleza et al. (2011) further breaks down Ghana's agricultural context into seven cropping systems, based on the observed the agro-ecology and cropping patterns. They draw upon Ruthenburg's classification of cropping systems. Most of Ghana's three northern regions are described as "cereals" cropping systems, although several non-cereal crops are widely cultivated along with sorghum, millet, and maize (in particular, yam cassava, soybean, groundnut, and cowpea are grown in this region). The transitional zone, loosely captured by Brong-Ahafo, and parts of Central, and Eastern regions, is classified as a "high maize belt" (Ngeleza et al., 2011), with additional area under cassava, yam, cocoyam, and plantain. Apart from Greater Accra, maize and other staples are major crops across all the other cropping systems which are identified, even where cocoa may be the major cash

[11] Of course, some farmers have access to irrigation from ground water or river flow; even within a reasonably homogenous agro-ecological zone, there can be a high degree of individual variation. Even more significant, as I will argue, are variations in market access that may differ across communities and even across households within the same community. Heterogeneity at all levels is important – but this should not obscure the important underlying similarities.

crop.[12] For this thesis, the data used in the first paper covers the northern and transitional zones where cereal cropping dominates; the second paper cuts across all areas; and the third paper of this thesis focusses on one district in the Northern region.

Distinct from many other farming systems in West Africa, Ghana does not have a tradition or recent history of animal-plowing. Starkey (2000) extensively reviews the history of animal traction in Africa. Efforts to promote animal traction in Ghana failed in the 1970s and 1980s due to the high prevalence of animal sickness; some observers have also attributed this failure to the lack of historical experience with animal traction.

### *c. Experiences of agricultural machinery in smallholder farming systems*

The spread of tractors and other agricultural machinery in Sub Saharan Africa has been dominated by failed government schemes since the 1940s. There was optimism that the post-war uptake of tractors in North America and Europe would be replicated in SSA. Colonial attempts to transform over 20,000 hectares of land for groundnut cultivation in East Africa were driven by the belief that tractors would unlock potential supply for UK markets (Hogendorn & Scott, 1981). Within a few years, the scheme was abandoned and the considerable stock of tractor machinery was transferred to private and state-owned large-

[12] Other cropping systems identified by Ngeleza et al., (2011), are: high cocoa (Ashanti, and parts of Brong-Ahafo, Central, Eastern, Volta, and Wester regions); moderate cocoa (Western region); Volta valley (Volta region); and high onion belt (Upper East region). Greater Accra is identified as a mainly vegetable production area.

scale farms. Groundnut cultivation was also introduced in northern Ghana in the 1930s, alongside animal plowing (Whitehead 2006).

Tractorization schemes were attempted in West Africa as early as the 1950s, in order to replace labour which had been drawn in to the mining sector. These programs were also part of a wider focus on technology-driven solutions to global food production in the colonial post-war era (Richards, 1985, pp. 34–35). Top-down attempts to mechanize agriculture were replicated by the newly independent governments of SSA in the 1960s. In Ghana, the State Farm Corporation was started in 1962 and exemplified the prioritization of large scale, mechanized, production of cereal and export crops (Nweke & Haggblade 2010). Where smallholders were taking up mechanized traction, it was more frequently animal traction in Ethiopia, Kenyan highlands, and parts of West Africa (Starkey 2000).

There was increasing focus of government interventions on smallholders and their access to agricultural machinery in the 1960-1980s, through block cultivation and tractor hire schemes (Pingali 2007). In Ghana, and elsewhere, these tractorization schemes were criticized for promoting machinery which was inappropriate for local conditions, in contexts with poor state capacity for managing the schemes, and in settings where continued operation relied on heavy state subsidy (Richards, 1985; Seager & Fieldson, 1984). With the fiscal crisis which affected many African governments in the 1980s, these state mechanization schemes collapsed, and widespread adoption of such technologies by smallholder farmers was abandoned (Pingali 2007). This episode is frequently cited as key evidence that mechanization for smallholder farmers fails in the context of low commercialization and high labour abundance in Africa's agricultural systems (Pingali, Bigot, & Binswanger, 1987).

The experience of mechanization in South and East Asia has been markedly different. The 'Green Revolution' greatly increased rice yields in Asia through hybrid seeds and fertilizer application. The intensification of production and rising labour wages created power bottlenecks for harvesting, threshing, and land preparation which led to rapid increase in machinery use from 1980s onwards (Pingali 2007). For example, Bangladesh's government was subsidizing hiring services through farming groups for irrigation pumps and tillage, but it was not until a cyclone decimated the draught animal population that import restrictions were lifted on cheaper power-tillers that their use became widespread amongst smallholders in Bangladesh. By 2000, 80% of agricultural land was cultivated using a power-tiller, whilst only one in 30 farmers owned such a machine (Khondoker et al. 2017). There is now a vibrant service market for power-tillers, irrigation pumps and threshing machines in Bangladesh. Similar patterns of policy and smallholder take-up occurred in Thailand, Vietnam, and Nepal where government initially supported mechanization for large-scale farming, but subsequently the private sector opened up access to small-scale machinery for smallholders, particularly for rice cultivation (Mandal et al. 2017).

For smallholders in SSA, the development of certain crops has facilitated access to mechanization. In Nigeria, new cassava varieties were introduced in the 1980s which required early harvesting and therefore processing, unlike traditional varieties which can be stored in the ground until needed. Mechanical cassava graters therefore become popular alongside the new cassava variety (Johnson & Masters 2004). Cotton farming in Ghana was opened up to the private sector in the 1985. Production was organized through out grower-type arrangements with inputs, including tractor plowing services, provided to the farmers on credit (Poulton 2004). In the author's discussions with farmers, they said the tractor provider would also plow non-cotton plots for cash. Cotton production has collapsed in Ghana since the 2000s, but it is likely that the specific provision of tractor services for cotton, paved the way for wider adoption by smallholders for other crops.

Much of the policy focus for SSA has been to promote 'green revolution' technologies such as improved seeds and fertilizer, rather that mechanization, which is seen as both too expensive and labour replacing (Evenson & Gollin, 2003; Morris, Kelly, Kopicki, & Byerlee, 2007). New partnerships between emerging economies – China and Brazil – and African countries are reigniting debates over mechanization in Africa (Amanor & Chichava, 2016; Cabral, 2016). It has been widely noted that agricultural productivity growth in SSA has been stagnant, and uptake of 'green revolution' technologies has been limited.

Given this backdrop, the motivation of this thesis is to revisit the understanding of where and how mechanization technologies are adopted in developing country agriculture. This thesis focuses specifically on the mechanization of land preparation (tractor plowing) in tropical cereal-producing farming systems of Ghana. The following section will discuss the existing theoretical and empirical literature relating to agricultural technology adoption and mechanization specifically. This will set the context of the literature which this thesis sits within, before each paper is introduced.

## II. Literature review

This section reviews the literature and theoretical concepts which will be relevant for the thesis. First, research on the evolution of farming systems and the associated drivers of change has been the area of literature that most directly considers the role of mechanization in agricultural development. Second, farming systems research and its conceptualization of the individual and aggregate farming units is discussed. Third, the role of social capital in supporting agricultural development and technical change has been explored to some extent in the economic development literature, and an overview is provided here. Finally, related literature on agricultural technology adoption, and the relationship between scale and productivity, are summarized.

### *a. Recent literature on agricultural mechanization*

Although there has been much research on agricultural development in SSA, very little recent literature has focused on the role of mechanization, either empirically or theoretically. Pingali (2007) recapitulated the theoretical ideas regarding mechanization in the context of SSA. Several papers by researchers at the International Food Policy Research Institute have documented the use of mechanization in Ghana and Nigeria and have analyzed associated policy questions (Diao, Cossar, Houssou, & Kolavalli, 2014; N. Houssou et al., 2013; Takeshima & Yamauchi, 2012). In Nigeria, there is a mix of animal traction and machinery use in some areas. Takeshima (2015) compares marginal adopters and non-adopters of machinery in two states of Nigeria where tractor use is common, through service markets. He finds that adoption is positively related to household wealth and endowments, as well as the proximity to large scale farmers. Rural mechanization in Asia has been the focus of much work in the literature. The shift from draft animals to mechanization of land preparation, irrigation systems, and other rural activities in several south Asian countries has proven the potential of small-scale machinery to transform smallholder farming systems (Child &

Kaneda, 1975; Mandal, Biggs, & Justice, 2017). Outsourcing of power-intensive harvesting operations to mechanized service providers has alleviated the pressure from rising labour costs or small-scale farms in China (Zhang, Yang, & Thomas, 2017).

On Mozambique, Cabral (2019) documents a very similar story of government-sponsored mechanization to the recent policies in Ghana. Supported by Brazilian imports, Mozambican government has supported provision of tractors to privately-run mechanization service centres, in order to promote mechanization use amongst smallholder farmers. Her analysis of the scheme finds that mechanization provision continues to heavily rely on state support, unlike Ghana, and that smallholder engagement with mechanization and other modern technologies continues to be minimal. The questions raised by the 'appropriate technology' literature of the 1980s (e.g., Stewart, 1987) continue to be relevant with regards to such top-down state-sponsored schemes which either fail to benefit smallholders, to take account of existing agrarian structures.

### *b. Evolution of farming systems and mechanization*

Agricultural mechanization can be understood to some extent through broad theories of agricultural transformation and the evolution of farming systems. Boserup (1965) and Pingali et al. (1987) consider farmer demand for mechanized technology to be a result of the agricultural intensification process. Boserup's (1965) famous contribution was to make a theoretical and empirical link between population growth, technological innovation, and agricultural intensification. This relationship has been explored extensively in the literature and found using empirical data, although the causal relationship is often unclear (see Lele & Stone 1989; Turner & Fischer-Kowalski 2010; Chavas 2008). She argued that farming system evolution and technology adoption are endogenous processes in which population growth is the main determinant, given agro-ecological conditions. The evolution of the farming system involves more intensive land use, whereby long fallow cultivation practices are replaced with more frequently cultivated, yield-enhancing techniques are adopted, and more land is brought into regular cultivation. To enable more frequent cultivation on existing and new agricultural land, new technologies are developed and adopted such as higher levels of input use – including labour and fertilizer, and incorporating non-human sources of power – whether animal traction or machinery. She argued that mechanization, as a labour-saving technology, would be adopted where there is growing demand for food, either because of population growth or because of growth in the non-agriculture sector. Pingali et al. (1987) find a positive correlation between the intensification of farming systems, as described by Boserup (1965), and the mechanization of agricultural production[13].

Boserup's discussion of mechanization does not extend to consider the source of mechanized technology, nor the relative prices of land, labour, and outputs. The only attempt in the literature to theorize the conditions under which farmers choose mechanized technology, rather than agricultural intensification more generally, is the application of the induced innovation hypothesis (IIH) by Binswanger & Ruttan (1978). Farmer demand for labour or land intensive technology is driven by the relative prices of land, labour, capital, and output,

[13] Pingali et al, Boserup, and Ruthenburg consider intensification to include bringing virgin and long-term fallow land into more frequent cultivation. This is especially useful when considering shifting cultivation systems as they move to annual cultivation and multiple cropping. Other authors consider this as 'extensification' of farm land.

which incentivizes public or private research institutions to innovate and adapt their production of new technologies in response to farmer needs. Hayami and Ruttan further develop this theory and propose that the capacity for a country to develop technology consistent with resource endowments as the single most important variable which explains the growth of agricultural productivity of nations (Hayami & Ruttan, 1985). Technical and institutional change are understood as endogenous to the economic system – i.e. public and private suppliers of knowledge are components of economic system.

The long term and cross-country perspective taken by the IIH is valuable in understanding the broad patterns of technology adoption. However, in understanding the take-up (or lack thereof) of a technology in a specific context, the IIH does not offer useful detail. In many cases, the specific characteristics of local agro-ecologies and market environments are important for understanding the diffusion of new technologies.

In particular, the concepts of land abundance and population pressure that are at the heart of Boserupian theory and the IIH tend to assume rural communities that operate in autarky. It is not clear what these concepts mean in the case of northern Ghana. First, consider land availability. Land markets in Ghana (as in much of Sub Saharan Africa) are rarely complete and instead are governed by traditional land tenure systems. Traditional systems may make it costless for farmers to increase their cultivated land, or alternatively make it impossible, depending on the institutions and land rights of the particular farmer. Next, consider population pressure. Much of rural Ghana is integrated – albeit imperfectly – with urban markets. Urbanization has proceeded rapidly in recent decades, implying that rural areas are feeding large numbers of people who do not live on the land. Arguably it is connectivity with urban markets, more than rural population density, which will drive technology adoption. Given the tendency of governments to expand rural connectivity in areas of high agricultural potential, connectivity is itself likely to be higher in areas with favourable agro-ecological characteristics. Indeed, locations with higher agricultural potential are also more likely to urbanize earlier (Motamed, Florax, & Masters, 2012). The absence of these particular questions for agricultural intensification in light of urbanization, rather than purely changes in population density, is a limitation of the Boserupian and IIH literature. The thesis will add to this literature on the relationship of mechanization diffusion with population pressure and urbanization.

### c. *Farming systems research*

The thesis frequently makes reference to farming systems – but this is a term that has been widely used in academic literature in many difference contexts. I clarify in this section the ways in which I will use the term in the remainder of the thesis. The concept of a 'farming system' derives from the view that a systems approach is helpful in understanding the complex interactions of humans and bio-order that shape agricultural ecologies and economies. The farming system includes subsystems that range from the agro-technical processes governing the conversion of soil, water, and energy into the resulting crop or livestock products. In addition, there are social and economic subsystems which govern the households, communities, and markets involved in production. In fact, Ruthenberg (1980, p. 3) refers to the farm system as a 'man-biological-machine' system with a hierarchy of soil systems, machine systems (e.g. tractors), and social systems (e.g. workers). A 'cropping system' is the combined system of all crops on a particular farm, the 'farm system' being an individual farm, with a 'farm-household system' being the interconnected systems of farming and households. A distinctive characteristic of smallholder farm systems is that the farm and household sub-systems are closely interconnected. This hierarchy can be further aggregated to consider a wider farming system which consists of many farm-household systems with similar structure and production characteristics, and defined within a particular geographical area. This aggregation is often useful for analysis and policy measures, although inevitably an aggregation will overlook the heterogeneity among farm and farm-household systems (Whitfield et al. 2015).

A major critique of farming system research is the assumption of homogeneity across a large geographical and system scale in order to facilitate technology adoption and development (Whitfield 2015). Garrity et al. (2012) categorize only 10 farming systems to cover all of SSA with common agro-ecological characteristics and similar structures of household livelihoods. Northern Ghana is categorized as a cereal-root mixed farming system which is common across the guinea savannah of West Africa. As Garrity et al. acknowledge, it is tenuous to assume a single typical farm-household system across such diverse economic and institutional contexts. There could be a temptation to take the results of this thesis and assume their direct relevance for all farm-household systems across this highly aggregated group. Whilst this broader context may well be relevant and a useful first reference point to apply lessons, the focus of the thesis will be to analyze farming systems at a finer scale within Ghana and therefore limits its scope to the specific economic and institutional context.

The first paper of the thesis will consider a farming system as the collection of individual farm-household systems within a village community. This aggregation is meaningful given the interdependence between households within villages in Ghana for sharing of labour and land distribution. Furthermore, the system drivers which are discussed in the paper will be pressures which affect all farm-household systems in the village. The pressure from population density change and the extent of isolation from local and regional markets are challenges faced by all farm-households in the village. Some household will be more or less affects by these challenges, but the reliance on inputs from outside the farm-household unit such as hired labour, tractor services, and land availability makes the village aggregation an analytically meaningful one when considering use of tractor plowing.

In the second paper, the unit of analysis is a farm-household system. The context of the farm-household system sitting within the wider economic systems of the village or district is a key aspect to that paper. In a similar way, the third paper is analytically interested in the extent to which farm-household systems intersect with the social system at a village level, in order to support the interaction with the economic market (or system) for the provision of tractor services.

### *d. Technology and social capital*

Social capital is defined as the informal institutions, social norms, and networks - resulting from cultural norms and beliefs - that support the interaction of agents in the market (Fafchamps & Minten, 2001; J. Platteau, 1994). Its role in supporting economic development has been firmly established in the literature (Dasgupta & Serageldin, 2000; Ostrom & Ahn, 2003; Woolcock, 1998). I will not attempt here a review of the multiple disciplinary and theoretical perspectives on social capital, but rather highlight the ways in which the concept has been used in relation to technology adoption in agricultural development, specifically in developing country contexts.

Social norms and networks in SSA have been found to improve learning about new agricultural technologies, overcome information asymmetries associated with agricultural trade, and enhance market access (Lyon, 2000; Conley & Udry, 2010; Pender & Gebremedhin, 2008). Household participation in village council and marketing cooperatives are found to be associated with better and more timely access to modern inputs, improved agricultural practices, and cultivation of higher-value crops (Pender & Gebremedhin, 2008). The use of informal institutions by smallholders to mitigate consumption and other risks to income and assets has also be established. Hoddinott et al. (2005) use the case of informal networks for funeral expenses in Ethiopia to demonstrate the relationship between local social networks and risk-sharing in rural communities.

Amongst Ghana's manufacture and trading firms, it was found that personalized long-term relationships are used to facilitate trust amongst clients, in a context where formal enforcement or reputation mechanisms do not exist (Fafchamps, 1996). Lyon (2000) finds that that trust between farmers and agricultural traders in Ghana, created through informal and pre-existing networks, enables individuals to access new markets and increase incomes. He emphasizes the importance of social relations for the success of microenterprises where formal contract enforcement mechanisms are absent. Farmers learn from the experiences of those with whom they are socially connected about new agricultural technologies; Conley & Udry (2010) discuss this in the context of pineapple production (Conley & Udry, 2010).

Kansanga (2017) has similarly observed the importance of social capital for access to mechanized technology in Ghana.

Social capital changes dynamically through time. It is created, modified, and sometimes destroyed; social capital evolves in response to shifts in population pressures as well as economic and technological factors. Platteau (2000) particularly emphasizes that technical and institutional change are inseparable and evolve together in the face of rising population and economic development. The existing social norms and institutions can be supportive of technical change by providing networks and reciprocity that protect agents from some of the associated risks of new technology adoption.

Some literature sees social capital as something embodied in individuals. Other scholars understand it through a more sociological perspective, with social capital understood as vested in a group or community (Berry, 1993; Fafchamps & Minten, 2001; Granovetter, 2005). The existing norms and relations in a community or society matter for how agents find solutions to the challenges of adopting new technology. Marx considered a traditional economy as one where individuals are socially differentiated as they come to market exchange, in contrast to a capitalist economy where there is increasing anonymity between actors (Jean-P. Platteau, 2000, Chapter 1). Furthermore, in the process of development, tasks that may have been carried out within the domain of the extended family, move into the market domain. The social norms associated with the task may or may not apply in this transition, often creating confusion of what norms apply in which domain. Technological change has the potential to both disrupt existing social relations, and create new purposes for existing social relations and norms (Fafchamps, 2017). The approach of this thesis echoes the argument of Granovetter that economic life is embedded in existing social structures. This treads a theoretical line between an over-socialized view where trust is a result of generalized morality, and an under-socialized view where trust is a result of individual rationality (Granovetter, 2005).

My thesis will add to this literature to provide further evidence of the role that social institutions play in collective action problems, and not just those problems associated with community assets. Even in a case where the asset is individually owned and the benefits of its use are accrued individually, social institutions are able to provide mechanisms for cooperation and access to technical resources which would otherwise be out of reach due to market failure.

### *e. Other related literature*

Although not directly addressed, the thesis implicitly links to debates regarding the relationship between farm size and productivity, and also the literature on technology adoption.

There is an extensive literature looking at the relationship between farm size and productivity (Jayne, Mather, & Mghenyi, 2010; Barrett, Bellemare, & Hou, 2010; Feder, 1985; Larson, 2012). Small farms, both within and across countries, are found to have higher yields than large-scale farms. The theoretical reasons proposed are the increasing costs for labour supervision with farm scale, stronger incentives for family labour on smaller farms, and lower labour costs for small owner-operated family farms. This debate is relevant when considering mechanization as the technology is associated with a step-change in labour productivity and optimal farm scale. Whilst this literature frequently focusses on yield, or land productivity, the variation in labour productivity across countries is more pronounced, as is the variation in land-labour ratios (Gollin, 2018; Restuccia, Yang, & Zhu, 2008).

Some work on the farm-size and productivity relationship has considered the role machinery plays. Foster & Rosenzweig (2017) open up this debate to consider a U-shaped relationship between farm size and productivity in India. They propose a theoretical relationship, consistent with empirical findings, where farms are more productive at the lower end of the farm size distribution. However, as scale increases, a positive relationship is found between farm size and productivity, driven by a fixed transaction cost for labour hiring and economies of scale associated with machine use and capacity. They argue that a positive correlation between productivity and scale implies that farm consolidation could increase agricultural output in India. In their study of Vietnam, Liu, Violette, & Barrett, (2016) find that the inverse relationship is weakened over time as labour and the machine rental market improved. In Nepal, the use of machinery through a tractor services market for custom-hiring increases the returns to scale for smallholder farmers (Takeshima, 2016). This evidence indicates that mechanization can disrupt the often-cited relationship between scale and productivity for smallholders.

Finally, the technology adoption decision of farmers, especially in developing countries, is the subject of a vast literature (for comprehensive reviews see: Jack, 2013; Loevinsohn, Sumberg, Diagne, & Whitfield, 2013; Stewart et al., 2015). Sumberg (2005) challenges researchers on technology adoption to correctly distinguish between exogenous factors which are prerequisites for a particular technology to be taken up by farmers in a particular location, versus those which are endogenous to the matching up of farmers and the new technology. The first paper of the thesis attempts to explore the relationship between some of these exogenous factors, and mechanization, in Ghana.

Such endogenous factors, such as dynamic market and social structures, may appear to be barriers to mechanization in Ghana. Many market failures in credit and land markets remain, and yet adoption of agricultural machinery has proven profitable for farmers by their enthusiastic adoption. Part of the answer to this may lie in considering the seasonal constraint on farmer's agricultural decisions. Moser & Barrett (2006) investigate the importance of seasonality in labour markets, and social context for learning in explaining the low adoption of apparently profitable rice intensification technologies in Madagascar. A dramatic increase in herbicide use globally has been partly attributed to decreasing labour availability and increasing wages, especially in SSA (Haggblade, Minten, Pray, Reardon, & Zilberman, 2017).

## III. Detailed summary of thesis papers

The thesis consists of three papers, each of which each considers a different research question related to the use of mechanized technology. The different questions call for a range of empirical methods. This section will introduce the research questions and methodological approach for each paper, and draw out the distinctive contributions and complementarities of the three papers.

As noted above, all three papers focus on cereal production in Ghana. The agro-ecological context and economic characteristics have been discussed above and will be further elaborated in each paper. As a consequence, the results are most likely to have external validity and relevance for similar Guinea savanna farming systems of West Africa. However, there are some parallels and limited lessons for other regions of the developing world. Other locations – in Africa and elsewhere – may share characteristics such that the Ghanaian example can provide some insights. For instance, agricultural machinery is widely used in some other farming systems of eastern and southern Africa where large-scale farming and plantations are a more common feature of the agricultural landscape (Hans Binswanger, 1986; Mrema, Baker, & Kahan, 2008). The Ghanaian context of mechanization perhaps has more similarities to the use of mechanized irrigation and small power tillers in South Asia, where the market and social capital have enabled some small-scale farmers to access machinery (Ashford & Biggs, 1992; Lewis, 1996).

As a consequence of focusing on Ghana as the empirical case, the analysis across all three papers is limited to considering the types of mechanization which have been introduced and taken up by farmers in Ghana. As will be shown in the first paper, machinery is being used for plowing across many areas. For the most part, this is done using 4-wheel tractors and a disc-plow attachment. In some areas, a maize-shelling attachment for tractors is being produced and sold locally (N. Houssou et al., 2013). A tractor with trailer is also used by some to transport produce and inputs from the homestead to farm plot. These other uses of mechanization are referred to, but the thesis is primarily concerned with mechanized plowing.

As discussed above, there are plenty of contexts with similarities to Ghana where animal traction has been preferred by farmers.  Equally there are a multitude of factors which have led to the emergence of plowing machinery as a dominant technology in Ghana, some of which are explored in this thesis, but some which will inevitably be only mentioned tangentially. Land tenure, the nature of non-agriculture sector development, patterns of seasonal migration, changing government policies, energy costs, rising education levels, animal disease, and farmer preferences are some of these factors which are not fully explored in this thesis. The pathways which are examined are agro-ecological conditions, population density, urban connectivity, social norms and networks, as well as the implications of machinery use for smallholder farmers in this specific context.

***Research question 1: To what extent can the patterns of agricultural mechanization be explained by changes in population, urbanization, and agro-ecological conditions?***

The first paper aims to revisit the work of Boserup, (1965) and Pingali et al., (1987) to investigate the relationship between long-term drivers of farming system change, and agricultural mechanization as a component of agricultural intensification. The paper extends these previous models to incorporate the effects of demand from urban areas, which can drive intensification in ways both similar and different to population increases in rural areas themselves. The paper focuses on sub-national variation within a single country, rather than the cross-country analysis of Binswanger & Ruttan (1978). The focus is on how these drivers affect the local farming systems and its technological transformation, rather than the individual adoption decisions of farmers.

Two sources of quantitative data are used. First, I use a cross-sectional survey of farmers in eight districts of Ghana, representing the main cereal-producing regions. This data was collected by the International Food Policy Research Institute and the Savanna Agricultural Research Institute in 2013. The data cover 1,843 farm households. Both the survey questionnaire and sampling strategy were designed to capture detailed information on agricultural machinery use. Second, I use geo-spatial data on population density, travel time to urban centres, and agro-ecological conditions, which derive from models produced by HarvestChoice, to characterize long-term trends for the locations represented in the household survey. The combination of these datasets are used to carry out regression estimation to capture the partial correlations between machinery use by farm households, and population density, urban proximity, and agro-ecological conditions. Controls for district and household characteristics are also included in the regression model.

This method of analysis is similar to that of Binswanger-Mkhize & Savastano (2017) who use the World Bank's LSMS-ISA survey first round to test whether exogenous drivers of agricultural intensification - agro-ecological potential and economic activity - can explain local population density and several measures of agricultural intensification. Their methodology for combining household survey data with geo-spatial datasets to examine the drivers of agricultural intensification is particularly relevant for this paper. The approach of my paper differs in focusing on a single country and on the particular relationship between these drivers of farming system change and agricultural machinery use.

There is limited household survey data which adequately covers machinery use. The Ghana Living Standards Survey, which is repeated over several rounds, includes information on tractor ownership as a category of assets, but it does not provide information on the use of machinery in agricultural production. Moreover, the population-based sampling structure of this survey tends to give limited coverage of large farms and hence tractor owners. Foster & Rosenzweig (2017) highlight this issue and the advantage of a sampling frame based on landholding size for the dataset they use for analysing machinery in agricultural productivity in India. There is little capture of machinery ownership or use in the World Bank's LSMS-ISA country datasets either, due to sampling and inadequate questions in the survey to fully capture the rental markets (Sheahan & Barrett, 2017). With no useful panel data to draw on, ny analysis therefore relies on geographical variation within a single cross-section.

The empirical results provide evidence of the patterns of adoption of tractor use. The lack of longitudinal data and the absence of any natural experiment prevents any conclusions on the causality of these empirical relationships. Furthermore, the analysis provides evidence on the net relationship between variables and machinery use but does not easily inform us about the multiple potential channels through which these relationships may emerge. For example, the relationship between urban proximity and machinery use has several underlying pathways– labour availability and cost, access to output markets, and more efficient markets. The data do not allow for clean identification of the separate effects. The approach also makes the assumption that the diffusion of skills and knowledge about agricultural mechanization technology is widespread and established, given the long history of machinery use in Ghana through state farms and national mechanization programs. Therefore, the methodological approach which is used allows the paper to understand how population, urban proximity, and agro-ecological conditions are related to the mechanization of local farming systems, in the cereal-producing areas of Ghana.

The main findings of the paper are that farmers' decision to use agricultural machinery is associated with lower population density and proximity to urban centres. In northern Ghana, the time-saving benefit of machinery and cheaper access to machinery through urban markets are especially important in understanding farmers' technology choice. Furthermore, the analysis shows that the drivers of adoption which are common to all farms and farmers in the locale are more important than individual household characteristics in explaining machinery use.

***Research question 2: Given the heterogeneity of conditions and farming systems, can we assume that mechanization will reduce the labour requirement for production? What is the impact of mechanization use on other farming decisions and productivity?***

The theoretical understanding is that machinery will increase labour productivity and similarly reduce labour use in agricultural production. Land productivity is ambiguously affected by machinery use, apart from the tendency for tractor use to increased area cultivated and to pull in land of lower potential, which will tend to pull down average yields. However, as is illuminated in the third paper, the reality of markets and institutions in rural SSA means that access to technology cannot be assumed to be reliable. This paper focuses on within-season decisions of farmers to see what effect using machinery has on subsequent farming decisions and final output.

The method to answer this question is a result of happenstance. In 2009-10, the Economic Growth Centre (Yale University) and Institute for Social Science and Economic Research (University of Ghana) conducted a detailed nationally-representative survey of households in Ghana, as the first of several rounds of a panel survey. This survey includes information on machinery use, as well as the use of other inputs, crop decisions, and harvest for households across all regions of Ghana. The Ministry of Food and Agriculture began a program to set up privately-run mechanization service centres, operating 5-7 tractors, in all districts of Ghana. The introduction of this program was phased from 2008 onwards. The combination of administrative data on the date of allocation and district location of the mechanization centres, and the household survey covering the 2009 main season allows for a pseudo-experiment. Treatment and control districts are determined by those which were allocated a mechanization centre before and after the plowing season for the 2009 main season. This positive supply shock is used to instrument for use of tractor plowing by farm households. Conditional on local population density, urban proximity, and agro-ecological conditions (established as drivers of mechanized farming systems in paper 1), the treatment and control groups are found to be balanced. Instrumental variable techniques are used to estimate the local average treatment effect of machinery use on outcome variables for farm decisions over crop choice, cultivated area, and input use, as well as land and labour productivity. Gender differences in labour use and plot management are analysed also.

As discussed above, the lack of panel or repeated cross-sectional household surveys which include data on agricultural mechanization use in Ghana makes it a challenge to find a clean identification strategy. The method employed in this paper is therefore limited in its scope, but does provide insights into the effects machinery use can have on farming decisions, aside from other correlated factors. The focus on within-season farmer decisions is valuable, especially given the findings of my third paper, which shows that timely access to tractor services is a challenge for many farmers. This paper bases its estimates on the changes experienced by those farmers who were previously excluded from access to machinery services, due to market inefficiencies such as transaction costs, but who were then able to make use of machinery services when the supply was boosted. To the extent that these farmers are typical of others who lack access to machine services, the results have some external validity; to the extent that these farmers are atypical, the relevance is limited. The methodological approach limits the analysis to a consideration of the short-term impacts of machinery use. The paper cannot make any conclusions about the longer-term effect on land investments, rural institutions, or household welfare of sustained mechanization of agricultural production. Finally, the approach is sensitive to weather shocks affecting production and output for the particular year.

Findings indicate that for marginal users of agricultural machinery, mechanized plowing does not reduce the labour used for land preparation, and in fact increases labour used for other operations. The area cultivated increases with proportionate increases in maize cultivation and an increased proportion of land controlled by women. One possible interpretation is that tractor plowing alleviates a timing constraint for farmers, which enables cultivation of more time-sensitive crops and increases the expected returns to subsequent production activities.

***Research question 3: What role do informal institutions and social capital play in facilitating, or hindering, access to more productive technologies by farmers of all scales?***

The final paper of the thesis focusses on the functioning of the machinery services market. Farmers, for the most part, access mechanization technology though a service market in which they pay a tractor owner or operator to plow their plot. Work done by Houssou et al. (2013) to analyse the profitability of tractor services provision (for tractor owners) found it to be worthwhile under specific conditions. Given the high synchronicity of demand for services, and distances between service providers and farmers, there are problems of coordinating service provision and potential for exploitative pricing. It is therefore somewhat of a puzzle to find the service market functioning, and farmers of all scales able to take advantage of it. The aim of this paper is to investigate the way in which the service market functions, and the role which existing social capital plays in improving the functioning of the market.

A mixed method approach was used to address this question. First, a single district was selected to serve as a case study. Across communities within a district, many things remain approximately constant over time, including population growth, connectivity to large urban markets, rural institutions for agricultural land and labour exchange, and agro-ecological conditions. This enabled the data collection to focus on capturing variation in farmers' use of (and access to) machinery services due to social capital and other household-level factors. The criteria for selecting the district were (i) to be in the Northern region where agricultural activity is dominated by cereal-production, (ii) to have high use of machinery with some variation within district, as recorded in existing household survey datasets, (iii) to be logistically accessible. Data collection began with focus group discussions with farmers and semi-structured interviews with farmers, tractor owners, village and district officials, from 21 villages in the selected district. The objective of this data collection was to get information on (i) agricultural production practices and technology use, (ii) informal institutions and their evolution over time, (iii) perceived impacts of machinery use on agricultural, household, and community life, (iv) and the organisation of tractor services by owners and operators including price-setting and ordering service provision. Next, I carried out a small-scale survey of 250 households across 5 villages in order to gather data which would enable statistical analysis of the emerging relationships from the qualitative interviews. Villages were purposively selected from those which were covered by the qualitative data collection. The goal was to capture a range of village sizes, based on 2010 district census information. Households were selected using a random walk sampling approach which is described in the paper. The Appendices I-IV include the interview guide and survey instrument used for data collection.

This paper's use of mixed methods included a quantitative survey that was specifically designed to explore a hypothesis resulting from prior qualitative data collection (Greene, Caracelli, & Graham, 1989). Analysis of the different data types is separate, although both inform the theoretical framework (Plano Clark & Creswell, 2008). The micro-level approach to researching the tractor service market is similar to that of Mueller, Prescott, & Sumner (2002) who studied only a few locations in order to get a deeper analysis of the tractor rental market in India. Social capital is difficult to measure, and reducing it to quantitative metrics lacks the nuance and richness that qualitative approaches allow. This is why a phased approach to data collection was adopted, to paint a rich and detailed picture of the social norms and networks underlying the tractor service market. The quantitative analysis was used to establish that the existing social connections between farmers and service providers are important, but the qualitative data is used to give colour and detail to the way in which these social connections intersect with the market.

Both the quantitative and qualitative data collection involved primary field work, with the ethical considerations that such research requires. Appendices I-IV provide details of the data collection methods. For each method, a similar approach to consent was taken. Literacy rates among participants were low, and in addition a variety of local languages were spoken.

An oral consent script was provided to the translators and research assistants who worked together, in advance, to agree a reasonable translation of the script. Upon contact with the participants, an explanation of the research project was provided and oral consent was garnered. For the qualitative interviews and focus group discussions, audio recordings were made with the consent of participants. Furthermore, I worked with research assistants who were from the local area and could assist in thoughtfully considering the cultural norms in our introduction to each village. For each village, we consulted the senior members of the village, as appropriate, before conducting research in the area. I was also careful to set the expectations with participants and local leaders that the collected data was for purely academic purposes and would not be used to guide financial assistance or future programs from which the participants would benefit.

The drawbacks of this methodological approach is that its analysis does not directly compare with other, strictly quantitative, investigations of social capital in the economic literature. However, the approach has enabled a fuller appreciation for the ways in which the organisation of tractor services provision in a time-limited market interacts with the existing social structure and institutions in rural communities of Ghana. This is an important contribution, as more quantitative approaches are often concerned with explaining the farmer's technology adoption decisions, without considering the social context.

The analysis points to the crucial role that the existing social structures play in overcoming and minimizing the costs associated with this market. Farmers coordinate service requests through existing farming groups and call upon service providers within their kin networks. The strength of existing relationships and the strong social norms of cooperation in farming appear to facilitate these cooperative solutions, without any formal role of state planning or organisations such as official farmer groups or cooperatives. Furthermore, there is evidence to suggest that women are not disadvantaged in their access to tractor services compared to men.

Whilst each of these papers is distinctive in its research question and methodological approach, the above discussion highlights how the papers complement one another. To some extent, the framing of the research questions and methodological approaches rely on those of the other papers. However, each is written to stand alone. As a consequence there may be some repetition in the context and background provided for each paper.

The next three chapters of the thesis present the papers individually. The final concluding chapter will draw together the themes which run through all the papers and thereby synthesize the contributions of the thesis as a whole. These themes include debates over the inverse farm size- productivity relationship, the role of adaptive institutions in agriculture, the importance of timing as a motivation for mechanization (and the associated implications for increasing climate volatility), and the interaction of gender and technology in agriculture. I also use this opportunity to reflect upon the overall doctoral project, and further work which could improve the evidence base for the thesis findings. The contribution of my findings to the growing policy narratives regarding agricultural mechanization in Africa will also be discussed.

# Paper 1: Population density, urbanization, and agricultural mechanization in modern Ghana[14]

Abstract:

Farmers' technological choices take place within farming systems which are shaped by population pressure, connectivity to urban markets, and agro-ecological conditions. The relationship between these drivers and agricultural technology use is ambiguous. On the one hand, population growth can increase the supply of labour, driving down wage rates and reducing the incentives for mechanization. On the other hand, rural-urban movements of people can reduce rural labour supplies while simultaneously driving up the demand for food and hence the demand for mechanization. Past theories of agricultural mechanization have explained the low adoption of agricultural machinery in land-abundant cereal production systems of SSA in terms of these drivers. However, recent empirical observations find extensive adoption of mechanized plowing technology by small, medium, and large scale farmers in Ghana. Examining the Ghanaian experience can thus shed new light on theories of mechanization. A large household survey dataset covering eight districts is combined with geo-spatial data on population, urban proximity, and agro-ecological factors to consider whether the existing theories are able to explain farm-level adoption decisions in this context. The analysis finds that a farmer's decision to use agricultural machinery is associated with lower population density and proximity to urban centres. In northern Ghana, these drivers of technological change are as important as farm household characteristics in understanding cross-sectional patterns of machinery adoption.

[14] A previous version of this paper has been published as an IFPRI Discussion Paper:

Cossar, Frances. 2016. "Boserupian pressure and agricultural mechanization in modern Ghana". *IFPRI Discussion Paper* 1528. Washington, D.C.: International Food Policy Research Institute (IFPRI). http://ebrary.ifpri.org/cdm/ref/collection/p15738coll2/id/130312

## I. Introduction

The mechanization of agricultural operations in Sub Saharan Africa has been low, especially among smallholder farmers, who dominate agricultural production (Mrema et al., 2008). There is also evidence of unutilized arable land in many areas of SSA where poor infrastructure and low productivity are limiting the returns to cultivation (Jayne, Chamberlin, & Headey, 2014; Wiggins, 2014). Machinery use has the potential to improve labour productivity, especially as urbanization and structural transformation increase demand for labour outside agriculture whilst increasing food demand from net consumers (The World Bank, 2015). In Ghana and parts of west Africa, farming systems have mechanized in recent decades (Diao et al., 2014; Takeshima, 2015). Even within Ghana where there is greater homogeneity in farming systems and institutions than there is across countries, the take-up of mechanized technologies has been localized, although it reaches across areas with different levels of agricultural potential (Chapoto, Houssou, Mabiso, & Cossar, 2014). Government efforts to promote mechanization nationwide have also had mixed success (Benin, 2015a). The question arises of how the variation of machinery use within Ghana can be explained by the external factors which are common to proximate farm-households.

This question was explored by a body of literature which emerged in the 1980s on the evolution of tropical farming systems, with roots in the work of Boserup (H. P. Binswanger & McIntire, 1987; H. P. Binswanger & Ruttan, 1978; Boserup, 1965; Pingali, 2007; Pingali et al., 1987; Ruthenberg, 1980). Boserup (1965) was among the first to develop a theory of agrarian change which posits population change as the primary driver of technology change, through the pressures exerted on land and labour use. Her central argument was that farming practices, frequency of cultivation, and technology evolve in response to the increasing food demand and increasing competition over land which arises from rising local population. However, her theoretical derivations resulted from empirical observation of closed economies where movement of people and goods was less prevalent. McIntire & Binswanger (1987) further elaborated this theoretical strand to look at the relationship between population, migration, and trade on a range of institutions and production relations which support agricultural production. A second theoretical strand was the induced innovation hypothesis which attempted to formalize the relationship between population and other drivers to changes in relative prices of land, labour, and capital, which in turn affects the types of technology which is developed and adopted.

This paper draws upon these theoretical strands in considering the reasons for within country variation in machinery use. There is a departure from Boserup's work as the theoretical framework explicitly incorporates the effect of urban centres on market efficiency and the labour market. McIntire & Binswanger's work has a broader ambition than this paper. Its focus is on mechanized plowing in particular, and restricts variation in the external drivers to that which varies within country, namely Ghana. Finally, the paper does not follow the formal theory of Binswanger & Ruttan in representing changes in relative availability of production factors as changes to relative factor and output prices.

What this theoretical literature and this paper have in common is proposing that agro-ecological conditions, population density, and market demand are the fundamental drivers of agricultural intensification. Intensification in this context is the more intensive farming of land through the reduction of fallow periods, an increased cropping frequency and the use of fertilizer and other chemical inputs. Two of the three drivers – population density and market demand – are related closely to urbanization. Urbanization presents opportunities and challenges for farming systems. Urban growth implies that labour is pulled into non-agriculture sectors whilst demand for agricultural products increases. Furthermore, mechanization technology may rely upon urban centres for auxiliary services and skills more than other modern agricultural technologies such as fertilizers.

The approach of this paper will be to consider the relationship between the long-term drivers which shape farming systems and the adoption of mechanized technology by farmers within those farming systems. Ghana presents a particularly interesting case to explore these relationships. Farmers of small and medium scale have mechanized plowing in certain areas since the 1980s. Moreover, it is not only a handful of farmers who have adopted the more advanced technology; on the contrary, the majority of farmers in some locations are using agricultural machinery, either through ownership or through a service rental market. This variation in adoption across the country enables some investigation into the extent to which the variation can be explained by external drivers of farming system change, in a context where there is similarity in institutions, capacity for technology adaptation, and limited variation in agro-ecological conditions.

This study draws on a unique survey dataset of 1,843 farmers across 8 districts of Ghana, undertaken by the International Food Policy Research Institute, in collaboration with the Savanna Agricultural Research Institute in 2013. This farmer level dataset will be combined with geo-spatial data on population density, urban proximity, and agro-ecological conditions. Partial correlations, derived from regression analysis, are then used to investigate the theoretical relationships elaborated. Methodologically, this paper follows the approach of Binswanger-Mkhize and Savastano (2014) to combine household surveys with geo-spatial data in order to investigate the relationship between factors exogenous to the farming system and indicators of agricultural intensification.

Whilst population density is found to be important, of note is that farmers with better access to urban centres are more likely to be using machinery. Where Boserup imagined rural communities as existing in autarky, such that rural population density was the key driver of agricultural demand, the modern reality is that the demand for agriculture is closely related to urban markets and connectivity. As the literature on urbanization and its links to agricultural development evolves, the findings of this paper highlight the role mechanized technology plays in both facilitating and benefitting from increased urbanization. Any policy to promote mechanization will need to be considered in the context of investments in both urban and rural sectors to ensure the technological shifts are keeping pace with labour demands (Tiffen, 2003). Another surprising result is that areas which may be considered of lower agricultural potential due to short growing seasons and volatile rainfall patterns, are potentially more likely to adopt time-saving technology such as tractor plowing. As such, machinery adoption may not represent a further form of intensification in areas that have already made investments in other inputs; on the contrary, it may be more important in transforming low-potential areas into high-potential areas by altering the effective length of the growing season. This also means that the technology may have its biggest impacts in poor agricultural areas, rather than on highly profitable commercial farms in favourable areas.

The paper is structured as follows. Section II will elaborate a theoretical framework which draws upon existing literature and develops these arguments regarding the adoption of mechanized technology specifically. Section III describes the data and empirical methods. Descriptive statistics and regression results are presented in sections IV and V respectively. Section VI discusses these results and their implications for policy and research of agricultural technology adoption.

## II. Theoretical framework

Several theories have been posited by authors such as Boserup, Binswanger, and Ruttan to explain the exogenous drivers of agricultural mechanization. At points, these theoretical perspectives are aligned, at other points they differ. In particular, rising population density may lead to increased demand for food production, intensification, and machinery use (e.g. Boserup). On the other hand, rising population density may lower the cost of agricultural labour, making machinery use expensive and unnecessary for many smallholder farmers (e.g. Binswanger & Ruttan). This section presents and discusses a range of theoretical understandings of the relationship between several drivers of agricultural change – namely, population density, agro-ecological conditions, and urban proximity. A theoretical framework is developed which discusses the influence these drivers could have on the availability of production inputs and therefore the returns to agricultural mechanization.

The theoretical framework specifically focusses on drivers common to all farm-households in the locale, rather than individual household characteristics, in order to explain locational differences in mechanization. For machinery use, there are considerable local spillovers. If a farmer is using machinery services, the probability that a neighbouring farmer uses mechanized plowing is much higher. Once these drivers induce a substantial number of farmers in a village to choose mechanized technology, it is likely that the supply of machinery services will respond. This paper is concerned with how these external factors differ across villages, leading to differing levels of demand for machinery. Individual household characteristics will be considered in order to demonstrate that differences between households alone cannot adequately explain differences between the mechanization of local farming systems.

Farming systems are complex, with farm households responding to both external factors and internal incentives in order to maximize household income and leisure opportunities given the specific resource endowments of physical, human, and social capital. Whilst internal incentives will vary by household, the external factors are by and large common to all households within a local farming system. Ruthenberg (1980) identifies these external factors as (i) the state of knowledge and information about agricultural techniques that exists within the country; (ii) the institutional environment that governs land tenure, farm size distribution, labour laws, credit and extension services; (iii) the natural environmental conditions that will constrain the crops which can be grown and their means of production; (iv) the relative prices of inputs and outputs; and (v) the extent to which household food demand is met by subsistence or from engaging in market exchange. In loosely following this framework, I will argue that (iii), (iv), and (v) are powerful in explaining not only locational variation in crop production but in the choice of technology by farmers. As will be discussed, the focus is on within country variation, therefore I consider (i) and (ii) to be homogenous across villages.

The framework assumes that farmers are choosing between two agricultural technologies or production techniques. Each technology requires a different combination of land and labour. Manual technology uses traditional techniques and requires more labour, relative to land. Mechanized technology involves the use of tractors for land preparation. It may also include the use of machinery for post-harvest threshing or shelling, and for transport. In some contexts (but not in northern Ghana) mechanized technology can also extend to planting, harvesting, fertilizer application, or weeding; those operations are not considered here. Mechanized production of the kind considered here requires less labour per unit of land; capital substitutes for labour. This is especially true of land preparation. Power-intensive operations, such as land preparation, are typically the first to become mechanized in a farming system (Pingali, 2007). More control-intensive operations such as planting and harvesting are mechanized at later stages of development, when the cost of labour is high. Farmers' choice of technology will be simultaneous with the crop choice. However, the model is restricted to considering cereal farming systems for which mechanized production is possible.

The theoretical drivers of farming system evolution and mechanization are discussed in the following sub-sections, along with expectations of the possible direction of relationships which will be explored in the empirical regression analyses which follow.

### *a. Population density*

A major strand of the literature on agricultural intensification points to population pressure as the key exogenous driver of changes in farming systems and the technology used in cultivation. The theory is that population density drives patterns of intensification by shifting the relative prices of land and labour (on the supply side) and by affecting the output prices of agricultural goods (on the demand side). These relative prices are thought to affect the pathways of technology take-up and use, including mechanization. Boserup (1965) argued that farming system evolution and technology adoption are endogenous processes in which population growth is the main determinant, given agro-ecological conditions. The evolution of farming systems involves a process of land intensification whereby land is more frequently cultivated, yield-enhancing techniques are adopted, and more land is brought into regular cultivation. To enable intensification, new technologies are developed and adopted such as higher levels of input use – including labour and fertilizer, and incorporating non-human sources of power – whether animal traction or machinery. She argued that mechanization, which enabled progression from fallow systems to annual cultivation, would be adopted where there is growing demand for food, either because of population growth or because of growth in the non-agriculture sector. Pingali et al. (1987) find a positive correlation between the intensification of farming systems, as described by Boserup (1965), and the mechanization of agricultural production. Combined with their empirical observations of the time, they conclude that the demand drivers required for agricultural intensification – population growth or non-agriculture sector growth – will need to be in place for African farmers to adopt agricultural machinery.

The induced innovation hypothesis simplifies these theories to consider the relative prices and elasticities as the conduits for trends in demographics, markets, and agro-ecological conditions to impact farmers' incentives to mechanize production. Farmer demand for labour or land intensive technology is driven by the relative prices of land, labour, capital, and output, which incentivizes public or private research institutions to innovate and adapt their production of new technologies in response to farmer needs (Binswanger & Ruttan 1978). The Hicks-Ahmad model takes a similar approach whilst keeping the process of technology development exogenous[15]. Where agricultural labour is relatively scarce, the agricultural labour wage will be high relative to the cost of agricultural land. In this case, farmers will be looking for technologies which will reduce the labour-intensity of production, in order to reduce overall costs per unit of output. Mechanical technology that is labour-saving will be demanded by farmers and lead to increased land area per worker. If the opposite were true and land was relatively scarce, we would expect land-saving technologies such as chemical and biological technologies to be sought by farmers, which increase output per acre.

It is this land-labour ratio, or population density, which is taken to be first key driver of machinery use. Differences in population growth and migration across locations will lead to different levels of population density. Three aspects to the relationship between machinery use and population density are elaborated here.

[15] In this model, a set of isoquants represent the innovation possibility curve (IPC) which captures all the available technologies which use a range of proportions of capital and labour. In this sense the rate of technological change is not endogenous to the model. An exogenous change in the available technology, equivalent to a shift in the IPC, can be factor-neutral, or biased towards labour or capital use. The relative price of labour and capital determines which technology is harnessed by a firm (or farmer). Changes in the relative price will lead to selection of a different technology which is cost minimizing in its use of labour and capital. If the number of available technology choices is fixed, then the effect of changes in the land-labour ratio will look more step-wise and non-linear. (H. P. Binswanger & Ruttan, 1978, pp. 26–29).

Firstly, high population density could potentially increase supply for the agricultural labour market. Agricultural labour supply will depend on the local population demographics, the extent of inward migration, and demand for labour from other sectors. Where the agricultural labour supply is determined mainly by the local population, we might expect that high population density lowers the agricultural wage which will discourage farmers from adopting labour-saving machinery. In this case, we would find a negative relationship between population density and machinery use. However, if there is costless movement of labour, we would find this link weakened. With costless labour movement, labour wages should equalize across locations. However, rarely is labour movement costless, and the seasonality of agricultural labour demand creates excess demand or supply at different moments within the season. Non-agricultural labour demand also varies across locations. For example, there may be an area with high population density but with high demand for labour to work in the mining sector. We would then find high population density but possibly high machinery use if labour is being pulled away from agriculture and labour wages are rising.

Issues of labour mobility may be empirically important for the analysis in this paper. There is considerable seasonal and permanent migration of labour migration in Ghana from the rural north. Workers migrate both to cocoa-growing rural areas of the south and to urban centres such as Kumasi and Accra (Kolavalli et al., 2012; Otiso & Owusu, 2008). As there is demand from other economic sectors for rural labour and some movement of labour, local population density may not be as powerful a driver of mechanization on farms as it might be in other contexts. However, the stickiness of labour movement and seasonality of demand will still lead to seasonal and locational differences in agricultural wages and costs for farmers. Through the labour market, we would expect high population density to be associated with cheaper agricultural labour, and therefore low adoption of machinery, especially where movement of labour is costly, e.g. remote areas.

A second link between population density and machinery use is through the availability and distribution of farm land. Areas with high population density will be more land constrained, and the shadow price of land will be higher than sparsely populated areas. Where the price of land relative to machinery is high, farmers will prefer to adopt land-saving technologies such as fertilizers and improved seeds. Where this relationship will be weakened is when the institutions governing land allocation are such that access to land is restricted, even if the population density is relatively low. In the case of Ghana, land is allocated through a traditional tenure system in which land was allocated to families in previous generations and has been subsequently divided and passed down by inheritance (Ghebru, Khan, & Lambrecht, 2016; Lambrecht & Asare, 2016). In some areas, farmers will be restricted to using only their family land; in other areas, there may still be unallocated land which farmers are able to access easily and at low cost. In urban and peri-urban areas, competition over land for non-agricultural uses will exacerbate an agricultural land constraint. Overall, areas with higher population density will have a higher cost of land which reduces the ability of farmers to harness the economies of scale associated with mechanized plowing.

Finally, high population density can also increase the demand for food, driving up output prices and motivating farmers to increase production. However, better market integration between villages and with urban centres can weaken this link between local population density and food demand. Thus, the demand-side relationship between population density and technology adoption is likely to be strongest in those communities that are least well connected to markets.

### b. Urban proximity

Beyond purely higher population density, urban centres provide additional economic benefits which may lead to higher mechanization use for households that are geographically proximate to them. Isolation presents additional pressures on the farm-household system, beyond the simple price and availability of production factors. The transport costs between farmer and urban centres creates a price differential for labour, output, and other input prices. Furthermore, the volume of industrial economic activity associated with urban centres creates agglomeration effects which may reduce the cost of machinery ownership and maintenance. As discussed above, the extent to which local farmers are well connected to urban labour and output markets will also affect the strength of the relationship between population density and machinery adoption. Areas which are well connected to urban centres will not be restricted to the local population for agricultural labour supply, but migrant workers will more easily and cheaply be able to provide additional labour supply at peak times. Where there is low population density but close proximity to a major town, there may be a less binding labour constraint.

A major component of the transaction costs associated with market integration is the quality of the physical infrastructure between the farm and urban centre (Renkow, Hallstrom, & Karanja, 2004; Stifel & Minten, 2008). Therefore the distance of the farm to the nearest urban market will capture the extent to which farmers are able to benefit from increased urban demand for agricultural output. These transaction costs create a differential in the farm gate price for agriculture products between proximate and remote farmers. The incentive for farmers to increase production that comes from higher product prices and more elastic demand in urban centres will be less for more remote farmers. Moreover, the types of agricultural products which are demanded from urban consumers may differ to that of rural households. If markets are well integrated, farmers at all locations will be responding to the same demand curves. If not, then we may find rural farmers facing an inelastic demand curve limiting their production to own consumption or sale in the local market, while farmers closer to the urban centres face an elastic demand for agricultural products and produce crops demanded by urban consumers. Therefore, farmers may focus more on staple and storable food crops and less on perishable cash crops as they move farther from market centres (Fafchamps & Shilpi, 2003; Katzman, 1974; Stifel & Minten, 2008). The more elastic demand from urban areas will give farmers an incentive to increase production, potentially through the use of agricultural machinery where land is relatively cheap.

Furthermore, labour wages in urban areas may be higher than rural areas (Fields, 1975). Increased labour supply due to population density puts downward pressure on the labour wage, but higher labour productivity and increased demand for labour from urban-industrial sectors can lead to higher labour wages in the agriculture sector (Byerlee, 1974; de Brauw, Mueller, & Lee, 2014). As has been noted, agricultural labour wages are higher in the more urbanized (and more densely populated) south and east of Ghana than in the sparsely populated but less urbanized north (Ngeleza et al., 2011). Therefore, for urban areas with labour demand from non-agriculture sectors, we may see farmers located closer to the urban centre to be more likely to mechanize as the technology enables increased scale of production without the proportional increase in labour use. However, a concentration of casual urban labour may improve the supply of seasonal labour for agriculture in areas proximate to urban centres (Katzman, 1974). This would create an offsetting force.

Other characteristics of urban areas may also afford particular benefits for mechanization. Education and skills to harness new technology also usually flow through urban areas (Theodore W. Schultz, 1980; Stifel & Minten, 2008). Farms located in the 'hinterland' around growing urban centres benefit from lower transaction costs and increased availability of capital despite the increased pressure on land (Masters et al., 2013). Machinery is closely linked to the industrial sector for inputs and skills, whilst it is applied to the agricultural sector. The lower transaction costs associated with sourcing spare parts, securing mechanic services, and recruiting qualified tractor operators will reduce the cost of machinery ownership and lower the price of machinery services in urban and peri-urban areas.

For all these effects, we may expect to find a positive relationship between farmers' proximity to an urban centre and the use of agricultural machinery, all else equal. This is driven by higher agricultural wages in urban and peri-urban areas, and lower costs of machinery ownership and maintenance. The only caveat is that the effect of urban proximity on the labour supply depends on the nature of economic activity in the urban centre and the extent to which alternative sectors use labour at the times of seasonal demand from the agriculture sector.

### c. *Agro-ecological conditions*

Third and possibly most obvious determinant of the type of farming system is the local agro-ecological conditions. Climate, soil, and altitude are key in determining both the crops which can be cultivated, and the types of technology which can be used efficiently for cultivation in a particular location. These are factors will vary by location, rather than over time. Not all agricultural technologies can be applied for all crops, even for production systems at the technological frontier. Furthermore, these agro-ecological conditions will affect the returns to agricultural technology use for cultivation of a particular crop. For example, in areas with rich soils for maize cultivation, the returns to fertilizer use will be much lower than areas in which soil nutrients have been depleted.

In the context of the Guinea savanna area of northern Ghana, the agroecology shares characteristics with tropical savanna areas across West Africa. According to Ngeleza, Owusua and Jimah (2011), the agro-ecological conditions of northern Ghana result in farming systems which support cultivation of cereal crops - maize, sorghum, millet, soybean, cassava, yam, cocoyam, and other mixed cropping systems. A range of cropping patterns are observed across the region but cereal cultivation dominates. In contrast, the forest zone of south-western Ghana supports cocoa farming which is a permanent crop i.e. it does not require annual land preparation. Given the technology available in Ghana, cocoa production is unable to be mechanized. By contrast, in the cereal-producing savannah, mechanized plowing is feasible with existing technologies (Chapoto et al., 2014; N. Houssou et al., 2013).

In addition to the agro-ecology supporting farming systems for which mechanization is technically feasible, these conditions also affect the returns to machinery use. The particular challenges of tropical environments, compared to temperate, are the difficulty of retaining soil moisture and the high variability of rainfall (Ruthenberg, 1980). Weed regrowth between growing seasons is considerable in the tropics and a major reason for lower than potential yields. At the start of the season, farmers are presented with dry and hard soil, with extensive weed coverage. The first rains are unpredictable, short, and heavy. The manual work to prepare this land for planting each year is considerable, but it must be done quickly to take advantage of the variable rainfall patterns. This is particularly true for farmers who wish to cultivate maize, a crop that fetches a high price in urban markets and is highly profitable – but which must be planted early to produce a crop successfully within this agro-ecology (Food and Agriculture Organization, 2017; Kolavalli et al., 2012). Machines are able to work faster and can turn the soil at times when it is too hard to be cultivated with hand tools or animal-drawn plows. In this way, machinery allows for a highly profitable shift in cropping patterns in locations in northern Ghana with high rainfall variability and few total days of rainfall over the season. In this context, tractors can lead to timely cultivation, better plowing-in of weeds, deeper plowing and more effective use of fertilizers (Ruthenberg, 1980, pp. 105–106). Within the Guinea savanna of northern Ghana, we expect to find the length of the rainfall period to be important in explaining variation in machinery use.

### *d. Other considerations*

There are several household characteristics such as income, wealth, education, household size, which we can easily imagine will be affected by the aforementioned drivers and in turn, affect the probability of a household adopting mechanization technologies. For example, higher population density is associated with urban areas, where household are more likely to have access to education and non-agriculture employment opportunities. The additional skills and income from such opportunities will likely increase the ease with which households can afford to use machinery. A shorter growing period will lead to lower economic development over the long term, as well as a short time window for land preparation. This effect on economic development will lead to lower household wealth, and again fewer education and employment opportunities, all of which lessen the probability of machinery use. Competition between agricultural and urban land use close to urban centres will lead to smaller farm sizes, and may reduce machinery use. Empirically, the key determinants and their association with machinery use will be considered with and without controls for these household characteristics which have been captured by the survey data.

The preceding theoretical framework relies upon mechanized technology actually being available to farmers through the market or public provision. It also depends upon the necessary knowledge and awareness of the technology being available to actors in the aggregate local farming system. In Ghana, mechanized plowing was introduced through state-led agricultural programs as early as the 1970s. Several subsequent rounds of mechanization programs have continued to strengthen awareness. Furthermore, public interventions and private investment have boosted the availability of machinery for plowing across the country. This makes it reasonable to analyze the diffusion of the technology as dependent on external factors rather than on changes in knowledge and awareness of the specific technology due to specific localized interventions.

Another concern for the empirical approach used here would arise if the plowing technology is inappropriate in some areas. Acemoglu (2002) makes the argument that imported technologies in developing countries are often developed in response to the factor-bias in developed countries. The types of mechanized technologies which are available in Ghana are somewhat constrained by the limited domestic capacity for research and development, or for adaptation. This leaves farmers with a stark choice between an imported mechanical technology and the traditional manual techniques. However the widespread adoption of the mechanized plowing technology indicates that the specific technology is feasible and beneficial to farmers, evidenced by their voluntary adoption. Whether it is the most appropriate or efficient technology (from amongst the global technology set) for Ghana's farming systems is a bigger question, and beyond the scope of this paper.

Institutions are an additional component which will affect access and returns to mechanized technology. For example, the local land institutions which determine land distribution, credit institutions which can facilitate investment in mechanized equipment, and knowledge services such as public extension services which inform farmers on the use of mechanized technologies. Some scholars have argued that land and credit institutions evolve with population and economic growth (Gyasi, 1994; J.-P. Platteau, 1996). Others have considered technical and institutional change to be endogenous to the economic system – i.e. public and private suppliers of knowledge are components of economic system (H. P. Binswanger & Ruttan, 1978). Land institutions in Ghana are complex and have been found to vary across the country, and to evolve with changing demands from agriculture (Ghebru et al., 2016; Goldstein & Udry, 2008; Lambrecht & Asare, 2016; Quisumbing, Payongayong, Aidoo, & Otsuka, 2001) Gyasi (1994). For this paper, local institutions and their role in the spread and adoption of mechanization will not be considered directly. Lack of data on such measures of institutional quality at the village level make it difficult to be incorporated in the empirical model. The third paper of this thesis explores some aspects of market and informal institutions in the supply of tractor services.

## III. Empirical approach

### *a. Data*

In order to better understand the use of agricultural machinery in Ghanaian agriculture, the International Food Policy Research Institute, in partnership with the Savannah Agricultural Research Institute, carried out a survey of 1,843 farm households in eight districts of Ghana during October-December 2013 (IFPRI & SARI, 2016). The advantage of this dataset is that the sampling strategy and survey questionnaire allow us to understand the behavior of tractor users. The concurrent listing exercise provided a near-census of tractor owners in each district. The sample structure of most household surveys in Ghana (and other sub-Saharan countries with low mechanization in agriculture) is such that these surveys tend to capture few machinery users. The surveys typically also ask questions about the ownership of agricultural equipment, as a form of asset holding, rather than asking detailed questions about the use of this machinery.

The IFPRI data describe an agricultural context in which mechanization of agriculture is not reserved for a few large-scale commercial farmers but is instead accessed by many small and medium scale farmers through an active market for machinery plowing services (Diao et al., 2014). Furthermore, the survey confirmed that machinery use is not uniform across the savannah areas of Ghana, but varies by location. The analysis in this paper will consider this variation in machinery use, drawing on this single cross-sectional dataset of eight districts.

The two-stage stratified sampling strategy began with purposively selecting eight districts in the cereal-producing areas of Ghana where mechanization use is feasible (see Figure 2). Districts with a range of population density and urbanization rates were chosen. The second sample stratification was by farm size (small 0-5 ha; medium 5-20 ha; large >20 ha). Within each district, medium and large scale farmers were randomly selected from a listing exercise. Small-scale farmers (less than 5 hectares cultivated) were selected using the sampling frame of the Ghana Agricultural Production Survey. This involved randomly selecting 5-9 enumeration areas per district[16], and then 8-11 households from each enumeration area were sampled. Full details of the survey and sampling strategy are in Chapoto *et al.* (2014). The household questionnaire contained detailed questions on household characteristics, land holdings, crop production, mechanization, and employment. It is variables constructed from these survey modules which will be used to control for household characteristics.

The household survey data is combined with geo-spatial datasets, made available through HarvestChoice[17]. GPS coordinates were not recorded at household level during the survey data collection; however, GPS information on the enumeration area (or village) in which the household was situated has been adequate to match the geo-spatial datasets at the level of

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[16] Districts are split into approximately 50 enumeration areas.

[17] https://harvestchoice.org/products/data, accessed 18/01/2018

enumeration area[18]. Matching of geo-spatial data to the survey data was done using ArcGIS and data from the Ghana Statistical Service on the enumeration areas that were used for the Ghana Agricultural Production Survey (the sampling frame for the IFPRI/SARI survey). The resolution of the GIS datasets is approximately $10km^2$ (or 5-arc minute grid cells). As such, the value of each driver variable for the enumeration area is taken as that of the grid cell closest to the enumeration area, or the median value of the all grid cells which intersect with the enumeration area if more than one grid cell intersected. Through this, measures of agro-ecology, population density, and urban proximity were matched at the level of village (or enumeration area) to individual household observations. In total, 1,606 households from 205 enumeration areas were successfully matched through this process. Some household observations are dropped from the analysis, as there is no clear match with an enumeration area. No systematic bias was found in the key variables between the matched and un-matched households.

Village (or enumeration area) level population density is represented by a geo-spatial dataset on population distribution, which was constructed from LandScan 2012 at $10km^2$ grid cell resolution (HarvestChoice, 2015b). This dataset estimates the average population of each grid cell over a 24-hour period, calibrated to the national census data at district level. Census population data are combined with data on land cover, roads, slope, urban areas, and village

[18] Enumeration areas are determined by the Ghana Statistical Service for census and national survey purposes. Most enumeration areas in the surveyed district had estimated population of 500-800 persons.

locations to spatially model the population distribution at a finer resolution[19]. This data is used to capture the land-labour ratio at the local level (Figure A 2). The rate of population growth (as opposed to population levels) is also important for the analysis. The specific relationship between the rate of growth and mechanization use is not theorized, but the rate of district population growth over 1984-2000 and 2000-2010 is included as a control variable. These data are taken directly from the Ghana Population and Housing Census (Ghana Statistical Service, 2013). The quality of institutions, both formal and informal, will likely be affected by the speed of population growth particularly for land (Boserup, 1965; J.-P. Platteau, 1996).

Urban proximity is measured using the estimated median travel time to the nearest settlement of 50,000 people (HarvestChoice, 2015c). Each household is assigned the median travel time for the enumeration area, based on the geo-spatial dataset from HarvestChoice (10km$^2$ resolution). The travel time dataset is derived from a cost-distance model which uses information on the location of settlements and their corresponding population estimates; road networks, elevation, slope, land cover types (HarvestChoice & International Food Policy Research Institute (IFPRI), 2016). The model takes the least-cost path from the 1km pixel to the nearest urban centre as an estimate of the travel time, which is the aggregated for the 10km$^2$ grid cell value. The measure is a useful index for comparing travel times on a large scale, and it should not be taken as an accurate absolute measure of travel time. As Figure A

[19] For more details: Bright, E. A. and Rose, A. N. (2012) "LandScan Global Population Database 2012", Oak Ridge National Laboratory, July 2013. Retrieved from http://web.ornl.gov/sci/landscan/.

3 shows, there is considerable variation among enumeration areas in the travel time required to reach a settlement of 50,000 people or more. Travel time can be considered as a proxy for the transportation cost and associated price differential of inputs and outputs between rural and urban centres. A squared term for travel time is also included in the regression to reflect the non-linear relationship between urban proximity and the travel time to urban centres. The differential effect of urban proximity between the farmer located 30mins from the urban centre and 1.5 hours from the urban centre is likely to be greater than the differential between farmers 10 or 11 hours from an urban centre.

Variation in agro-ecological conditions will be captured using data on the length of the growing period. The data on length of growing period was derived from the IIASA and FAO dataset from 2010, provided by HarvestChoice (HarvestChoice, 2015a). The measure used for the length of growing period gives the total number of days in the year when the temperature is above 5 degrees Celsius and soil moisture conditions are adequate to support crop growth (IIASA/FAO, 2012). Soil moisture is considered as a combination of both daily rainfall and holding capacity of the soil, with reference to the moisture requirements for a reference crop. Figure A 1 shows the density plot for the average length of growing period in the surveyed enumeration areas. Whilst differences in growing periods is a key measure that varies across locations, controls for farmer-reported land type (grassland or forest) is also included in the regression analysis. No data on soil quality or type was collected as part of the household survey. There is minimal variation in altitude across Ghana, with its highest point being 883 metres and areas north of the forest zone lying between 91m and 396m.

### b. Method

Regression analysis is used in order to investigate the partial correlations between measures of the three proposed determinants of variation in machinery use – agro-ecology, population, and urban proximity – and household use of agricultural machinery for land preparation on at least one of their farm plots. The theoretical relationships are represented by the following empirical model.

$$\mathrm{P}(y_{ivd} = 1) = \beta_0 + \beta_1 PL_{vd} + \beta_2 AEZ_{vd} + \beta_3 M_{vd} + \ \beta_4 M_{vd}^2 + \beta_5 C_{ivd} + \beta_6 PG_d + \varepsilon$$

The left hand side is the probability that an individual farmer *i,* in enumeration area *v,* and district *d,* is using machinery for land preparation, when $y_{ivd}$ is a dummy for an individual farmer using machinery for land preparation on at least one plot. $PL_{vd}$ is the level of population density for a particular enumeration area. $AEZ_{vd}$ is a measure of agro-ecological conditions, namely, the number of days in the growing season. $M_{vd}$ is a measure of urban proximity, namely, the median travel time to the nearest 50,000 populous town.

Controls are included for household level characteristics and the historical population growth at the district level. At household level, $C_{ivd}$ is a vector of household characteristics including the total area of land owned (in hectares) by the household; number of household members; a dummy for female-headed households; formal employment; highest education level; whether the household received government or NGO assistance; and a dummy for farmer reporting whether their largest plot is on grassland or forest. These are variables frequently used to capture the household endowments which may affect technology adoption in agriculture. Whether the largest plot is grassland provides a useful self-reported indicator of the type of soil conditions for the farmer[20]. $PG_d$ is district population growth over 1984-2000, and 2000-2010. This captures the longer term trends of the district. The speed of population growth will create different pressures on the evolution of institutions, economic development, and technology adoption (Boserup, 1965).

The estimation is done first using a linear probability model. Probit and logit models are used as a robustness check on the coefficient estimation. Both linear and nonlinear estimation methods for limited dependent variables have their advantages and disadvantages. Linear estimation is generally preferred for its simplicity, whilst the nonlinear approaches are used as robustness checks (Angrist & Pischke, 2009). The Stata command for survey data (svyset) was used to ensure standard errors are adjusted for clustering according to sampling strata.

I also note that urban proximity and population density are not exogenous over the long term, making a causal interpretation problematic. Areas with high agricultural potential will attract population growth through income effects that drive natural population growth and also encourage inward migration. As population increases and agricultural production improves, the economic surplus will lead to development of urban-industrial centres.

The shadow prices for land and labour are highly endogenous to machinery use. For example, as machinery use is adopted in an area, this will have an effect on local demand for labour.

[20] This self-reported measure captures the inherent characteristics of the soil, as one view of soil quality (Karlen et al., 1997). From the survey, forest land is less likely to be used for maize cultivation, associated with smaller farm sizes, and less likely to be plowed mechanically. It gives a proxy for the appropriateness of the soil for certain crops and cultivation methods, in lieu of more scientific data on soil type and quality which is unavailable.

The demand for agricultural labour may fall, and in turn seasonal labour, in particular, may migrate elsewhere for work. If we were to observe seasonal labour supply directly, we could find no relationship between machinery use and labour supply if this adjustment has already occurred. Similarly, market efficiency is improved by the urban setting, but it may also be improved by increased use of machinery. As more farmers adopt the new technology, the skills, maintenance services, and credit markets which support machinery use will develop.

Furthermore, prices for land, labour, inputs and market outputs were not observed directly by the survey, nor is such data available from other sources in sufficient detail. Seasonality and the remaining norms of payment in-kind for some agricultural activities mean that market prices do not necessarily reflect shadow prices. Therefore, as the theoretical framework illuminates, the empirical approach uses the exogenous determinants of variation in farming systems as proxy variables. The analysis focuses on the partial correlations between these variables, in order to explore the variation in mechanization across locations.

## IV. Descriptive statistics

To set the scene for the regression analysis which follows, this section explores the data to understand the relationship between tractor use and agricultural intensification. This follows from the theoretical literature which considers mechanization as one component of in the process of agricultural intensification. The section also looks into the correlations between the exogenous determinants and the household characteristics, in order to better understand the interactions between these variables.

### a. *Tractor use and other measures of agricultural intensification*

The highest concentration of tractors is found in Ejura, Yendi and Gushiegu districts which each have over 90 tractors. Sissala East also has a high number of tractors (Table 2). Interesting to note is the high level of tractor use in most districts, despite a low stock of tractors. A healthy rental market and the movement of tractors with the variation of plowing season explains this across locations (Nazaire Houssou, Asante-addo, Diao, & Kolavalli, 2015). The most common operation to be mechanized is plowing, followed by maize shelling and transportation of harvest from the field (Table A 1).

**Table 2: Tractor stock and density by district**

| Survey district | Total number of tractors | Tractor density (no. of tractors per 100 km$^2$) | Proportion of farmers using machinery for tillage | No. of households surveyed |
|---|---|---|---|---|
| Ejura Sekye Dumase | 165 | 16.96 | 0.92 (.02) | 176 |
| Yendi | 124 | 4.15 | 0.95 (.01) | 264 |
| Gushiegu | 96 | 4.12 | 0.96 (.01) | 226 |
| Sissala East | 52 | 2.23 | 0.8 (.03) | 220 |
| Bawku Municipal | 9 | 2.38 | 0.19 (.03) | 195 |
| Kintampo North | 9 | 0.9 | 0.3 (.03) | 173 |
| Kasena Nankana East | 9 | 1.49 | 0.67 (.04) | 160 |
| Techiman | 1 | 0.08 | 0.03 -0.03 | 199 |
| Whole survey sample | - | - | 0.62 (.01) | 1,613 |

Source: IFPRI-SARI 2014. NB: Linearized Standard Errors in parentheses. Total number of tractors is from listing exercise of all tractor owners in each district of the survey.

The theories of Binswanger, Pingali, Boserup and others considered mechanization as one component of a broader process of agricultural intensification. It is therefore important to understand machinery use in relation to adoption of other productive technologies and practices, which increase agricultural output. Table 3 shows several measures of agricultural intensification for tractor users and non-users, most of which have a significant difference in means. The definition of a tractor user is a farmer that uses machinery for land preparation on at least part of their cultivated land. These farmers may own machinery themselves or they may be borrowing/renting-in machinery services from others. The average farm size for tractor users is greater than that of non-users, both in terms of cultivated land and land owned. However, the average farm size for tractor users is still relatively small at only 3.89 ha of cultivated land – i.e. it is not only large-scale commercial farms that are using machinery.

**Table 3: Mechanized plowing and other measures of agricultural intensification**

| | Not using tractor | Using tractor | N | Difference in means |
|---|---|---|---|---|
| Cultivated land(ha) | 2.77 | 3.89 | 1827 | 1.12*** |
| | (0.12) | (0.13) | | |
| Land owned (ha) | 4.88 | 7.38 | 1827 | 2.50*** |
| | (0.39) | (0.50) | | |
| Plan to develop farm | 0.27 | 0.42 | 1827 | 0.13** |
| | (0.03) | (0.03) | | |
| Received government or NGO assistance | 0.06 | 0.09 | 1827 | 0.03 |
| | (0.01) | (0.02) | | |
| Hired-in labour for rice cultivation | 0.52 | 0.76 | 698 | 0.24* |
| | (0.08) | (0.07) | | |
| Hired-in labour for maize cultivation | 0.67 | 0.70 | 1300 | 0.03 |
| | (0.04) | (0.03) | | |
| Used herbicide | 0.51 | 0.87 | 1827 | 0.36*** |
| | (0.03) | (0.02) | | |
| Used inorganic fertilizer | 0.62 | 0.83 | 1827 | 0.21*** |
| | (0.04) | (0.02) | | |
| Used organic fertilizer | 0.30 | 0.13 | 1827 | -0.17*** |
| | (0.04) | (0.03) | | |
| Sold maize in 2013 | 0.63 | 0.71 | 1611 | .08 |
| | (0.04) | (0.03) | | |
| Fallow land (ha) | 2.36 | 4.55 | 938 | 2.19*** |
| | (0.20) | (0.56) | | |
| Virgin land(ha) | 6.23 | 7.54 | 429 | 1.31 |
| | (1.97) | (1.85) | | |
| Hired-in machine for plowing | 0.07 | 0.83 | 1827 | 0.76*** |
| | (0.02) | (0.02) | | |
| Hired-in machine for shelling | 0.08 | 0.33 | 1827 | 0.25*** |
| | (0.02) | (0.03) | | |
| Hired-in machine for transport | 0.08 | 0.37 | 1827 | 0.29*** |
| | (0.02) | (0.03) | | |

Source: IFPRI/SARI 2014. NB: Linearized standard errors are in brackets. Stars represent the significance level for the difference in means: *p<0.05 **p<0.01 ***p<0.001. The sample includes all surveyed EAs and unweighted observations from all three farm size strata. Weighting does not change the results notably.

Most farmers are hiring in labour, using herbicide and inorganic fertilizer, and selling to the market to some extent. There are slightly higher levels of use for these inputs among tractor users. However, the difference for labour use is not significant between users and non-users of tractors. The variable here is not the quantity of labour used, but whether any labour was hired in. As the farming systems in tropical areas intensify, the regrowth of weeds in between growing seasons becomes a major challenge (Pingali et al., 1987). Both mechanized plowing and chemical herbicide are used to clear the land before planting. Herbicide is a complement to mechanized tillage in Ghana. Fertilizer use is also a sign of agricultural intensification and depletion of soil fertility due to more frequent cultivation of the land and is particularly used for maize cultivation. These results show machinery use to be a complement to other technologies associated with agricultural intensification, as the theoretical literature would predict.

The final pattern to note from Table 3 is that 83% of tractor users hired-in machinery services for plowing. This confirms the extensive use of the hiring market by farmers who do not own their own machinery. There is a smaller market for hiring-in machinery for shelling and transport, but it is still considerable with over 30% of those using tractor for land preparation, also hiring in machinery for these operations.

### *b. Village and Household characteristics*

Table A1 (in Appendix V) provides the descriptive statistics for both the village level variables, and a set of household characteristics. The average length of growing period for the sampled villages is 215 days, with a standard deviation of 45 days. This reflects the bimodal pattern typical of the region, with some areas receiving over 230 days of rainfall a year over two seasons, and other areas receiving 160-220 days of rainfall and only one growing season (see also figure A1). There are three agro-ecological zones categorized in Ghana – north, transition, and south (HarvestChoice, 2015a; Kolavalli et al., 2012). Figure 2 maps the surveyed districts in relation to these agro-ecological zones. No districts were surveyed in the forest zone as the perennial cocoa trees do not require annual tillage and are not easily mechanized. Table A 1 also shows there is considerable variation across villages in terms of population density – from 14 persons per km$^2$ at the 10$^{th}$ percentile to 231 at the 90$^{th}$ percentile – and in terms of travel time to the nearest large town. The travel time ranges from 1 to 5 hours at the 10$^{th}$ and 90$^{th}$ percentiles with a mean of 2.86 hours across villages in the survey.

**Figure 2: Agroecological Zones of Ghana and IFPRI Survey Districts**


Source: Harvest Choice and GADM

Empirically, a key question will be whether the exogenous drivers of farming system change are merely reflected in household level characteristics, or whether these drivers add to our understanding of patterns of mechanization beyond considering household characteristics. Before moving on to partial correlations in the regression analysis, Table 4 provides the simple correlation coefficients for a range of household characteristics and the village-level drivers.

**Table 4: Correlation between village and household variables**

| | Population density | Days in growing period | Travel time |
|---|---|---|---|
| *Village-level drivers* | | | |
| Population density (EA, 2012, pers/km$^2$) | - | | |
| No. of days in growing period | 0.09 | - | |
| Travel time to nearest 50,000 populous town (hours) | -0.28 | 0.42 | - |
| *Household characteristics* | | | |
| No. of household members | 0.07 | -0.21 | -0.18 |
| No of household member per ha of owned land | 0.14 | -0.12 | -0.12 |
| Female headed household | 0.09 | 0.03 | 0.03 |
| Current or former formal employment | 0.12 | 0.14 | 0.01 |
| Highest education level of hh members | 0.14 | 0.21 | 0.05 |
| Hh received government or NGO assistance in last 5 years | 0.01 | 0.05 | 0.02 |
| Land owned by household (ha) | 0.09 | 0.05 | 0.04 |

Note: Pearson's correlation coefficient is reported for each pair of variables.

For the village-level drivers, there is unsurprisingly some considerable correlation between them. Population density is uncorrelated with the agro-ecological conditions, but negatively correlated with the travel time to the nearest town. Areas with higher population density are more likely to be large towns which will reduce the travel time. Interestingly, the number of days in the growing period is positively correlated with the travel time. This is likely driven by northern areas of Ghana having a single growing period with less than 220 growing days. The northern areas also have fewer urban centres and weaker physical infrastructure, both of which will increase the travel time to the nearest urban centre.

As noted above, population density is likely to reflect more urbanized areas and we find it is correlated with household characteristics which are more common in urbanized areas. Whether the household has had formal employment and the level of education of the household are both positively correlated with population density. We would expect employment and education opportunities to be greater in more urban areas. The household's land-labour ratio (captured as the no. of household member per ha of owned land) is also positively associated with population density, as would be expected.

The days in the growing period is correlated with household characteristics which are likely to vary between the northern areas and areas further south with two growing seasons. The north has a higher proportion of Muslim households with larger family sizes. Both the no. of household members and household land-labour ratio are negatively correlated with the number of growing days. Similarly, the south of Ghana has experienced more urbanization and stronger economic growth, thereby providing more employment and education opportunities. As we come to regression analysis, it will not be possible to separate the effect of these agro-ecological conditions directly on the timeliness constraint motivation farmer's machinery use, from the effect of longer growing periods on long term economic development, which in turn may affect the probability of a household using machinery.

The more remote households are also likely to have fewer household members, and fewer household members per ha of land. This is a direct correlation, and does not control for population density. Given that, it is as we would expect that more remote households, which are likely also less densely populated, will be more labour constrained.

As we move to considering the partial correlations between machinery use, and these village-level drivers and household characteristics, it is useful to bear in mind the relationship between the variables themselves. It will be important to see firstly, whether the drivers are important in determining machinery use, and secondly, whether their effect on machinery use persists when these household characteristics are controlled for.

## V. Regression results

### *a. Village-level drivers and machinery use*

The results of the linear probability model estimation are shown in Table 5. A variety of specifications are used to include individual household controls, as well as district controls for population growth. Models (1), (2), and (4) show a persistent result is the significant and negative correlation between population density of the village and the probability of machinery use. This result is consistent with the theoretical proposition that the returns to machinery use are higher in areas with relative land abundance[21]. A significant and negative correlation is also found between the travel time to the nearest urban centre and the

[21] This relationship would also be consistent with mechanization causing permanent out-migration of labour. Given mechanization has only occurred for a single operation, it is unlikely that this is the direction of causality.

probability of machinery use. This is the additional effect of urban proximity, having controlled for differences in population density. The non-linearity of the relationship between urban proximity and machinery use is evident in the significance of the squared term for travel time. Again, this is consistent with the cost of machinery use being lower in areas closer to urban centres where maintenance and skills for tractor operation are more easily accessed.

The partial correlation with the number of days in the growing period is less clear. The coefficient is not significant and its sign is sensitive to the model specification. As discussed in the previous section, this variable is correlated with the travel time variable therefore the lack of significance may be due to collinearity. The length of growing period variable is used to proxy for the timeliness constraint which faces farmers for land preparation. It is assumed that a shorter overall growing period will reflect a shorter time window for land preparation and planting at the start of the season. This is an imperfect proxy and will also reflect differences in economic development which emerged over the long term due to differences in agricultural potential. Between collinearity and an imperfect proxy, it is understandable that no effect is found in the regression models. The fact that a negative relationship is found at all provides some support to the proposition that returns to machinery use are higher in areas with shorter growing season, due to the time-saving benefit of mechanized plowing, but this is by no means conclusive.

### Table 5: Regression results - linear probability

| | *Dependent variable: dummy for tractor use* | | | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| *Village-level drivers* | | | | |
| Population density (EA, 2012, pers/km$^2$) | -0.0012*** | -0.0007*** | | -0.0006*** |
| | (0.00) | (0.00) | | (0.00) |
| No. of days in growing period[22] | 0.0009 | -0.0015* | | -0.0013 |
| | (0.00) | (0.00) | | (0.00) |
| Travel time to nearest 50,000 populous town (hours) | -0.1714** | -0.2230*** | | -0.2008*** |
| | (0.06) | (0.05) | | (0.05) |
| Travel time (squared) | 0.0191* | 0.0252*** | | 0.0220*** |
| | (0.01) | (0.01) | | (0.01) |
| *Household characteristics* | | | | |
| Total number of household members | | | 0.0095** | 0.0059 |
| | | | (0.00) | (0.00) |
| No. of hh members per ha of owned land | | | -0.0144** | -0.0150** |
| | | | (0.01) | (0.01) |
| Female headed household | | | -0.0236 | 0.0019 |
| | | | (0.05) | (0.05) |
| Current or former formal employment | | | -0.0532 | -0.0366 |
| | | | (0.06) | (0.06) |
| Highest education level of hh members | | | 0.0089* | 0.0112** |
| | | | (0.00) | (0.00) |
| Hh received government or NGO assistance in last 5 years | | | 0.1369* | 0.1138* |
| | | | (0.06) | (0.06) |
| Land owned by household (ha) | | | 0.0006 | 0.0004 |
| | | | (0.00) | (0.00) |
| Largest plot is grassland (not forest) | | | 0.2608*** | 0.0732 |
| | | | (0.06) | (0.07) |
| Constant | 0.7754*** | 1.6632*** | 0.6267*** | 1.4995*** |
| | (0.17) | (0.17) | (0.08) | (0.23) |
| District population growth controls | no | yes | yes | yes |
| N | 1609 | 1590 | 1568 | 1568 |
| R-sq | 0.16 | 0.38 | 0.34 | 0.42 |
| F statistic | 21.33 | 56.50 | 33.76 | 40.71 |
| Count R-Squared | 0.73 | 0.87 | 0.97 | 0.87 |
| Adjusted Count R-Squared | 0.28 | 0.65 | 0.87 | 0.64 |

NB: Standard errors are in parentheses. Significance level is indicated by: * p<0.10 ** p<0.05 *** p<0.01

[22] A squared term was included for the no. of days in the growing period but this was found to be small and insignificant.

### b. Controlling for household characteristics

A key difficulty with making conclusions from models (1) and (2) of Table 5 is that there are many confounding factors at household level which will be affected by the village-level drivers and indirectly affect machinery use. As mentioned previously, households in urban areas benefit from greater education and employment opportunities which will increase the opportunity cost of household labour and increase farmer efficiency. Both of these will indirectly affect machinery adoption. Furthermore, the supply of agricultural labour from local population density will be less important for farming decisions if the household has plentiful family labour to draw upon. Models (3) and (4) of Table 5 help to answer the question of whether these village-level drivers can explain machinery adoption, once household characteristics are taken into account. Even once household characteristics are controlled for, travel time to urban centre and population density are strongly correlated with mechanization use. A few comments on these household characteristics and their importance for machinery adoption are discussed below.

Both the household's labour constraint, captured as the no. of household member per hectare, and the village-level labour constraint, captured by village population density, are significant in explaining machinery use. The bigger the size of the household relative to their land size, the less likely the farm household is to use machinery. But, the population density, and therefore local agricultural labour supply, is also negatively correlated with machinery use. A further question may be whether the importance of the local population density for the farm household's machinery adoption is mitigated by the availability of family labour. This interaction term was tested in the regression and the coefficient was very small and insignificant.

Model (4) shows that within the village locale, more educated households are more likely to use machinery. It also reveals that receipt of assistance from NGOs or government programs has a large association with machinery use, even when village-level drivers are accounted for. What is striking is that these effects are true within the village locale, when differences in village-level drivers across villages are accounted for.

Whilst the focus of this empirical approach is on whether the village-level drivers are correlated with machinery adoption, the inclusion of household characteristics to the model is instructive to rule out alternative explanations for the relationships found between these drivers and mechanization. If the drivers were unimportant in explaining machinery use, we would find that the significance of their coefficients disappears once household characteristics are included in the regression model. These results confirm the importance of population density and urban proximity for understanding patterns of machinery use, over and above the effect that these drivers have on household size, employment, education, and land size.

### *c. Mechanization of other operations*

Table 6 shows the partial correlations between the same drivers of mechanized plowing use, and farmer's use of machinery for other operations via the hiring market. Whilst 46% of farmers in the survey hired in machinery for plowing, only 21% and 24% hired in machinery for shelling and transportation respectively (Table A 1). The results for mechanized maize shelling and transport use are notably different to those of mechanized plowing. Coefficients for travel time are not significant, and population density is only significant in explaining variation in mechanized transport use. Areas with lower population density are likely to have greater distances between homestead and farm plot, thereby increasing the benefit of mechanized transport. The theoretical drivers of mechanization of maize shelling and transportation are likely to be more related to the scale of production, rather than the timeliness and labour intensity of land preparation (Pingali, 2007). This is further evidenced by the significant and negative correlation between household land-labour ratio and mechanized plowing, but no relationship found for the other types of mechanization.

**Table 6: Regression results - across operations**

| | *Dependent variable* | | |
|---|---|---|---|
| | Hired in machinery for plowing | Hired in machinery for maize shelling | Hired in machinery for transport (farm to homestead) |
| Population density (EA, 2012, pers/km$^2$) | -0.0006*** | -0.0001 | -0.0003*** |
| | (0.00) | (0.00) | (0.00) |
| No. of days in growing period | 0.0044 | -0.0468*** | -0.0153 |
| | (0.01) | (0.01) | (0.01) |
| No. of days in growing period (squared) | -0.0000 | 0.0001*** | 0.0000 |
| | (0.00) | (0.00) | (0.00) |
| Travel time to nearest 50,000 populous town (hours) | -0.1167** | -0.0305 | -0.0314 |
| | (0.05) | (0.04) | (0.04) |
| Travel time (squared) | 0.0154*** | 0.0073 | 0.0082 |
| | (0.01) | (0.00) | (0.01) |
| No. of hh member per ha of owned land | -0.0153** | -0.0050 | -0.0070 |
| | (0.01) | (0.00) | (0.00) |
| Controls - other household characteristics | yes | yes | yes |
| Controls - district population growth | yes | yes | yes |
| N | 1587 | 1587 | 1587 |
| R-Squared | 0.23 | 0.24 | 0.15 |
| F | 17.90 | 13.22 | 7.43 |

NB: Standard errors are in parentheses. Significance level is indicated by: * p<0.10 ** p<0.05 *** p<0.01. Linear probability model estimated using OLS.

### d. *Robustness of the results*

As a goodness-of-fit measure, the percent of predicted probabilities or count R-squared (using 50% as the threshold) is considered, as well as the adjust count R-squared[23]. The adjusted count R-squared removes the effect of predicting the most common outcome and therefore being correct most of the time. For models including population growth controls, 85% of the predicted probabilities are correct, or 63% for the adjusted count ( Table 5 ). A common concern with the linear probability model is that there is no constraint on the predicted probabilities lying within 0 and 1 interval. The second concern with using ordinary least squares for a binary dependent variable is heteroscedasticity which leads to incorrect estimation of the standard errors. The stratified sampling methods for the survey data are likely to be a greater cause of heteroscedasticity and therefore the Taylor linearization method is used for variance estimation.

Given the potential problems with assuming a linear estimation method with a binary dependent variation, non-linear probit and logit estimation is used for the same model specification as model (4) in Table 5. The results are very similar in terms of the sign of the estimated coefficient and significance (Table A 2). The goodness-of-fit measure indicates that approximately 80% of the predicted probabilities for both the probit and logit model are correct. To get an idea of the magnitude and stability of the estimated coefficients under the probit model, the average partial effects at the mean are calculated. The relative partial effects

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[23] Adjusted count R-squared subtracts the count of the most frequent outcome from the numerator and denominator.

are similar under LPM, probit, and logit models. However, the absolute magnitudes are larger under probit and logit, when calculated at the mean. Under these models, the partial effect depends on the value of the independent variable. Furthermore, ordinary least squares and tobit models were estimated using the number of hectares on which machinery was used for land preparation as the dependent variable (Table A 4 ). The coefficients are of similar significance and sign as those in Table 5.

A further check on the regression model is to consider the explanatory power of the model compared to that of regressing tractor use on simply district or village fixed effects. The concern arises from the left hand side of the regression being at household level, and the village-level driver variables of primary interest are at the level of enumeration area. Are these drivers any more useful in explaining patterns of machinery use than simply using dummies for enumeration area or district? These fixed effects models are show in Table A 3. For the enumeration area fixed effects, the adjusted count R-squared is 64% and for the district fixed effects the same measure is 62%. This compares favourably with the equivalent measure for the full model in Table 5 which is 64%. The drivers of population density, travel time to urban centre, and length of growing period are doing a good job of capturing the variation in machinery use across locations.

## VI. Discussion

Overall, the empirical results are instructive in exploring the relationship between machinery use, population density, urban proximity, and agro-ecological conditions. The variables for market access and population density explain a considerable part of the variation across locations in mechanization use by farmers. Although these results are from a single time period and rely only on cross-section variation and causality cannot be established, the partial correlations provide strong evidence that the village-level drivers can explain patterns of machinery use, even when household characteristics are controlled for.

The coefficient on population density is found to be significant in the models. However, the magnitude of the association is small. If population density were one standard deviation higher in one location (i.e. an increase of 116 pers/km$^2$ at the median of 63 pers/km$^2$), the associated difference in the probability of machinery use would be a decrease of 7 percentage points[24]. This is consistent with the observation that farmers in areas with lower population density will have more difficulty in securing agricultural labour, especially during peak seasons such as during land preparation. There is also likely to be easier access to farm land. Both of these factors will increase the returns to mechanization use for farmers. Although this association is significant, the magnitude of the association between population density and machinery use is small. High levels of seasonal labour migration both inwards and outwards for agricultural and non-agricultural sectors will likely be weakening the importance of local population availability for agricultural labour supply (Van der Geest, 2011). Other research on Ghana's agriculture has failed to find a positive relationship between population density and the intensity of farmer's use of modern inputs such as seeds and fertilizer. The high cost of labour is found to be a key barrier to adoption of such labour-intensive technologies (Nin-Pratt and McBride, 2014). If the high cost of labour is prohibitive

[24] Interpretation of this and following coefficients is based on model 4 from Table 5

for farmers' technology decisions, then we would expect to find both a negative and relatively weak relationship between population density and machinery use. The high labour costs may be inducing farmers to use machinery, even in areas with relatively high population density.

The second result which is strongly supported is the increased probability of machinery use by farmers located closer to urban centres. The travel time to the nearest settlement of 50,000 people ranges from 30mins to 10 hours in the sample. From the regression estimations, an increase of travel time of 1.5 hours (one standard deviation) is associated with a lower probability of mechanization by 11 percentage points at the median of 2.9 hours, controlling for other variables including population density. As discussed in section II, after controlling for the population density associated with urban centres, we would expect the lower transaction costs and more efficient markets in urban areas to lead to farmers located close to urban centres to be more likely to be using machinery. The empirical findings also suggest that the effect of higher labour demand from non-agriculture sectors in urban areas is outweighing the effect of higher labour supply. This is consistent with findings in the literature that travel time is strongly (negatively) associated with commercialization and modern inputs use, both of which in turn will theoretically affect the probability of farmers using machinery (Stifel & Minten, 2008). We would expect the benefit of urbanization for farmers' use of machinery to be greater for farmers close to urban areas, than those far away. This is reflected in the significant and positive sign on the squared term[25]. The advantage of

[25] For travel time of greater than 8.81 hours, the overall effect of travel time on machinery use will become positive. Only a small number of households in the sample have travel time greater than 8.81hrs.

more efficient markets and lower transaction costs provided by urban markets are more important for mechanization, than purely the effect of differences relative supply of labour captured by population density. This result is particularly surprising as competition over land for non-agricultural uses is likely to be greater in peri-urban areas. Better connectivity to urban markets may be also enabling farmers to take advantage of more elastic food demand, and therefore use machinery to expand production.

The theoretical proposition was that we would find a negative correlation between the number of days in the growing period and mechanization use for plowing, but the empirical results are not conclusive. A reduction in the number of growing days is associated with a higher probability of using a tractor. The number of days in the growing period ranges in the sample from 163 to 291 days. Therefore, at the median of 200 growing days, farmers in an area with 45 more growing days (one standard deviation) are approximately 6 percentage points less likely to be using machinery for land preparation. However, this correlation is not significant, therefore the quantitative results are inconclusive. Qualitatively, farmers indicated that when the time for cultivation is restricted by rainfall, there is a greater need to prepare the land quickly in order to maximize the time between planting and harvesting (see paper 3 of this thesis). In areas with two seasons and a longer growing period, there is more time to prepare the soil, and therefore the length of growing period is less important in determining machinery use (at least for land preparation). The weakness in this quantitative result may be due to the imprecise measure for this seasonality. The variable is for the total length of the growing season, rather than the time available for land preparation specifically.

The time for land preparation will also vary by crop, which this aggregate analysis does not account for.

Before we consider these findings in relation to the established theories regarding mechanization, we can take note of the specific context which may affect their application beyond Ghana. For example, the distribution of land in Ghana is relatively equitable with the incidence of landless rural households very low. As such, the nature of farming systems and land distribution continues to be linked to local demographic characteristics, rather than other contexts where large-scale commercial farming dominates and a traditional tenure system is not in operation. In 2012/2013, 93% of households in the rural savannah area of Ghana owned or operated a farm (Ghana Statistical Service, 2014). This context is key in justifying the link between population density, agricultural land and labour supply, and farmers' choice of technology.

The relationship between land tenure systems and agricultural mechanization have not been explored directly in this paper, and the methodology does not allow for conclusions to be drawn. However, the existence of extensive machinery use in the context of a traditional land tenure system for agricultural land, with the absence of a formal land market, seems to counter the idea that land tenure reform is required for modern technologies to be adopted. As will be discussed in later papers of this thesis, the economic and social structures of rural Ghana have enabled farmers to access mechanized technology without land consolidation or tenure reform.

One further caveat is that this study has not considered the environmental sustainability of agricultural mechanization in this context. Soils in this type of tropical environment have poor structure which makes them less resilient to intensive cultivation. Heavy and short rainfall causes extensive leaching, with nutrients carried below the root zone, and the creation of subsurface hard pans (Ruthenberg, 1980). The paper has contributed to our understanding of why farming systems in some locations have mechanized and some have not, but cannot speak to whether this type of mechanization is appropriate or desirable for economic and environmental sustainability in the region.

Given these results and their context, what new light can be shone on the theories of mechanization found in the literature? The empirical case is markedly different from that which Pingali, Bigot and Binswanger (1987) drew from. In modern Ghana, there have been several years of sustained machinery use through private service providers, rather than the failed history of government-sponsored mechanization programs of the 1980s, where provision of services was managed directly by the government. Pingali et al. (1987) argued that the incentives from relative prices needed to be in place for farmers to adopt labour-saving technology, rather than sustained adoption being driven by government's supply interventions. The relative costs of land and labour, inasmuch as they are captured by local population density, continue to be a key component in understanding why some farmers have mechanized production. By finding that urban proximity is an important factor in mechanization, it seems that the improved market demand and access to those markets has stimulated and sustained farmer's adoption of mechanized technology. For theory, this pushes the framework to consider not only relative factors of production, but the role of urbanization with efficient markets and improved skills in developing the auxiliary markets for agricultural production. The extent to which a farmer is connected to such urban centres is just as important as population in enabling the adoption of modern mechanized technology. Whilst the previous theories of Boserup, Binswanger, Pingali and others did not ignore such barriers to accessing machinery, the empirical case which has been investigated here perhaps opens up further questions regarding the interaction of urbanization, remoteness, and mechanized agricultural technology.

The current literature on agricultural technology adoption more frequently focuses on the microeconomics of individual farmer adoption, rather than trends which are common to all farmers in a locale, as investigated here. Village or district level effects may be controlled for without seeking to open up the understanding of why variation is found at that level. Lessons can be drawn for such microeconomic studies of agricultural technology adoption in Ghana, and elsewhere. Analysis of household adoption decisions should be placed within the context of wider demographic and urbanization trends. From cross-country study of agricultural intensification in Sub-Saharan Africa, Sheahan and Barrett (2017) found that almost half of the variation in farm-level technology adoption is due to such aggregate level factors, rather than individual household characteristics.

## VII. Conclusion

As we consider the patterns of mechanization in the context of Sub Saharan Africa, the findings of this paper provide useful insight into the relationships between key trends affecting agricultural development and mechanization specifically. Mechanization is associated with lower population density and greater proximity to urban centres. Population density has less of an effect at the median on probability of mechanization use than the proximity of a farm to urban centres with the access to markets and auxiliary services supporting machinery use..

The observational data has given credence to the broad relationships between variation in machinery use, and drivers of farming system change. Given the limited work empirically and theoretically on this topic since the 1980s, finding current empirical evidence of the relationship between these drivers and mechanization is informative as more research and attention is given to mechanization. Lack of demand for agricultural output no longer appears to be the reason for farmers low adoption of mechanization, as concluded by Pingali, Bigot and Binswanger (1987). Rather, factors such as urban proximity and seasonal rainfall provide a more convincing explanation for the uptake of mechanization in countries such as Ghana which have seen considerable economic growth and urbanization since the 1980s. The theoretical focus on exogenous drivers which the previously literature took, continues to be pertinent.

For policy makers and others looking to promote agricultural mechanization, the results of this study should help to refocus their attention. The importance of urban proximity for use of mechanized plowing indicates that the lower transaction costs and flow of skills from urban centres are key in determining the returns to mechanized plowing. The agglomeration benefits of urban centres for maintenance services and skills, as well as the lower transportation costs associated with good road infrastructure reduce the costs of accessing machinery, especially when through a hiring market. Interventions to support the supply of machinery services should focus on reducing these transaction costs for farmers in rural areas, rather than exacerbating the concentration of the supply of services for urban and peri-urban areas. Another point to note for policymakers is the seasonal availability of agricultural labour and its role in motivating farmer's adoption of mechanized plowing. It is not merely the cost of labour, but its availability at critical points in the season which lies behind mechanization. This will be true for the adoption of other modern technologies for which the complementary labour requirement may be discouraging adoption.

Finally, any policy maker concerned with agricultural development should also be concerned with the environmental sustainability of new and existing technologies. As this study has shown, mechanization use is associated with more remote locations with lower population density, which for northern Ghana implies areas which also have poorer conditions for agricultural production. Before any policy interventions are enacted to promote mechanization, further investigation of the environmental sustainability of the specific technology is critical, particularly in the context of tropical farming systems where soils are fragile.

# Paper 2: Impact of mechanization on smallholder agricultural production: evidence from Ghana

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Abstract:

Mechanization is accompanied by changes in the quantity and type of labour required for an activity. Agricultural mechanization is often touted by policy makers as reducing the drudgery associated with agricultural work and as increasing the productivity of farming systems, especially in contexts where traditional technologies appear to be stagnant. For good or for ill, mechanization is expected to replace labour in agriculture. This can either create unemployment, in a pessimistic scenario, or release labour for more productive work outside of the agriculture sector. However, little rigorous analysis has examined the impacts of agricultural mechanization on labour use in agriculture. This is partly due to the challenge of measuring these impacts in a well-identified setting. It can be difficult to attribute changes in production systems and household welfare to the use of mechanized technology, rather than to more general changes in agricultural conditions and associated infrastructures.

This paper considers these claims and provides evidence of a more complex set of impacts. By reducing labour use in some activities and at certain points in the growing season, agricultural mechanization can actually increase demand for labour in other activities and at other seasons. In northern Ghana, tractor use allows for shortening the length of time required for land preparation, making it possible for farmers to grow maize in locations where the crop would otherwise be marginal at best. Because maize cultivation is relatively labour-using, compared to other agricultural activities, mechanization of land preparation leads to an increase in the overall demand for agricultural labour.

In this context in Ghana, small- and medium-scale farmers' access mechanized plowing technology via a service market, rather than through individual ownership of machines. This paper bases its causal identification on a government scheme that generated plausibly exogenous positive shocks to the supply of machinery services at the district level. Bearing in mind the methodological difficulties and limitations of the approach, evidence is presented of the short-term impact on a range of variables relating to the farming system and household welfare.

Findings indicate that for these marginal users of agricultural machinery, mechanized plowing does not significantly reduce the labour used for land preparation, and in fact may lead to increased labour use for other operations. The area cultivated increases, with proportionate increases in maize cultivation and an increased proportion of land controlled by women. I propose that these results are consistent with tractor plowing alleviating a timing constraint for farmers, which enables cultivation of more time-sensitive crops and increases the expected returns to subsequent production activities.

## I. Introduction

Agricultural mechanization is often considered in the context of large-scale commercial farming, in the style of capital-intensive agricultural production systems of North America and Europe. However, farmers in developing country contexts, where labour is still relatively cheap, are using agricultural machinery, particularly in parts of Asia where small-scale machinery has become widespread (de Groote et al. 2018; Mottaleb et al. 2017; Pingali 2007). In particular, farmers in the cereal-producing areas of northern Ghana have adopted mechanization as part of their preferred set of agricultural technologies. This is in a context where average farm sizes are less than 5 hectares. This observed trend raises theoretical and empirical questions around the conditions under which mechanization of at least some operations becomes profitable for small-scale farmers in sub-Saharan Africa, and the implications of machinery use for other farming decisions regarding land, labour, and input use.

Economic theories have tended to link agricultural mechanization to broader processes of population growth and structural change. Boserup (1965) and Pingali et al. (1987) consider farmer demand for mechanized technology to be a result of the agricultural intensification process, which is fundamentally driven by agro-ecological conditions, population pressure, and market demand. Hayami & Ruttan (1985) and Binswanger & Ruttan (1981) consider that farmers will demand technology innovations that intensively use the relatively abundant factor of production. For land preparation, mechanized technology will be demanded when there is relative land abundance. The indivisibility of production factors, such as machinery or draft animals, has led several to posit that in the presence of weak credit markets, high transaction costs associated with rental markets will prohibit investment in mechanization (H Binswanger & Rosenzweig, 1986). However, the availability of smaller and cheaper machinery reduces this problem, and indeed their use has become prevalent in Asia (T. W. Schultz, 1964; Mandal et al., 2017). Furthermore, evidence from northern Ghana demonstrates that a strong rental market for machinery services has overcome the lumpiness of investment in agricultural machinery.

The process of mechanization has been understood in the literature as one of changes in relative factor use and of intensifying agricultural production. This paper furthers this understanding to consider the effect of a timing constraint which faces many farmers in sub-humid and semi-arid tropical farming systems. Rainfall patterns are highly variable and the single growing season in many areas creates a short time window for land preparation to be completed and planting to be done at the optimum time (Ruthenberg, 1980). Mechanization can be considered as a technology which both reduces the labour required for an operation, and the time required to carry out the operation. It does not merely change the cost structure for production, but it may also enable more efficient production in settings where returns are sensitive to timely planting.

Ghana provides an excellent case in which to investigate the impact that machinery use has on other farming decisions. Mechanized tractor plowing has been used by farmers in Ghana for several decades, with smallholder uptake increasing substantially in more recent years.[26] The adoption decisions by individual households are not constrained by knowledge or exposure to the technology as its use is widespread amongst small and medium scale farmers. These tractor users do not engage directly in the market for the purchase of tractors, but are directly engaging in the market for tractor services. The analysis of this paper will rely upon this distinction. By making use of the service market, a farmer's actual use of tractor plowing is renegotiated each season, rather than representing a one-time investment decision. An important distinction, however, is that for farmers who rely upon the tractor service market, there is no guarantee in any given year that they will be able to access tractor services at the moment when the services are needed. This uncertainty is due to weaknesses in the tractor service market which are more fully explored in Paper 3.

The contribution of this paper is twofold. First, a broader theoretical framework is developed in which two different pathways lead to mechanization. One is a substitution of capital for labor the other is the use of tractors to address ussies of timeliness of land preparation. This paper then considers the empirical impacts of mechanization on a range of farm practices and outcomes. The empirical results highlight the benefits for farmers of having access to tractor services. Farmers stand to lose if they miss out timely tractor services at critical moments during the cropping season. The paper is novel in identifying the specific effect of machinery use upon the agricultural system, distinct from other aspects of agricultural intensification. It

[26] Tractors were introduced by colonial administrations, with further government support and promotion of the technology through state farmers and public mechanization services in the 1960s and 1970s (Richards, 1985; Seager & Fieldson, 1984)

considers a positive shock to the supply of tractors, which in turn is assumed to increase the supply of tractor services. This shock identifies the impact of tractor plowing on other farming decisions of the household. This allows us to draw broader inferences about the ways in which mechanization affects farm-level production and the aggregate farming system. At the farm level, we will attempt to identify the associated changes in land and labour productivity, labour use per hectare, cultivated area, and crop choice. We can also ask whether there are differential effects for male and female farmers within the household. The paper focuses on the short-term impact of increased machinery use on within-season farming decisions.

This paper proceeds as follows. Section II develops the theoretical argument regarding the changes that would be expected due to increased tractor use. Section III provides the Ghanaian context of tractor use, including the private service market, and related government programs. This is followed by detailed discussion of the methodological approach and data used, with its strengths and weaknesses in Section IV. The results are then presented in Section V, followed by a concluding discussion.

## II. Theoretical impact of mechanization use

Several assumptions underpin the theoretical discussion which follows. First, I assume that farm households are utility maximizers with regards to agricultural production. Agricultural produce may be consumed by the household or sold on the market, but the assumption is that farmers make their decisions over production in order to optimize their utility from agricultural production (Singh, Squire, & Strauss, 1986). Farmers' choices regarding the area cultivated for each crop, the type of technology to adopt, and the use of other inputs are made at the start of the season, and are updated during the season in response to weather and other conditions. Their ability to maximize is constrained both by their budget constraints, and by the availability of each of these inputs to production.

Second, I assume that not all input markets are complete, particularly the market for machinery services. As discussed in the third paper of this thesis, timing constraints and transport costs create a coordination problem in the service market which leads to the exclusion of some farmers from accessing services, despite farmers being willing to pay at market prices. Therefore, for farmers who do not own a tractor, there is uncertainty within the season regarding whether or not they will get access to tractor services or not.

Third, farmers are assumed to make production decisions sequentially during the season, rather than simultaneously at the start of the season. They also make such decisions independent of other farmers. They are able to adjust their decisions over crops cultivated, labour use, and other inputs in response to rainfall patterns at the start of the season, and whether they have used tractor plowing services. Therefore, the use of tractor plowing in a particular season is determined both by the farmer's intention to adopt mechanized plowing technology in general, and the success of the farmer in securing tractor services in that particular season.. The subsequent farming decisions over crop choice, input and labour use for weeding, pest control, fertilization, and harvesting, are dependent upon the technology used for land preparation. For the purposes of this paper, the focus is on machinery use for land preparation (plowing) as this is the only operation that is mechanized by a large proportion of cereal-producing farmers in Ghana.

Farm households are the primary unit of analysis. This is the meaningful decision-making unit with regards to agricultural production. Agricultural land in Ghana is most frequently allocated to the household head who may then allocate land to individual household members (Lambrecht & Asare, 2016). Most agricultural land has been allocated to families and is passed down through inheritance. I then make the assumption that family labour is used across all plots, regardless of which household member may have control over the farming activities on the plot. Underlying this approach is the assumption that household members coordinate, share resources, and seek to maximize utility for the household as a unit, although I do consider the potential effect of unequal bargaining power between men and women over family and hired labour use (Singh, Squire, & Strauss, 1986; Alderman et al, 1995; Haider et al., 2018; Palacios-Lopez & Lopez, 2015).

I consider two potential channels of impact for mechanization; the two are not mutually exclusive. The first is the direct effect of reducing the labour required for land preparation. Much of this theoretical strand is rooted in the work of Boserup (1965), Pingali et al. (1987), and Binswanger & Ruttan (1978), which emphasized the relative cost of labour as a driver of mechanization. The second impact is the increased chance of timely planting which comes with completing land preparation in a shorter time than when using labour power for the same area. This second impact has not previously been considered in the economic theory regarding mechanization and its impacts, although it is well understood in the agronomic literature. Others have made reference to the higher returns to machinery use in tropical farming systems with unpredictable rainfall patterns and a short planting window (Richards, 1985; Ruthenberg, 1980). This paper lays out the theoretical implications for farm production when this timeliness constraint is alleviated through tractor plowing. From these initial immediate impacts – reducing labour requirement, or enabling timely planting – the consequences for subsequent decisions over agricultural production are considered.

### *a. Mechanization reducing the labour-intensity of production*

The frequently considered direct consequence of tractor plowing is a shift away from using labour-intensive hand-hoeing for land preparation. Per hectare, less labour is used for land preparation. However, some labour may still be required to operate machinery and clear the land of larger stumps and weeds. This is not trivial in Ghana's farming systems. Weed re-growth between seasons is considerable and farmers often apply herbicide to kill weeds before using the tractor to plow. If the primary constraint for farmers is securing adequate labour for land preparation, the total effect would be to reduce labour use for this stage of production, without any change to labour use per hectare for other operations.

The impact on total labour use for all operations depends on the farmers' land constraint and elasticity of demand for their output. Where there is elastic demand and land is available, farmers will increase the total area cultivated with tractor plowing. If the scale of production increases sufficiently and labour use per hectare for other operations remains the same, then total labour use may actually increase, even though labour use per hectare declines. However, the total land available for farming is constrained, and moreover, the individual farmer is constrained in accessing land due to non-market allocation mechanisms. Land allocation in Ghana is governed by traditional tenure systems (or at least by a modern set of institutions that have emerged from traditional tenure systems). Family land was allocated in previous generations and this is the primary land which individual farmers access for agriculture. A farmer can easily cultivate more family land, but access to virgin or communal land will require either payment in formal market or negotiation with the local chief or farmers. Therefore, the results may be ambiguous in showing whether the increased availability of machinery leads to a farmer increasing her cultivated area, depending on the ability to access more family land within the season. A lack of effect may be due to a binding constraint on the availability of land.

I assume that family land can be accessed costlessly within the season, but other types of land require negotiation and search costs. The extent to which access to land is a constraint on the farming system will depend in part upon the local population density and urbanization. In areas with high population density, farmers may want to cultivate more land (as a result of accessing machinery services) but they may be unable to do so, due to competition over land from other farmers and for non-agricultural uses.

If tractor plowing is used to alleviate a labour constraint, there is not necessarily any impact on the farmer's yield or land productivity. The composition of crops would not necessarily change, and in terms of agronomy, land is not necessarily more productive with tractor plowing over hand-hoeing. However, increasing the cultivated land size is also associated with decreasing returns to scale in the literature. The inverse farm-size productivity relationship has frequently been documented in the agricultural development literature (e.g. Barrett et al., 2010). This may reflect market frictions of failures, rather than a technological decreasing return. For example, farmers may struggle to increase total labour use for weeding, harvesting, and processing beyond the labour available from family members.

Hired labour may be less productive than family labour, due to the costs of supervision and lower effort of non-family members. Farmers may instead choose to use more labour-saving chemicals such as herbicide and pesticide as farm scale increases. Furthermore, machinery use may lead farmers to start cultivating new plots which are of a lower soil quality and require more effort to cultivate. These factors may all lead to a finding that average yields actually decrease with machinery use, or that chemical input use increases in order to maintain yield.

If securing labour for land preparation for women is more difficult than men, tractor use may also lead to a change in the allocation of plots between male and female household members. There is much diversity in the nature of female ownership and tenure over agricultural land in SSA, as well as the participation of women in agricultural production (C. Doss, Meinzen-Dick, Quisumbing, & Theis, 2018; Theis, Lefore, Meinzen-Dick, & Bryan, 2018). Land preparation without machinery is a physically demanding activity that is often carried out by men.[27] Furthermore, women may find it more difficult to secure labour due to competition with men for family and hired labour. Therefore, the benefit of labour-saving machinery may be greater for female-managed plots than for male-managed plots (Palacios-Lopez, Christiaensen, & Kilic, 2017). If the labour requirement for land preparation were preventing women from cultivating land themselves, the use of tractor plowing could increase the area cultivated by women. Traditionally, women are less able to participate in communal labour

[27] Land preparation in this context includes clearing weeds and brush which regrows extensively between seasons, in addition to hand-hoeing. Depending on the extent of weed re-growth, some clearing by hand is still required with tractor-plowing.

due to reproductive activities in the household, and household labour may be prioritized for 'main' plots. Doss and Morris (2001) find that gender differences in adoption of improved maize seed and chemical fertilizer are explained by differences in access to land and labour inputs. In particular, female farmers find it more difficult to secure male labour for land preparation. In this way, not only will increased availability of machinery increase the total area cultivated by the household, but it might disproportionately increase the land area that women are cultivating.

Women's engagement in agriculture also includes their labour hours spent on their own plots and the plots of other family members. Agricultural mechanization may affect the amount of labour which women allocate to agricultural activities, whether on their own plots or those of other household members. In some countries of SSA, there is greater female labour use for food crops and for operations other than land preparation. However, this only holds for a few countries and is not generalizable (Palacios-Lopez et al., 2017). The same authors find a negative correlation between machinery access and the share of female labour use. They find a gender difference in labour use due to machinery but not for other modern inputs such as fertilizer. Therefore, it will be interesting to consider how the share of male and female labour use is affected by machinery adoption, in addition to the management of cultivated plots.

### *b. Mechanization opening up earlier planting*

The second direct effect of mechanization is to increase the probability that farmers can plant early, thanks to the time-saving nature of mechanized plowing. If the timing of planting were a constraint on farmer's optimization, then alleviating that constraint through tractor plowing will lead to changes in the choice of crops, and the allocation of labour (and other inputs) for subsequent production activities, such as weeding, crop maintenance, harvesting, and post-harvest processing.

There is no agronomic reason for farmers to engage in different post-planting management practices when they use mechanized plowing than when they prepare land by hand. Consequently, there is no obvious reason to expect an increase in yield. However, machine plowing may allow farmers to have seeds planted in time to take advantage of early rains. And, because machine plowing lengthens the effective growing season, it may allow farmers to alter their crop choices and therefore inputs in complex ways (see also: Ruthenberg 1980, pp.105–106). For crops such as maize (in northern Ghana), there is a limited planting period due to the longer growing period needed for maize and the volatile rain patterns. Maize requires earlier planting and is more sensitive to the time of planting than traditional cereal and root crops such as sorghum, millet, yam, and cassava (FAO & FEWSNET, 2017). Maize is also a higher value and market-orientated crop. Therefore, farmers will increase their cultivation of maize when tractor plowing is used (M. Kansanga et al., 2018). Maize cultivation is also associated with higher use of fertilizers in order to achieve good yields in northern Ghana. The use of tractor plowing therefore induces farmers to cultivate a crop which has a higher potential return but is also more expensive and riskier to cultivate.

With higher expected yield due to timely planting and a shift to higher value crops, the expected returns to carrying out crop maintenance activities such as weeding, fertilizer application, and pest control will also increase. Farmers will then allocate more labour to those activities. Subsequently, labour used to harvest and process the output will also increase if crop maintenance activities increase the yield. We may in fact find that labour use or chemical use for these operations increases due to tractor use for land preparation. The underlying assumption here is that farmers, without tractor plowing, were choosing an effort level which was a low-level optimum, due to the constraint of not planting early.

Inasmuch as there are gendered differences in which crops are cultivated, and whose labour is used for which crops, then alleviating the timing constraint the mechanization could have a differential impact on male and female agricultural activities. The timing of planting for maize is the same whether the plot is cultivated by a male or female household member. The difference would come in whether the female household member were able to respond by increasing labour use for weeding and harvesting on their plots, as easily as male household members.

The two theoretical impacts of machinery use which have been outlined point to potentially contradictory expectations of the empirical impact of mechanization use of a range of production decisions. Some patterns in the data may support the idea that mechanization arises as a response to a labour constraint; other patterns may point to the value of mechanization for early planting. Obviously, these constraints are linked with each other; but the key distinction is that the timing constraint provides a motivation to use machinery independent of relative factor costs. Previous theories would have suggested that machinery use could be predicted solely from changes in relative factor prices. The timing channel implies that tractor plowing may become attractive because of changes in relative crop prices (e.g., a sufficiently high relative price of maize) or weather patterns, without any change in relative factor prices.

This theory adds a new mechanism to those considered by the theories of mechanization which have come before. Binswanger and Pingali, following Boserup and others, focused on land abundance and factor scarcity as the predominant determinants of mechanization. The contribution here is that I consider a potential timing constraint. In the next section, I report on analysis that asks whether the timing constraint is empirically salient for farmers in Ghana.

## III. Context of tractor plowing in Ghana

Apart from import data on agricultural machinery, there is little reliable information on the total stock of tractors and other machinery either currently or over previous decades in Ghana. Diao et al. (2012) show import data from Customs and Excise that indicates that 200-900 pieces of agricultural machinery were imported annually over the period of 2002-2012. This is likely an over-estimate as the data may also include some construction machinery. Another indication is administrative data from the Ministry of Food and Agriculture, which shows that approximately 900 pieces of newly imported agricultural machinery have been distributed since 2007 under their mechanization programs across the entire country. Whilst there is no clear data on the number of functional pieces of equipment in use, these data on government programs and imports indicate that there is a substantial stock of machinery in the country.

Furthermore, there is evidence of high use of agricultural machinery amongst farmers, based on recent household surveys. The 2009-10 Ghana Socioeconomic Panel Study Survey provides data from a nationally representative survey of household agricultural production. According to these data, 31% of farm households across Ghana were using agricultural machinery for cultivation on at least one of their plots in 2009 (Table 7). Once this is broken down by region, 88-95% of farm households in the three northern regions used tractors for cultivation on at least one plot. The representativeness of this survey confirms that tractor use is not isolated to a few large-scale farmers; on the contrary, mechanized land cultivation is now standard amongst farmers of all scales in some parts of Ghana. The patterns are highly geographically concentrated. Tractor use is ubiquitous in the northern portions of the country, but further south, tractor use declines, and there is almost no tractor use in some regions in the forest and coastal zones.

**Table 7: Levels of tractor use in Ghana by region**

| Region | % of farm households using tractor on at least one plot | No. of farm households surveyed |
|---|---|---|
| Western | 0% | 262 |
| Central | 1% | 156 |
| Greater Accra | 46% | 28 |
| Volta | 24% | 243 |
| Eastern | 4% | 267 |
| Ashanti | 7% | 181 |
| Brong Ahafo | 6% | 282 |
| Northern | 95% | 347 |
| Upper East | 88% | 125 |
| Upper West | 95% | 56 |
| Total | 31% | 1947 |

Source: 2009-10 Ghana Socioeconomic Panel Study Survey, EGC-ISSER.

In particular, the increased use of tractor plowing in recent decades has been associated with increased area of cultivation and shift towards production of maize for an increasingly urban domestic population. Kansanga *et al.*, (2018) find that between 2005 and 2016, farmers increased their farm area by 1.08ha on average in their study of two districts in northern

Ghana. Qualitatively, farmers attributed this increase to their growing reliance on tractor plowing and cultivation of maize. The technology choice for land preparation is between using manual labour and a hoe to turn over the soil; and the alternative of applying herbicide followed by plowing with a tractor. Farmers in northern Ghana do not tend to plow more than once, nor do they use harrows and other implements to level and fully prepare the land for planting. The standard approach calls for a four-wheeled tractor of 55-75 horsepower that pulls a disc-plow attachment. In some irrigated rice projects, walking power-tillers are used but they are not commonly found beyond those irrigated schemes.

The market for tractor plowing services is more thoroughly analyzed in the third paper of this thesis; however a summary is provided here for context. Tractor owners provide services to farmers of all scales. A rate of 45-60 Ghana cedis is paid per acre for a single plow of the land (approximately £7-£10).[28] Tractor owners are usually medium- or large-scale farmers who have bought one or two tractors through the second-hand market. The owners often pay an operator to drive the tractor, who is responsible for organizing service of customers, and maintaining the equipment. The price the farmer pays includes the cost of fuel as well as the payment to the driver to carry out the plowing. Most often, farmers do not operate the tractor themselves.

[28] Maize price for 100kg in 2008/09 was 54 GHC. Average yield for Northern Ghana was 1.15 MT per ha (Boadu, 2012). Therefore, from 1 ha of land, a farmer will earn approximately 620 GHC (approximately £100). The cost of tractor plowing is approximately 18% of revenue per ha.

The government does not directly provide services to farmers for tractor plowing or engage in the market for tractor services directly. However, the market for tractor equipment has been impacted by government subsidizing the import of agricultural machinery since the early 2000s. Several iterations of mechanization policy resulted in the government's Agricultural Mechanization Service Center scheme which took place in phases over 2007-2010. The scheme involved the allocation of 5 or 7 tractors to a single entrepreneur in a district. The machinery would be imported by the government and then sold to private entrepreneurs under hire-purchase arrangements, with the intention that tractors and the provided implements be used to provide services to other farmers. The government is not involved in the tractor service market, in the organisation or allocation of tractor services, nor the ongoing maintenance of the subsidized machinery.

It has been estimated that in the context of Ghana, a tractor can plow up to 180 ha per year in the north, and 240 ha per year in the south (N. Houssou et al., 2013). For the average household farm size of 2.75 ha in the EGC/ISSER survey, this equates to an additional capacity in each district to serve between 330 and 620 additional farm households. For the northern districts in the survey, their population of households ranges from 15,000 to 28,000 per district. Thus, if the tractors were allocated evenly across the region, there would have been the potential for the scheme to enable an additional 2-4% of households to access tractor plowing services. The only accurate information on the stock of tractors in Ghana by district is from 2013 when a USAID and ACDI-VOCA project conducted a census of tractors in northern Ghana. On average there were 81 tractors found per district in the Northern Region. These figures should be taken as an upper limit on the actual stock of tractors in 2009, as the census was carried out in 2013. With that in mind, a conservative estimate would be that the government scheme increased the tractor stock by 6-8% per district on average.[29] The precise numbers do not matter for the analytical approach, but illustrate that there is potential for a quantitatively meaningful effect of the government scheme on the supply of tractor services.

## IV. Methodology

This paper seeks to identify the average effect of a farmer using tractor plowing (either through ownership or service provision) on productivity, scale of production, labour use, and chemical input use. The effect on gender differences in control over plots and labour use will also be considered. There are challenges in identifying such effects in a single time period. A simple ordinary least squares approach would fail to account for likely endogeneity in tractor use. The main reason for this suspicion is that any variable capturing household tractor use may also be capturing other factors such as farmer ability, quality of local extension services, market access, or agro-ecological potential which would all increase the probability of a farmer using tractor-plowing, whilst also improving agricultural productivity, relative factor costs, and access to technologies complementary to tractor-plowing. A simple OLS regression would not reveal whether tractor-using farmers have higher productivity because of tractor-plowing per se, or whether more productive farmers are able to afford access to tractor-plowing technology and therefore more likely to have plowed their land with machinery. In fact, under OLS, the estimated coefficient for tractor use would be biased. For

[29] These are just back-of-the-envelope estimates but should illustrate the potential for the government scheme to create a meaningful supply shock.

example, we would expect the OLS coefficient to overestimate the effect of tractor use on productivity since the variable for tractor use may be capturing not just tractor use, but a farmer's ability as well.

For this reason, an instrumental variable approach will be used which allows for causal inference in a non-experimental setting. The causal effect will only be identified for those farmers whose machinery use changes in response to an exogenous supply shock, i.e. those who ordinarily just miss out on tractor plowing due to weaknesses in the service market. The effect that is estimated will only be for short-term within-season effects.

This approach is relevant because most farmers in Ghana access machinery technology through a service market rather than through individual ownership. For many farmers, timely access to machinery services is not guaranteed and so changes to the local market for tractor services have the potential to impact smallholder agricultural production each season. Given the weaknesses in the service market, it is important to understand how farmers who face uncertainty over accessing mechanized plowing will respond in their subsequent production decisions. With this focus on changes within-season, land ownership will be somewhat fixed as land holdings are more easily changed between seasons than within season. However, in many cases, farmers in Ghana only cultivate a fraction of their total land, leaving some fallow. They will own or have rights to more land than is cultivated in a particular season. In this way, tractor plowing allows them to increase the area which is cultivated along that margin.

The unit of analysis is the farm household throughout. Plot-level variables are used and aggregated to the household level. The reasons for this are that labour and other resources are often shared across plots farmed by the same household, so that it is not meaningful to consider variables for each plot individually. Even if a tractor is used on only one of the household's plots, there may be a reallocation of labour and other resources which affects all plots.

Other papers have sought to look directly at the impact of the government scheme to increase the supply of tractor service through setting up agricultural mechanization centres (or AMSEC). Benin (2015) surveyed tractor owners and their service recipients, as well as a sampled comparison group to investigate the impacts of the scheme. This paper benefits from a sample design which is independent of the scheme. It also does not directly consider the effectiveness of the scheme, but instead uses its implementation as an instrument for tractor use.

### *a. Data*

The primary dataset which will capture farmer behavior is the 2009-10 Ghana Socioeconomic Panel Study Survey that is a nationally representative survey of over 5,000 households in Ghana. The survey is a joint effort undertaken by the Institute of Statistical, Social and Economic Research (ISSER) at the University of Ghana and the Economic Growth Centre (EGC) at Yale University.[30] It was funded by the Economic Growth Center.

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[30] Disclaimer: ISSER and the EGC are not responsible for the estimations reported here.

The survey includes approximately 2,800 households that responded to a detailed agricultural module relating to the 2009 main season. The survey was administered from November 2009 to April 2010, and questions were asked about the last main season and the last minor season. Our attention is on the last main season, which would have been May-October 2009. The data currently available is a single cross-section. The survey used a two-stage sampling design whereby 334 enumeration areas were selected in order to be representative of each of the 10 regions in Ghana. Within each enumeration area, 15 households were randomly selected. Information on district locations for each sampled enumeration area is provided, but the sample is not stratified by district. Furthermore, the survey dataset has captured plot-level machinery use. Previous national agriculture surveys which have captured machinery as an asset but have not documented machinery use in agricultural production.

As mentioned above, an instrumental variable will be used to deal with suspected endogeneity of tractor use and several of the outcome variables. The instrument relies upon administrative data obtained from the Agricultural Engineering Services Directorate at the Ministry of Food and Agriculture (Government of Ghana) which has the ongoing responsibility to administer the mechanization policy and associated schemes. The data provides information on each allocation of machines to private entrepreneurs as part of the Agricultural Mechanization Service Centre scheme which was done in phases over 2007-2010. Information is provided on the date of allocation, the number of machines which were allocated, and the address of the enterprise receiving the machinery allocation.

In addition to household survey data, information on population density, agro-ecological conditions, welfare level, remoteness, and election results are used as controls. District population density is taken from the Population and Housing Census from 2000, provided through Minnesota Population Center (2015)[31]. From HarvestChoice, measures of the length of growing period and travel time to the nearest 50,000 populous town are used (HarvestChoice, 2015a; HarvestChoice & International Food Policy Research Institute (IFPRI), 2016). The median value for each district was used, based on the geo-spatial administrative boundaries from IPUMS 2000. These indicators have been shown to be important in explaining the conditions which are correlated with mechanization use (Paper 1 of this thesis). Controls for income or welfare cannot be used from the household survey, as they will be affected by the use of machinery. As a proxy, I use the Core Welfare Indicator Questionnaire from 2003 (Ghana Statistical Service, 2005). This provides a welfare index for which the mean is taken for each district. Finally, public records of results from the 2004 Parliamentary Election are used to construct a dummy variable for those districts where the results were marginal, i.e. the winning candidate received less than 60% of the vote share. This is used as a district control, as it may be that more marginal constituencies attract more public funding, both in terms of the agricultural mechanization program and other productivity-enhancing public investments.

[31] The author wishes to acknowledge the statistical offices that provided the underlying data making this research possible: Ghana Statistical Services, Ghana.

*b. Empirical model*

The model which would ideally be estimated is the following. The unit of analysis is the household, denoted by $i$, which sit within a district, denoted $j$.

$$y_{ij} = \alpha + \beta T_{ij} + \gamma X_{ij} + \delta C_j + \epsilon_{ij} \quad (1)$$

where,

$y_{ij}$ : vector of outcome variables for agricultural productivity, labour use, chemical use, and the scale of production. More details on their measurement follow in this section.

$T_{ij}$ : dummy variable taking the value 1 for households which used machine plowing on at least one plot

$X_{ij}$ : set of variables capturing household characteristics such as quality of housing, assets, number of household members

$C_j$ : set of district characteristics capturing population density, remoteness, welfare, length of growing period, and election margins.

This model is initially estimated by OLS but those estimates of $\beta$ are likely to be biased due to endogeneity. Therefore, we cannot conclude any causality from OLS estimation of this model. However, estimated coefficients will indicate the partial correlations between outcomes and tractor use. The covariates at household and district level provide some limited control for endogeneity from observables such as household wealth, local population density, and agro-ecological conditions. The observables will affect whether a farmer uses tractor plowing, and also affect outcomes such as productivity and labour use. For example, labour use for land preparation will fall if tractor plowing is used, but equally it would be true that tractor plowing is more likely to be used where there is a lack of labour available either due to small household size, or lack of hired labour availability.

However, these covariates are not sufficient to deal with all the endogeneity that is present. Firstly, the single cross-section limits the analysis to using control variables which are collected ex-post and which are unaffected by tractor use. Propensity score matching relies upon the observable variables sufficiently controlling for all differences between households, except those variables affected by tractor use. With this in mind, the method was used as a robustness check, although in this case there is not sufficient common support on observable variables to confidently use the method.

With non-random pseudo experiments, the challenge of identifying causality is hampered by differences between tractor users and non-users due to observable and unobservable factors. In this case, the unobservable variation between tractor users and non-users will be considerable. It is feasible that some districts or villages have a longer history of machinery use due to private or public investments which have created individual and market capabilities for the supply and use of machinery. This unobserved capability - over and above the observed variation in urban proximity, population density, wealth, and agro-ecological conditions – will increase the probability of a farmer using machinery, and also be correlated with higher input use, more cultivation of maize, and higher farm productivity. To deal with these unobserved sources of endogeneity, an instrumental variable approach will be used.

A pseudo-experiment is constructed using the government mechanization scheme as a plausibly exogenous supply shock. The dummy variable indicating assignment to treatment and control groups, $Z_j$, is then used as an instrument for $T_{ij}$, household tractor use. The estimation strategy will use a Local Average Treatment Effect (LATE) approach to create an appropriate counterfactual to estimate the effect of machinery use. The treatment effect – tractor use – will be instrumented by the intention to treat – residing in a treated district.

The created treatment group is the set of farm households in those districts for which a mechanization centre was established before the 2009 main season (up to March 2009). The control group is farm households in districts which received AMSECs from July 2009 onwards. Figure A4 indicates the location of these districts. In total, 89 AMSECS were set up between 2008 and 2010. The control districts are selected as those districts which eventually received a mechanization centre, but not before the machines would be operational for the 2009 main season; i.e. the difference between the districts is the timing of program receipt. Those districts which were allocated AMSECS in the period April-June 2009 are excluded as the exact timing of the arrivals of the tractors relative to the plowing season is unknown. Table 8 indicates the survey coverage in terms of districts and households, by treatment and control group. A total of 662 surveyed households are included in the treatment and control districts, with information on tractor use recorded for 422 of those households.

**Table 8: Survey coverage, treatment, and control groups**

| Region | No. of districts | | | No. of farm households | | |
|---|---|---|---|---|---|---|
| | All survey | Treated | Control | All survey | Treated | Control |
| Western Region | 10 | 0 | 1 | 465 | 0 | 23 |
| Central Region | 13 | 1 | 0 | 420 | 15 | 0 |
| Greater Accra Region | 4 | 1 | 1 | 585 | 20 | 7 |
| Volta Region | 14 | 1 | 2 | 495 | 36 | 76 |
| Eastern Region | 18 | 1 | 0 | 630 | 11 | 0 |
| Ashanti Region | 24 | 0 | 2 | 900 | 0 | 20 |
| Brong Ahafo Region | 19 | 3 | 1 | 510 | 32 | 15 |
| Northern Region | 18 | 3 | 4 | 584 | 74 | 118 |
| Upper East Region | 6 | 2 | 0 | 240 | 68 | 0 |
| Upper West Region | 5 | 4 | 0 | 180 | 147 | 0 |
| | 131 | 16 | 11 | 5009 | 403 | 259 |

This empirical model follows the LATE theorem through which we can estimate the average treatment effect for those farmers who respond to the treatment. To apply the LATE theorem, an additional assumption of monotonicity is required. In this application, we need to reasonably assume that there are no farmers who would have used tractor services, but are not able to because the supply of tractor to the district has increased. This seems a reasonable assumption in the context.

### c. *Exogeneity of district allocation for government program*

As with any instrumental variables approach, exogeneity of the instrument and its relevance will need to be justified. If there had been a randomization of the order in which districts benefitted from the government program, then we could be sure of the exogeneity of the instrument. As documented in the literature, where this randomization is imperfect, covariates can be used in order to satisfy the unconfoundedness assumption (Angrist & Pischke, 2009; Imbens & Wooldridge, 2009). The covariates must be variables which are unaffected by the treatment. I will make the case that there is as-good-as random assignment of households into the treated or control groups. What follows will explain (i) the assignment of districts to treatment and control groups, and (ii) evidence of balance on key household and district variables.

Over 2008-2009-2010, the government distributed packages of 5-7 tractors and implements to entrepreneurs under hire-purchase arrangements, and with subsidized cost. The machinery was imported new from India and Brazil. The distribution was phased, coinciding with each round of imports. The documentation relating to the program indicates that allocation was based on (i) having one mechanization centre per district, and (ii) that the entrepreneur's demonstrated their ability to repay the loan and to operate a hiring business with the machines. From interviews with government officials involved in the program, there is no indication that the selection of districts between each phase was based on prioritizing areas with higher agricultural potential, or with a deficiency in tractor stock. In fact, there was no record of the stock of tractors by district in Ghana at that time. The order in which districts were allocated was not formally randomized. The exact process of allocation is opaque, although it was not officially correlated with the demographic, economic, or agricultural conditions of the district. However, we obviously cannot ignore that there may be political and other undocumented reasons for the phasing of the government intervention that could well be correlated directly with machinery use.

We now need to consider those variables which could capture any undocumented correlation between the government allocation of districts, and the outcome variables regarding farmers' machinery use, and agricultural production decisions. Districts which are wealthier and have higher agricultural potential may be likely to have a private sector with greater capacity to make use of the government scheme, as well as farmers who can afford to pay for machinery services. Areas with better road infrastructure could also have been given priority in the allocation of machines, due to the lower transport cost of delivering the government package of machines and implements. Finally, local farming systems with lower population density and shorter growing periods may have higher returns to machinery use due to relatively abundant land and timeliness benefit of machine use (see Paper 1 of this thesis; Cossar 2016). The government program effectively reduces the price of machinery services through a positive supply shock. The extent to which this induces farmers to use mechanized technology, instead of manual labour, will depend upon the relative availability (and cost) of land and labour, and the returns to machinery use.

Although not documented, it could be imagined that political factors which enabled some districts to receive the government allocation earlier than others, also enable those districts to receive other public investments such as agricultural support and transport infrastructure which would reduce transaction costs and increase farm productivity. This would be an important violation of the exclusion restriction, with the instrumental variable affecting the farm outcomes directly. To assuage this concern, data from the 2004 parliamentary elections is used to construct a dummy for those districts where the result was close (defined as the winning candidate receiving less than 60% vote share). It is a common hypothesis in the literature that marginal electoral areas attract more public funding in subsequent years than electorally safe areas. Some evidence of this has been found in Ghana (André & Mesplé-

Somps, 2011; Bossuroy, 2011). In addition, the survey provides data on the frequency of households' contacts with agricultural extension agents.

These district-level factors which may violate the exclusion restriction are presented in Table 9. Whilst there is no significant difference in the variables between treated and control districts, the sample size is small which will under power statistical tests. The treatment districts do seem to have higher population density, shorter growing periods and slightly shorter travel time. The welfare index indicates that the districts are very similar in terms of average welfare of the district. On the political variable, 75% of the treated districts had a marginal election result in 2004, whereas 55% of the control districts did. Given this variation, all these district variables will be included as controls in the empirical models.

In addition to looking at the difference in means, these district variables are plotted by the month in which government machinery was allocated to the district. Figure A 5 shows these scatter plots, with the cutoff for before and after the main plowing season in May 2009. There is little evidence of a systematic relationship between the timing of allocation and these district level variables. The exception would be the travel time to nearest town variable (denoted as tt50k). Both Figure A 5 and Table 9 show evidence that the slightly more remote districts with longer travel times were more likely to receive the government allocation later.

Table 10 considers a range of variables which capture differences between households in the treatment and control districts. A range of farm household characteristics are presented to check that, without the intervention, the households in each group are as similar as possible. Significant differences are found for the quality of housing and land. Households in the treated districts are less likely to have better quality housing, evidenced by having a cement floor in the main dwelling. By farmer-reported measures, plots in the treated districts less likely to be described as heavy clay. There is no significant difference in land area owned by households.

The biggest concerns which would threaten this assumption would be (i) local government capacity, or (ii) better infrastructure. If local governments with greater capacity for implementing the scheme received the mechanization centre first, and that government capacity is also enabling better agricultural extension services, then the estimated effects for productivity and modern input use could be due to local government capacity rather than household machinery use. Table 10 indicates that fewer than 5% of surveyed farmers in the treated districts, and 8% of surveyed farmers in the control districts had been visited by an extension agent in the last six months. It is unlikely that differences in the local agricultural extension system are driving the estimated effects. The second concern would be that better connected districts benefit from the scheme first because it is quicker and cheaper to get the machinery to the district from Accra. Table 10 does shows that treated district are slightly better connected that the control districts. Visual inspection of the fourth plot in Figure A5 also suggests a relationship between the average travel time for the district and when the program was implemented. The travel time variable is included as a covariate in all the regression models to account for this, as are the other district level covariates.

However, as with most instruments, there may remain some unobservable variables that affect both the instrument and the outcomes directly, thereby violating the exclusion restriction. Where the exclusion restriction fails, the estimates of treatment effects will be more sensitive when the instrument is weak. The statistical tests do not indicate that the instrument is weak, but given the small number of clusters in the sample, we should be wary of this. As part of the robustness checks, there will be analysis of the sensitivity of the estimated treatment effects to direct correlation between the instrument and the outcomes. This will be done following the methods developed by Conley, Hansen and Rossi (2012) which produces a set of confidence intervals for the treatment effect, allowing for different levels of correlation between the instrument and outcome variable.

On the basis of the above discussion, I assume unconfoundedness of the instrument, controlling for the aforementioned covariates at district and household level. Observable differences between the two groups are controlled for; unobserved differences are assumed to average out through the pseudo-random ordering of the government allocations. Although exogeneity cannot be tested for a single instrument, evidence on the balance between groups and on the policy process provide sufficient confidence that the instrument is as-good-as orthogonal to the outcome variables.

### Table 9: Balance for district level variables

| | Control districts Mean | n | Treated districts Mean | n | Difference in means | p-value for equality of means |
|---|---|---|---|---|---|---|
| Population density (district, 2000) | 65.13 | 11 | 119.33 | 16 | 54.2 | 0.32 |
| Average length of growing period (district) | 244.01 | 11 | 223.31 | 16 | -20.7 | 0.21 |
| Travel time to nearest 50,000 populous town (median, district) | 3.79 | 11 | 2.92 | 16 | -0.87 | 0.17 |
| Welfare Index (2003, mean, district) | 15.73 | 11 | 15.53 | 16 | -0.2 | 0.70 |
| Marginal election result (2004) | 0.55 | 11 | 0.75 | 16 | 0.2 | 0.29 |

Sources: Population density source from IPUMS using 2000 Population and Housing Census (Government of Ghana); length of growing period and travel time to 50k town are from IFPRI's HarvestChoice; and Welfare Index is from the Core Welfare Indicator Questionnaire survey conducted in 2003. Marginal election result is a dummy which takes the value 1 if the winner got less than 60% of the vote share, and zero otherwise. N is the number of districts.

**Table 10: Balance for household level variables**

| | Control districts | | Treated districts | | Difference in means | p-value for equality of means |
|---|---|---|---|---|---|---|
| | Mean | n | Mean | n | | |
| Female hh head | 0.21 | 259 | 0.19 | 402 | -0.02 | 0.54 |
| Age of hh head | 50.1 | 259 | 51.06 | 402 | 0.96 | 0.46 |
| Education level of hh head | 20.47 | 103 | 20.36 | 120 | -0.11 | 0.88 |
| Size of hh | 5.09 | 259 | 4.85 | 402 | -0.24 | 0.28 |
| Urban area | 0.13 | 259 | 0.07 | 402 | -0.06 | 0.01 |
| HH owns a motorbike | 0.08 | 259 | 0.12 | 402 | 0.04 | 0.19 |
| Hh head in-migrated less than 5 years ago | 0.02 | 259 | 0.01 | 402 | -0.01 | 0.48 |
| Main dwelling has cement floor | 0.31 | 259 | 0.14 | 402 | -0.17 | 0.00 |
| Land owned by hh (ha) | 2.63 | 254 | 2.48 | 400 | -0.15 | 0.50 |
| % of land described as heavy clay | 0.08 | 259 | 0.06 | 402 | -0.02 | 0.09 |
| % of land described as less wet than local community | 0.12 | 259 | 0.08 | 402 | -0.04 | 0.07 |
| Contact with agricultural extension agent in last 12 months | 0.08 | 259 | 0.05 | 402 | -0.03 | 0.25 |

Sources: Data from EGC/ISSER Socioeconomic Panel Survey 2009/10. N is the number of households

### d. Relevance of the instrument for tractor use

Is there good reason to think that the scale of the government program would create an adequate supply shock in the market for tractor services in each district to influence farmer tractor use? As mentioned in the context, the scale of the government program relative to the scale of the market for tractor services has the potential to have a small but noticeable impact. In this section, I will consider the first-stage regression and the statistical relationship between the instrument and tractor use. I also randomize the allocation of districts into treated and control groups, to show that the first stage effect that is found is not just down to chance.

Statistically, evidence that the instrument is relevant and strong is from the first-stage regression, formulated as follows:

$$T_{ij} = \alpha + \beta Z_{ij} + \gamma X_{ij} + \delta C_j + \epsilon_{ij} \qquad (2)$$

Where, for household $i$, in district $j$:

$T_{ij}$ : dummy variable taking the value 1 for households which used machine plowing on at least one plot

$Z_{ij}$ : dummy variable taking the value 1 for households in treated districts (received machine package before 2009 season), and 0 for households in control districts (received machine package after 2009 season).

$X_{ij}$ : set of variables capturing household characteristics such as quality of housing, assets, number of household members

$C_j$ : set of district characteristics capturing population density, remoteness, welfare, length of growing period, and election results

Table 11 shows the results of a first stage regression of tractor use (by the household on at least one plot), on treatment dummy with district and household controls. There are some missing values for tractor use in the survey which reduces the sample to 422 households.[32]

Each of the estimated models indicates that being in the treated group increases the probability of the household using tractor plowing on at least one plot. For model (3), the increase is 11 percentage points. The coefficient is significant across the specifications where regional fixed effects are included and the F-statistic for the joint significance is consistently greater than the rule-of-thumb value of 10 and the relevant critical value from Stock and Yogo (2002).[33] This indicates that the instrument is not weak and is partially correlated with tractor use.

[32] Non respondents in the matched districts are less likely to be female headed households, more likely to be in an urban enumeration area, and less likely to have a cement floor in the main dwelling. These are controlled for in the regressions. Other balance variables were not significantly different between response and non-response households.

[33] For one endogenous regressor, one instrument, 5% significance level, and a desired maximal bias size of 0.25 for a 5% Wald Test of B=Bo, the critical value is 5.53. If the F-stat is greater than the critical value, we reject the null of a weak instrument, and can conclude that the instrument is relevant.

### Table 11: First stage regression

*Dependent variable: Dummy for tractor use by hh on at least one plot in major season*

| | (1) OLS | (2) OLS | (3) OLS | (4) Probit | (5) Probit | (6) Probit |
|---|---|---|---|---|---|---|
| treated district | -0.09*** | 0.10** | 0.11** | -0.33* | 0.76** | 0.69** |
| | (0.03) | (0.05) | (0.06) | (0.18) | (0.31) | (0.33) |
| Population density (2000, district) | -0.00* | -0.00*** | -0.00*** | 0 | 0 | 0 |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) |
| Length of growing period (district median) | -0.01*** | -0.01*** | -0.01*** | -0.02*** | -0.08*** | -0.09*** |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.02) | (0.02) |
| Travel time to nearest 50k town (district median) | -0.12*** | -0.11*** | -0.11*** | -0.35*** | -0.27* | -0.35** |
| | (0.02) | (0.02) | (0.02) | (0.08) | (0.16) | (0.16) |
| Welfare index (district mean) | -0.14*** | -0.02 | -0.02 | -0.90*** | -0.15 | -0.15 |
| | (0.02) | (0.03) | (0.03) | (0.20) | (0.28) | (0.29) |
| Marginal election result (2004, district) | -0.15*** | -0.11* | -0.13* | -0.43* | 0.2 | 0.16 |
| | (0.05) | (0.07) | (0.07) | (0.23) | (0.36) | (0.39) |
| regional fixed effects | no | yes | yes | no | yes | yes |
| household controls | no | no | yes | no | no | yes |
| R2/pseudo-R2 | 0.67 | 0.69 | 0.69 | 0.62 | 0.60 | 0.63 |
| N | 422 | 422 | 422 | 422 | 387 | 387 |
| F-stat/Wald | 534.69 | . | 768.58 | 170.00 | 389.52 | 330.78 |

Note: Household controls are: owning a motorbike, migrating into the area in last 5 years, main dwelling has a cement floor, no. of household members, age of household head, female household head, proportion of land described as heavy clay, contact with an agricultural extension agent, and being in an urban enumeration area. Standard errors are robust. Model (6) is used for subsequent second stage regressions.

The question is whether the difference in tractor use between the treatment and control groups can be attributed to the exogenous supply shock, captured by the timing of allocating government machinery. The effect which is found could just be down to chance. In order to rule this out, the assignment of districts between the pre-2009 main season and post-2009 main season treatment and control groups was randomized. If the roll out of the government program is meaningful in affecting tractor use at the district level, we would expect a random assignment into these groups to find no significant effect of treatment on tractor use. This randomization was carried out 1,000 times, the first stage regression model estimated for each placebo treatment variable, and the resulting estimated $\beta$ (from equation 2) plotted in a histogram (Figure A6). Given this distribution of estimated coefficients, the probability of getting the estimated effect from my sample is less than 10%. This gives confidence that the effect which is found is due to the government program, and not due to chance.

### *e. Outcome variables*

The purpose of this methodological approach is to understand the effect of tractor use on farmers' decision over other farm inputs, scale of production, and productivity. The variables which will be used to represent these outcomes are described below, and their descriptive statistics provided in Table 12.

Productivity is considered in terms of the total value of agricultural output, and the quantity of production for maize. Maize is the most commonly grown crop and is also one which is particularly used with tractor plowing. Yield, or land productivity, is the total maize harvest for the household, divided by the total labour days, family or hired, used on all maize plots.

Yield or land productivity is similarly the total maize harvest for the household, divided by the total area of all maize plots farmed by the household members. The shift towards maize production may have a negligible effect on maize yield by weight, but overall value of production for all crops may increase as the price of maize relatively to other crops is high. The second measures of productivity take the farmer-reported market value for all crops, across all plots and consider this total value per hectare cultivated, and per person day used for agricultural production. Table 12 shows the average yield and output per person day for the sample, for both maize and the value of all crops. These statistics are consistent with estimates in the literature for maize yields in Ghana and elsewhere (Nin-Pratt & McBride, 2014; Suri, 2011).

As discussed widely in the literature, productivity is often found to vary with the scale of production. Therefore, the variable for the area of land which is owned by the households is included in the regressions for land and labour productivity. Small farms, both within and across countries, are found to have higher yields than large scale farms, yet smallholder farmers often struggle to achieve adequate incomes (Jayne et al., 2010). The theoretical reasons proposed are the increasing costs for labour supervision with farm scale, higher incentives for family labour over smaller farms, and lower labour costs for small owner-operated family farms (for example: Barrett, Bellemare, & Hou, 2010; Feder, 1985; Larson, 2012). Studies that have found evidence of the inverse farm size-productivity relationship in SSA, however these are frequently challenged on the basis of measurement issues which affect plot sizes, labour use, and recorded information on agricultural output (Carletto, Savastano, & Zezza, 2013; Desiere & Jolliffe, 2018). If productivity is dependent upon the scale of cultivation, then the estimate of treatment effect will be biased if land area is not included. However, the argument could be made that area owned is affected by the use of machinery, and therefore should not be included as a control variable. However, the extent to which a farm household can borrow, rent-in, or acquire more land during the season is likely limited.

Both measures of productivity rely on the farmer-reported harvest. There is considerable heterogeneity in land and labour productivity across farmers in Ghana. Some of this is due to differences in farmer ability, soil quality, and input use. However, some of this difference is due to difficulty of accurately measuring output, plot area, and labour use in household surveys of this type. In the survey, quantity of output is reported in terms of a variety of units (e.g. kg, litre, bucket, beer bottle). Precise conversions have not been provided from the survey and so there may be some inaccuracy in the measurement. There are also limitations in basing the analysis of productivity on the output for a single year. The harvest will be susceptible to weather variations. In the case of the 2009 main season, this was particularly true. Excessive rainfall in the western Sahel caused flooding and destruction of crops in some areas of Ghana (OCHA, 2009; UN News, 2009). A control for those districts which were worst affected by the flooding, according to UN OCHA reports, is included (see Figure A 4).

**Table 12: Summary of tractor use and outcome variables**

| | Observations | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| Tractor use (on at least one plot in main season) | 422 | 0.61 | 0.49 | 0 | 1 |
| Yield (maize only, in kg) | 233 | 566.81 | 440.12 | 5.19 | 1976.80 |
| Output per person day of labour (kg) | 258 | 9.79 | 11.42 | 0 | 70.18 |
| Value of output per ha (cedis) | 418 | 116.22 | 286.41 | 0 | 1562.69 |
| Value of output per person-day (cedis) | 258 | 4.67 | 9.50 | 0 | 50.10 |
| Area cultivated (ha) | 407 | 2.54 | 2.70 | 0 | 24.28 |
| Area cultivated - maize (%) | 252 | 63.89 | 32.30 | 10 | 100.00 |
| Area cultivated - female holder (%) | 407 | 20.78 | 40.26 | 0 | 100.00 |
| Herbicide use per ha (kg) | 182 | 1.55 | 5.25 | 0 | 45.83 |
| Insecticide use per ha (kg) | 182 | 0.07 | 0.51 | 0 | 6.18 |
| Fertilizer use per ha (inorganic, kg) | 182 | 30.05 | 63.38 | 0 | 247.10 |
| Labour use per ha (land preparation, days) | 394 | 22.96 | 19.53 | 0 | 70.63 |
| Labour use per ha (field management, days) | 393 | 27.22 | 26.04 | 0 | 95.31 |
| Labour use per ha (harvest, days) | 383 | 19.18 | 15.92 | 0 | 55.60 |
| Labour use per ha (post-harvest, days) | 398 | 6.87 | 6.75 | 0 | 24.30 |
| Labour use per ha (all operations, hours) | 393 | 85.48 | 62.60 | 3.99 | 243.39 |
| Labour share: family and exchange | 412 | 73.66 | 30.82 | 0 | 100 |
| Family labour share: female | 392 | 40.15 | 28.66 | 0 | 100 |
| Labour share: hired | 412 | 26.34 | 30.82 | 0 | 100 |
| Hired labour share: female | 296 | 17.67 | 28.66 | 0 | 100 |

Note: Above variables are derived from the EGC/ISSER Socioeconomic Panel Survey 2009-10. Productivity and area variables were winsorized for high values at 0.5%. Chemical and labour use per ha were trimmed for extreme high values, and then winsorized for high and low values at 5%

The EGC/ISSER survey used farmers' self-reported plot sizes. To triangulate this information, an example plot of land was measured in each village and the farmer asked to compare their plot to this example plot. The variables I use are (i) total area cultivated by the household for the 2009 main season (may be less than area owned), (ii) area cultivated with maize as the main crop as a percentage of area cultivated, and (iii) the area of cultivated plots which are held by female household members as a percentage of area cultivated. Work on the measurement of farm sizes through farmers' self-reporting or using GPS estimates have found that smaller plots tend to be over-estimated by farmers. For the larger end of the size distribution, there can be under-reporting of land size (Carletto et al., 2015). Land size for smaller farmers may be over-estimated, and yield may be under-reported. These problems with measurement of land area and output may hamper estimation of treatment effects on these outcomes.

The survey questionnaire relied upon recall information at the end of the season on the labour use per plot. The questionnaire responses for labour hours by operation, by gender, and by labour type were aggregated across plots to the household level. The reported units for labour are person-days equivalent.[34] Labour type was combined into family labour which included exchange labour (i.e. labour provided on reciprocal basis by neighbouring farm households), and hired labour which included casual and permanent labour paid to work on the household's plots. There is evidence that this method of collecting labour data leads to over-

[34] Labour person days is calculated from the total number of hours spend working for all labourers. This total is then divided by 8 to give the number of person days (assumes 8-hour working day).

estimates of labour use (Arthi, Beegle, De Weerdt, & Palacios-López, 2018). However, this bias is likely to exist for both the treatment and control groups. The share of labour by type, and the share of each type which is provided by female labour is also derived. The mean total labour use for the sample is high but consistent with Ruthenberg's description of the labour intensity of fallow farming systems in tropics (Ruthenberg, 1980, pp. 88–89).

Theoretically, where there are labour market imperfections which constrain female participation in agriculture, we would expect that women will increase the absolute area of land which they cultivate. This would show up in a measure of the proportion of land which is cultivated by women v. men. Land ownership in the context of agricultural land in SSA is a concept which requires definition. Doss *et al.*, (2015) provide a useful overview of both conceptual definition and empirical measure of gender differences in land ownership and control. For the purposes of this paper, I am primarily concerned with changes in (i) male and female labour use across all plots in the household, and (ii) the land area over which women and men in the household have control in terms of decision-making and use of outputs. In Ghana, there is meaningful distinction between plots managed by men and women, with the choices over technology use relatively distinct (Doss & Morris, 2001).

Finally, measures of farm household use of herbicide, pesticide, and inorganic fertilizer per hectare are derived. The questionnaire collected information on the total amount of each chemical used per application and per plot. This was aggregated to give the total chemical use across all plots, and then divided by total cultivated area. The unit of measurement and conversion to kilograms is problematic. Many farmers provided the quantity used in terms of ambiguous units (e.g. bucket or beer bottle). Reasonable conversion rates were chosen, but the variables will remain imprecise.

### f. Method

The model will be estimated by two-stage least squares. The endogenous variable, $T_{ij}$, is a dummy variable, therefore estimating the first stage using OLS would incorrectly assume a linear model for a limited dependent variable. I use the fitted values from a probit regression of (2), $\hat{T}_{ij}$, as the instrument instead of $Z_{ij}$ directly (Wooldridge, 2010). Table 11 shows the results for the OLS and Probit regression models for the first stage (2). The standard two-stage least squares estimation procedure was then used with $\hat{T}_{ij}$ as the instrument for tractor use, in order to estimate the treatment effect of tractor use on the outcome variables. It is the local average treatment effect which is estimated, averaged across covariates (Angrist & Pischke, 2009, pp. 175–181). The effect which is estimated is only for compliers, namely those farm households which were induced to use tractor plowing due to the positive supply shock, and would not have used tractor plowing without the government-induced supply shock, all else equal.

Evidence on whether the instrument is sufficiently correlated with the endogenous variable (tractor use) is provided for each model. The F statistic for the first stage of each model is reported, and should be compared to the Stock & Yogo critical values for a weak identification test, which is 5.53 in this case (Stock & Yogo, 2002). If there is only weak correlation between the endogenous variable and its instrument, the standard errors for 2SLS will be much larger than for OLS, therefore making it less likely to find significant treatment effects. The p-value and confidence intervals for the coefficients in the main regression are calculated with the assumption that the instrument is not weak. Anderson-Rubin (AR) provide an alternative test statistic and p-value which are robust to whether the instrument is weak or not. The p-value for this test statistic, with the null that the coefficient in tractor use is zero, is reported in the tables of results. In most cases, the results of the AR test are consistent with the conventional test.

Given the modelling procedure, heteroscedasticity in the residuals may be a concern. Where there is heteroscedasticity, the conventional OLS standard errors will be under-estimated. The p-value for the Pagan & Hall test statistic for heteroscedasticity is reported, for the null hypothesis that the residuals are homoscedastic. Robust standard errors are more appropriate where there is heteroscedasticity, although in some cases the conventional standard errors maybe be larger (Abadie, Athey, Imbens, & Wooldridge, 2017; Angrist & Pischke, 2009). Angrist and Pischke (2009) suggest using the larger of the estimated standard errors. A further concern is that several of the covariates are aggregated at district level which reduces the effective sample size. Therefore, conventional standard errors are reported in the main results (Tables 13-17). Table 18 then provides results for the same model using robust standard errors with adjustment for small samples, and bootstrapped standard errors.

### *g. Robustness checks*

An alternative regression model is used, which also deals with concerns over unobservable which may affect both outcomes, and tractor use. Heckman's treatment effect model uses a control function approach to estimate the average treatment effect on the treated. This approach requires stronger assumptions than the 2SLS approach; namely it assumes joint normality of the errors. However, it has the advantage of allowing to tests for endogeneity and making it possible to estimate the average treatment effect for the sample, rather than just for those households affected by the government program. These results are reported in Table 19.

A further alternative method, which does not rely upon the instrumental variable is used. In order to construct a meaningful control group to those households found to be using tractor plowing, the simple treatment effect was estimated, using propensity score matching. The propensity score is calculated from the logit regression of tractor use on the same covariates of the main regression model. This method assumes that observed covariates which may explain tractor use and non-use are captured, and that any unobservable characteristics that affect tractor use and the outcomes are correlated with the observables. Data limitations make it difficult to rely on these assumptions. There are only limited variables in the ex-post dataset that are unaffected by treatment and so can be used as matching variables. Furthermore, the problems of endogeneity of tractor use are not fully dealt with. However, the approach is illustrative in verifying the robustness of the main findings. It is presented in Table A 5.

A final robustness check is to use an alternative dataset which enables me to control for unobservable variation across households. As a check on the results from the instrumental variable approach above, household and plot level data from a single district in Ghana is used. A major drawback of the method above is that unobservable household characteristics which will affect agricultural decisions and may also affect machinery use are unaccounted for. The assumption is that households in the treatment and control group are similar, on average, on unobservables. To check that this is not driving the results, Appendix VI: Tables and Figures for Paper 2 (p. 238) present results from a single district data set with plot-level observations and allows for household fixed effects, following the method of Shaban (1987). The full method and results are presented in Appendix VI. Whilst the dataset has considerable limitations for this purpose, the results are consistent with those of the main data and method.

## V. Results

Given the potential limitations of the data and method, the regression results will be presented with reference to alternative methods employed in the paper, to the qualitative understanding gathered from discussions with farmers, and to findings from the broader literature. The evidence from the main estimation results indicate that, for those farm households affected by the supply shock, machinery use leads to (i) an increased area of cultivation with proportionate increase in maize production, (ii) an increase in labour use for operations other than land preparation, and (iii) increased female engagement in agriculture. The proportion of land allocated to maize does not change, although absolute area increases along with total area due to tractor use. Herbicide use is found to be complementary to tractor use, but other chemical use remains unchanged. Labour and land productivity, in terms of output value, increase, but the effects are not significant in the two-stage least squares estimation. Estimates of the average treatment effect for the full sample, rather than just those affected by the supply shock for tractor services, indicate that tractor use leads to a shift to increased maize production as a proportion of land area, and increases in land and labour productivity. The results are presented in Table 13 to Table 17, and discussed in detail below.

## Table 13: Main results for productivity

| | Yield (maize, kg per ha) | | | Labour productivity (maize, kg per person day) | | | Output value per ha (all crops, cedis) | | | Output value per person day (all crops, cedis) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (1) OLS | (2) IV with area control | (3) IV with flood control | (1) OLS | (2) IV with area control | (3) IV with flood control | (1) OLS | (2) IV with area control | (3) IV with flood control | (1) OLS | (2) IV with area control | (3) IV with flood control |
| Tractor use | 41.77 | -190.2 | -182.6 | 1.85 | -8.94 | -9.66 | -27.11 | 207.97 | 169.55 | 1.07 | 9.44 | 10.15 |
| | (116.01) | (256.83) | (271.11) | (2.46) | (9.08) | (9.30) | (44.58) | (176.39) | (184.22) | (2.03) | (7.48) | (7.68) |
| Area owned by hh (ha) | | 13.8 | | | 0.31 | | | -14.37** | | | 0.24 | |
| | | (10.83) | | | (0.27) | | | (5.59) | | | (0.22) | |
| flood district (dummy) | | | -78.32 | | | -3.56 | | | 42.29 | | | -0.67 |
| | | | (115.92) | | | (2.82) | | | (64.18) | | | (2.33) |
| N | 233 | 233 | 233 | 258 | 256 | 258 | 418 | 411 | 411 | 258 | 256 | 258 |
| R2 adjusted | 0.08 | 0.07 | 0.06 | 0.19 | 0.12 | 0.11 | 0.27 | 0.23 | 0.23 | 0.2 | 0.14 | 0.13 |
| F-stat | 2.03 | 1.98 | 1.92 | 3.92 | 3.49 | 3.49 | 7.87 | 7.59 | 7.36 | 4.13 | 3.78 | 3.71 |
| F-stat (first stage excluded instruments) | | 48.85 | 44.64 | | 18.52 | 17.96 | | 26.94 | 24.81 | | 18.52 | 17.96 |
| Pagan & Hall's heteroscedasticity test (p-value) | | 1 | 1 | | 0.75 | 0.97 | | 0.01 | 0.21 | | 0.98 | 1 |
| Anderson-Rubin weak instrument F test (p-value) | | 0.48 | 0.52 | | 0.33 | 0.3 | | 0.24 | 0.36 | | 0.21 | 0.19 |

Note: Tractor use is instrumented using the predicted values of 'treatment' variable from probit regression of tractor use on treatment, hh assets, size, and urban EA variables, population density, length of growing period, travel time, marginal election result, and regional fixed effects (model 6 in Table 11). The p-value for Pagan and Hall's (1983) test of heteroscedasticity for instrumental variables (IV) estimation (null is homoscedasticity) is reported. For significance test of tractor use that is robust to a weak instrument in the first stage, the p-value for the Anderson-Rubin F statistic for the significance of the coefficient on tractor use is reported. Conventional standard errors are used in Tables 13-17; Robust standard errors, adjusted for small samples, and bootstrapped standard errors are used in Tables 18-19.

### Table 14: Main results for scale of production

| | Area cultivated (total) | | | Area cultivated (maize, %) | | | Area cultivated (female holder/cultivator, %) | | |
|---|---|---|---|---|---|---|---|---|---|
| | (1) OLS | (2) IV (conventional SE) | (3) IV with flood control | (1) OLS | (2) IV (conventional SE) | (3) IV with flood control | (1) OLS | (2) IV (conventional SE) | (3) IV with flood control |
| Tractor use | 0.53** | 4.32** | 4.94*** | 12.70*** | 9.78 | 16.82 | 2.16 | 26.76** | 27.99** |
| | (0.23) | (1.70) | (1.89) | (4.37) | (20.78) | (21.82) | (1.55) | (11.97) | (13.03) |
| flood district (dummy) | | | 1.17* | | | 11.51* | | | 2.31 |
| | | | (0.62) | | | (6.06) | | | (4.29) |
| N | 407 | 400 | 400 | 252 | 252 | 252 | 407 | 400 | 400 |
| R2 adjusted | 0.38 | 0.23 | 0.19 | 0.51 | 0.5 | 0.51 | 0.86 | 0.82 | 0.82 |
| F-stat | 13.23 | 10.46 | 9.47 | 37.1 | 13.57 | 13.22 | 631.15 | 93.65 | 87.77 |
| F-stat (first stage excluded instruments) | | 25.95 | 22.38 | | 16.96 | 15.14 | | 25.95 | 22.38 |
| Pagan & Hall's heteroscedasticity test (p-value) | | 1 | 1 | | 1 | 1 | | 0.05 | 0.08 |
| Anderson-Rubin weak instrument F test (p-value) | | 0.01 | 0 | | 0.66 | 0.47 | | 0.02 | 0.02 |

## Table 15: Main results for labour use by operation (person days)

| | Land preparation | | | Field management | | | Harvest | | | Post-Harvest | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (1) OLS | (2) IV (conven tional SE) | (3) IV with flood control | (1) OLS | (2) IV (conven tional SE) | (3) IV with flood control | (1) OLS | (2) IV (conven tional SE) | (3) IV with flood control | (1) OLS | (2) IV (conven tional SE) | (3) IV with flood control |
| Tractor use | -8.77** | -8.72 | -6.35 | -0.32 | 39.28** | 43.42** | 0.97 | 33.92** | 36.18** | 1.71 | 10.92** | 11.61** |
| | (4.04) | (12.79) | (13.66) | (5.32) | (17.09) | (18.55) | (3.29) | (13.72) | (15.13) | (1.27) | (5.37) | (5.88) |
| flood district (dummy) | | | 5.18 | | | 8.71 | | | 3.76 | | | 1.2 |
| | | | (4.79) | | | (6.63) | | | (4.53) | | | (1.82) |
| N | 394 | 387 | 387 | 393 | 391 | 391 | 383 | 376 | 376 | 398 | 391 | 391 |
| R2 adjusted | 0.07 | 0.07 | 0.07 | 0.15 | -0.05 | -0.09 | 0.13 | -0.2 | -0.25 | 0.07 | -0.09 | -0.12 |
| F-stat | 3.73 | 2.15 | 2.13 | 292.33 | 3.24 | 3.01 | 4.94 | 2.85 | 2.62 | 2.5 | 1.83 | 1.71 |
| F-stat (first stage excluded instruments) | | 31.74 | 27.95 | | 33.15 | 29.21 | | 21.17 | 18.14 | | 22.46 | 19.18 |
| Pagan & Hall's heteroscedasticity test (p-value) | | 0.88 | 0.89 | | 1.00 | 1.00 | | 1.00 | 1.00 | | 1 | 1 |
| Anderson-Rubin weak instrument F test (p-value) | | 0.51 | 0.65 | | 0.01 | 0.01 | | 0.00 | 0.01 | | 0.03 | 0.04 |

## Table 16: Main results for labour use by type

| | Total labour hours - female | | | Total labour hours - male | | | Female labour as share of family labour | | | Hired labour as share of total labour | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (1) | (2) | (3) | (1) | (2) | (3) | (1) | (2) | (3) |
| | OLS | IV (conventional SE) | IV with flood control | OLS | IV (conventional SE) | IV with flood control | OLS | IV (conventional SE) | IV with flood control | OLS | IV (conventional SE) | IV with flood control |
| Tractor use | 8.63 | 145.48** | 168.27** | 19.67 | 197.76 | 221.84 | 4.15 | 38.69** | 42.29* | 2.09 | -0.30 | 3.08 |
| | (10.79) | (70.66) | (77.89) | (19.46) | (134.63) | (146.72) | (4.28) | (19.32) | (21.79) | (5.63) | (19.77) | (21.58) |
| flood district (dummy) | | | 45.99* | | | 48.62 | | | 5.83 | | | 6.11 |
| | | | (26.97) | | | (50.80) | | | (6.94) | | | (6.97) |
| N | 422 | 415 | 415 | 422 | 415 | 415 | 392 | 385 | 385 | 412 | 405 | 405 |
| R2 adjusted | 0.11 | -0.02 | -0.06 | 0.15 | 0.11 | 0.09 | 0.34 | 0.22 | 0.19 | 0.25 | 0.26 | 0.26 |
| F-stat | 6.05 | 3.29 | 3.07 | 7.41 | 4.60 | 4.32 | 7.32 | 8.81 | 8.13 | 5.63 | 7.73 | 7.42 |
| F-stat (first stage excluded instruments) | | 28.71 | 24.75 | | 28.71 | 24.75 | | 21.07 | 17.24 | | 23.64 | 19.96 |
| Pagan & Hall's heteroscedasticity test (p-value) | | 1.00 | 1.00 | | 0.00 | 0.00 | | 0.93 | 0.98 | | 0.18 | 0.28 |
| Anderson-Rubin weak instrument F test (p-value) | | 0.03 | 0.02 | | 0.14 | 0.13 | | 0.03 | 0.04 | | 0.99 | 0.89 |

### Table 17: Main results for chemical use (kg per ha)

| | Herbicide | | | Pesticide | | | Inorganic fertilizer | | |
|---|---|---|---|---|---|---|---|---|---|
| | (1) OLS | (2) IV (conventional SE) | (3) IV with flood control | (1) OLS | (2) IV (conventional SE) | (3) IV with flood control | (1) OLS | (2) IV (conventional SE) | (3) IV with flood control |
| Tractor use | -0.62 | 11.30* | 11.15* | -0.22* | -0.24 | -0.27 | 18.87 | 4.38 | 10.64 |
| | (2.51) | (5.94) | (5.95) | (0.13) | (0.51) | (0.51) | (19.25) | (63.27) | (63.54) |
| flood district (dummy) | | | -0.18 | | | -0.04 | | | 7.48 |
| | | | (1.98) | | | (0.17) | | | (21.18) |
| N | 182 | 181 | 181 | 182 | 181 | 181 | 182 | 181 | 181 |
| R2 adjusted | 0.12 | -0.24 | -0.24 | 0.02 | 0 | -0.01 | 0.03 | 0.03 | 0.03 |
| F-stat | . | 1.74 | 1.66 | . | 0.89 | 0.85 | . | 1.28 | 1.23 |
| F-stat (first stage excluded instruments) | | 12.8 | 12.58 | | 12.8 | 12.58 | | 12.8 | 12.58 |
| Pagan & Hall's heteroscedasticity test (p-value) | | 0.76 | 0.82 | | 0 | 0.01 | | 0.98 | 0.99 |
| Anderson-Rubin weak instrument F test (p-value) | | 0.03 | 0.04 | | 0.66 | 0.62 | | 0.95 | 0.88 |

### a. Main results

For the ordinary least squares estimates, the correlation between tractor plowing and productivity outcomes is not significant (Table 13). Similarly, the instrumental variable estimation does not show evidence of any significant relationship between tractor use by farm households and their land or labour productivity. Even using the Anderson-Rubin test for significance under weak instruments, none of the productivity outcomes is significantly affected by tractor use. The lack of significance in these results is likely due to the relatively small sample size and the poor measurement of farm output, particularly when using a single cross section to capture differences in yields across farmers. The impact of flooding across Ghana in 2009 has likely caused considerable noise in the variables for agricultural output. As discussed above, measurement error can lead to the underestimation of treatment effects for yield. Since yield is a noisy outcome measure, researchers often prefer to look at input use and intensity as indicators of the farmers' responses to an intervention – in this case, the use of tractor plowing. Input use decisions are made during the growing season and are more directly controlled by the farmer. We are interested in how these within-season farming decisions are affected by the use of agricultural machinery.

The OLS estimation indicates that the area cultivated and tractor use are positively correlated. On average, farm households that used a tractor for plowing cultivated 0.53 ha more land (Table 14). If the instrumental variable is identifying the causal impact of tractor use we can further conclude that using tractor plowing causes a significant increase in cultivated land for those just-excluded farm households, by 4-5 ha. The magnitude of this increase is quite large.

However, the magnitude of the impact is within the range of cultivated hectares for the sample and not inconsistent with farmers responses during qualitative interviews in Yendi, although it is at the upper end of what may be plausible. As discussed above, the measurement of land sizes for smaller farms tends to be over-estimated in surveys like this. When standard errors are adjusted for heteroscedasticity and small samples, the relationship remains significant (Table 18). Cautiously, these results seem to support the conclusion that some of the higher area cultivated by tractor-using farm households, compared to non tractor-using, is due to the use of tractor plowing at the start of the season.

Furthermore, the OLS results indicate that tractor-using farmers are associated with a greater proportion of land being cultivated with maize, by approximately 13 percentage points. However, the significance of this effect is lost when using the instrumental variable estimation (Table 14, Table 18, & Table 19). The effect is positive, but it is not found to be significant. A possible interpretation is that the correlation between maize cultivation and tractor use is due to machinery is being used in areas which are more suitable for maize cultivation, rather than tractor use in and of itself causing farmers to cultivate maize.

The final panel of Table 14 indicates that for some farm households, women may be more engaged in agricultural production due to tractor plowing. Focusing on those farm households affected by the treatment, women, on average, have control over an additional 27 percentage points of the household's land, due to the use of tractor plowing by the household. However, the relationship is not significant under the OLS regression model, which indicates that any causal relationship is only true for those just-excluded households. Control over agricultural land is defined as the household member who is identified as the main holder or cultivator of the plot. This causal relationship between tractor use and women's engagement in agriculture is consistent with qualitative discussions with farmers who repeatedly claimed that women would farm more when they were able to access tractor services. The significance of the quantitative result is also found when the standard errors are adjusted for heteroscedasticity (Table 18). Overall, it seems that the total area of cultivation by a farm household increases due to tractor use, with a proportional increase in maize production. Proportionately more of the increased area is controlled by women.

Table 15 provides somewhat surprising results for the effect of tractor use on labour intensity, which is particularly relevant for understanding the relative importance of labour constraints and timing issues in the take-up of tractor plowing. If farmers were responding to a labour constraint, we would expect that labour use for land preparation would decrease, as machinery power would be replacing manual labour. However, we do not see this clearly in the results; the first panel of Table 15 shows somewhat inconclusive results, which reflects the relatively small sample sizes. On average, tractor-using farm households use 9 fewer person days of labour for land preparation, and this partial correlation is significant from the OLS. However, this relationship is not significant under the IV model. Therefore, we cannot conclude with any confidence that tractor plowing is causing a decline in labour use for land preparation. Even the OLS correlation is difficult to interpret: it may be that labour-constrained farm households are more likely to use tractor-plowing, rather than tractors displacing labour.

The results for labour use in field management, harvesting, and post-harvest are surprising, but should also be considered with caution (Table 15). If we consider the instrument to be successful in identifying the effect of tractor plowing, then we have evidence that there is a significant and positive increase in the number of labour days used per hectare for these other operations, due to tractor-plowing. This result holds under weak instruments, and robust standard errors. However, caution arises due to the difference between the OLS and IV results. For the OLS, the relationship is small in magnitude and not significantly different from zero; for the IV regression, the magnitude of the coefficients is considerably larger. For field management, the results suggest that the farm household uses approximately an additional 40 person days per ha when using tractor plowing, compared to when just using hand-hoeing. We can consider whether the results are consistent with the other results and understandings of these farm households from qualitative work. A considerable increase in labour use per hectare is consistent with the previous result of an increased area cultivated due to tractor plowing, with a proportionate increase in maize cultivation. The per hectare increase in labour use would come from expansion into lower-quality land which may require more intensive weeding, or from early planting of maize which requires more application of organic or inorganic fertilizer. This is consistent with the idea that farmers are responding to a timing constraint in using tractor plowing.

A plausible explanation of these empirical results would be that the risk of poorer yield due to late planting has been reduced. Farmers are therefore investing more labour time into cultivation because the expected yield is higher with tractor plowing. Field management will include the labour required for weeding and application of fertilizer. Farmers are more interested in carrying out these activities when they have been able to plow and plant early. The labour time investment in subsequent activities is increased because a timing constraint at the start of their agricultural production has been overcome through machinery plowing. The important point here is that in this low-productivity labour-intensive farm-household system, there is little evidence that tractor-plowing is leading to a transformation in labour-use relative to land cultivated. In fact, tractor-plowing may be alleviating a timing constraint at the start of the season, which increases the labour effort for field management, harvest, and post-harvest operations.

Table 16 considers the impact on total labour days by gender, as well as the use of hired labour for tractor plowing. Consistent with the increased labour intensity, the total labour days for females increases significantly with tractor use under the IV specification. There is a similar increase for male labour, but the effect is not significant. The increase for men is greater, consistent with the higher share of agricultural labour which is undertaken by men in the sample (see Table 16). The effect of tractor use on the proportion of agricultural work undertaken by female household members is positive and significant under the IV regression. This indicates that tractor use leads to a greater increase in female labour time in agriculture, compared to male family members. These findings can only be argued for the just-excluded farm household; the OLS regression does not find a significant relationship on average between tractor use and the type of labour use. However, the increased female labour use is consistent with the previous finding that women control a greater agricultural area due to tractor use. The final panel of Table 16 shows that there is no conclusive effect of tractor use on the proportion of work which is done by hired labour, compared to family labour. Given that on average 26% of farm labour is hired workers, it is striking that both tractor-using and non-using household are employing a similar proportion of hired workers.

As expected, tractor use leads to a significant increase in herbicide use per ha for the just-excluded farm households (Table 17). These inputs are complementary as farmers use herbicide to kill weeds before using the tractor to turn over the soil. The results for pesticide, and inorganic fertilizer use per hectare are inconclusive. The survey responses to the chemical module of the survey was low which has reduced the sample size and power of the estimation for these outcome variables.

## Table 18: IV estimation using robust standard errors adjusted for small sample bias, and bootstrapped standard errors

| | | | | | | Labour days per ha | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Output value per ha (all crops, cedis) | Output value per person day (all crops, cedis) | Area cultivated (ha) | Area cultivated - maize (%) | Area cultivated - female (%) | land preparation | field management | harvest | post-harvest |
| Tractor use | 149.24 | 10.51 | 4.32 | 9.78 | 26.76 | -8.72 | 39.28 | 33.92 | 10.92 |
| *Robust small sample SE* | (147.42) | (5.86)* | (1.53)*** | (16.54) | (13.43)** | (14.28) | (20.53)* | (17.78)* | (6.33)* |
| *Bootstrap SE* | (151.94) | (11.19) | (1.88)** | (28.75) | (13.51)** | (14.40) | (19.40)** | (17.55)* | (8.02) |
| N | 411 | 258 | 400 | 252 | 400 | 387 | 391 | 376 | 391 |
| R2 adjusted | 0.24 | 0.12 | 0.23 | 0.5 | 0.82 | 0.07 | -0.05 | -0.2 | -0.09 |
| F-stat | 4.2 | 4.26 | 9.65 | 39.6 | 194.31 | 3.83 | 3.56 | 3.66 | 2.23 |
| F-stat (first stage excluded instruments) | 16.04 | 6.5 | 14.22 | 5.72 | 14.22 | 15.05 | 22.8 | 10.94 | 12.16 |
| Pagan & Hall's heteroscedasticity test (p-value) | 0.12 | 0.99 | 1 | 1 | 0.05 | 0.88 | 1 | 1 | 1 |
| Anderson-Rubin weak instrument F test (p-value) | 0.29 | 0.02 | 0 | 0.56 | 0.03 | 0.55 | 0.03 | 0.01 | 0.05 |

| | Total labour days | | | | Chemicals (kg/ha) | | |
|---|---|---|---|---|---|---|---|
| | Female family | Male family | female labour share of family labour | hired share of total labour | Herbicide | Insecticide | Inorganic fertilizer |
| Tractor use | 145.48 | 197.76 | 38.69 | -0.3 | 11.3 | -0.24 | 4.38 |
| *Robust small sample SE* | (70.84)** | (116.02)* | (23.29)* | (19.42) | (13.74) | (0.34) | (59.00) |
| *Bootstrap SE* | (114.82) | (115.37)* | (28.00) | (27.61) | (41.92) | (0.67) | (77.43) |
| N | 415 | 415 | 385 | 405 | 181 | 181 | 181 |
| R2 adjusted | -0.02 | 0.11 | 0.22 | 0.26 | -0.24 | 0 | 0.03 |
| F-stat | 4.23 | 6.34 | 6.25 | 5.87 | 0.87 | 0.33 | 1.29 |
| F-stat (first stage excluded instruments) | 16.15 | 16.15 | 11.71 | 12.86 | 3.76 | 3.76 | 3.76 |
| Pagan & Hall's heteroscedasticity test (p-value) | 1 | 0 | 0.93 | 0.18 | 0.76 | 0 | 0.98 |
| Anderson-Rubin weak instrument F test (p-value) | 0.02 | 0.07 | 0.06 | 0.99 | 0.22 | 0.47 | 0.94 |

## Table 19: Treatment Effect Regression Model (two-step control function method)

| | | | | | | | | Labour days per ha | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Yield (kg/ha) | Labour productivity (kg/day) | Output per ha (USD) | Output per person day (USD) | Area cultivated (ha) | Area cultivated - maize (%) | Area cultivated - female (%) | land preparation | field management | harvest | post-harvest |
| Tractor use | -229.43 | -9.59 | 140.63 | 6.54 | 3.17** | 1.2 | 19.83** | -11.39 | 25.80* | 25.78** | 11.66*** |
| | (225.70) | (7.01) | (147.88) | (5.77) | (1.34) | (17.49) | (9.63) | (11.11) | (14.30) | (10.02) | (4.36) |
| λ (inverse Mill ratio) | 193.56 | 7.13* | -98.99 | -3.4 | -1.55** | 7 | -10.35* | 1.56 | -15.54* | -14.44*** | -5.79** |
| | (137.46) | (4.02) | (83.01) | (3.36) | (0.74) | (10.09) | (5.34) | (6.27) | (7.96) | (5.45) | (2.39) |
| N | 233 | 258 | 418 | 258 | 407 | 252 | 407 | 394 | 393 | 383 | 398 |
| Chi2 (joint significance) statistic | 86.58 | 134.99 | 299.52 | 143.75 | 379.67 | 345.2 | 2497.74 | 159.79 | 201.71 | 181.6 | 165.69 |

| | Total labour days | | | | Chemicals (kg/ha) | | |
|---|---|---|---|---|---|---|---|
| | Female | Male | female labour share of family labour | hired share of total labour | Herbicide | Insecticide | Inorganic fertilizer |
| Tractor use | 99.97* | 135.2 | 31.76** | 8.38 | 8.74** | -0.71** | -8.58 |
| | (58.60) | (124.58) | (15.33) | (17.01) | (3.67) | (0.35) | (42.59) |
| λ (inverse Mill ratio) | -53.80* | -68.05 | -16.17* | -3.66 | -6.44*** | 0.33 | 18.9 |
| | (32.70) | (69.95) | (8.52) | (9.51) | (2.17) | (0.21) | (26.65) |
| N | 422 | 422 | 392 | 412 | 182 | 182 | 182 |
| Chi2 (joint significance) statistic | 202.55 | 222.48 | 328.26 | 293.63 | 114.8 | 95.66 | 96.77 |

Note: Where the estimated coefficient on λ is significantly different from zero, there is evidence of endogeneity therefore OLS estimates are inconsistent and these endogenous treatment effects should be used. Stata program etregress with two-step option used which estimates the first stage using probit model. See Wooldridge, (2010, sec. 21.4.2) for details on the method used for estimation.

### b. *Robustness checks*

The first check is to understand how sensitive the key results are to the exclusion restriction being violated; i.e. that there is correlation between the assignment into treatment groups and the outcome variables. Figure A 7 shows the union of confidence intervals for the treatment effect under different levels of direct correlation between the instrument and the outcome. These are shown for total area cultivated by the household, the proportion of cultivated area allocated to maize production and controlled by female household members, labour use per ha for land preparation and field management, and the total male labour person days. The main results find a significant effect for the total area cultivated, the proportion of land controlled by women, and labour use per ha for field management. The graphs in Figure A 7 tell us that these significant results hold for negative, zero, and a small positive direct correlation between the instrument and these outcomes.

Using the control function approach (Table 19), the estimated average treatment effects are consistent with the 2SLS estimation of the local average treatment effects. In fact, this alternative method finds a significant and positive effect of tractor use on the proportion of cultivated land allocated to maize production. For outcomes where the effect is significant and the coefficient is notably different to the OLS estimates, we find there also to be evidence of endogeneity (with significance of the inverse Mill ratio coefficient). This gives confidence that the estimated coefficients un the 2SLS specification, which account for endogeneity, are likely to be more accurate than simple OLS estimation. Finally, results using propensity score matching are reported in Table A 5. This approach does not rely on the instrumental variable and estimates the average treatment effects for the whole sample. The results are broadly consistent with the findings from the OLS and 2SLS specifications.

## VI. Discussion

The majority of farmers in Ghana use mechanized technology through a market for tractor services, rather than ownership. The consequence of this is that their decision or ability to use tractor plowing is partly determined by the functioning of the service market. Each year the farmer decides whether to seek tractor services. This is a repeating choice, rather than a a one-time switch in technology use which guarantees tractor use each season. Therefore, focusing on the effect of tractor use for those farm households which are just-excluded from the service market is important in understanding the constraints on farm production and the costs of a weak service market[35]. This paper estimates the average treatment effects of tractor use for compliers, i.e. farmers who without government-induced increase in the supply of services, would not have used machinery for plowing.

The most credible results come from a 2SLS analysis that leads to a relatively small sample size for treatment and control districts. As in any IV approach, the validity of the instrument may be challenged. A key issue is whether the roll out of the government mechanization scheme was as-good-as random, or whether the timing of allocations was indirectly prioritized to districts which are more or less likely to use tractor plowing for other reasons.

[35] Paper 3 of this thesis more fully elaborates the difficulties of coordination and timely access to services in the tractor services market.

If the exogeneity of the instrument is in fact violated, the results would be consistent with the government roll out being first to areas (i) with larger farm sizes, (ii) where women more engaged in agriculture, and (iii) with higher labour-intensity of cultivation. An analysis of the balance between the treatment and control districts offered only limited evidence of relevant differences in the timing with which districts to received the government tractors. These shortcomings cannot be ignored, and more work using recently collected panel datasets would potentially provide more confidence of the findings presented here.

However, the findings of this analysis are consistent with qualitative discussions with farmers (elaborated in Paper 3). Frequently farmers indicate that the scale of production is considerably increased when tractor services are secured. Households also reported that women would farm more due to the use of tractor plowing. It was clearly indicated from farmers that they choose to cultivate different crops when tractor plowing is done. It is therefore not implausible that cultivating more maize and other market-orientated crops would entail higher labour intensity of production.

Whilst the econometric results of this paper alone should be considered with caution, they are not inconsistent with other findings of this thesis, and the wider literature. The increase in maize production over recent decades has been strongly associated with increased use of mechanization both qualitatively and in other quantitative studies (Nazaire Houssou & Chapoto, 2015; Nin-Pratt & McBride, 2014). The results of this analysis are consistent with this literature. I find evidence of farmers shifting their crop composition to cultivate more maize, in proportion to the increase in cultivated land. The maize yield is not increased by mechanization use, but the overall value of agricultural production increases. This increase can be partly explained by the shift into maize from lower value crops. Farmers' decisions over which crops to plant are affected by whether or not they are able to use tractor plowing. The implication of this is that difficulty in accessing tractor services leads to a low-effort and low-return production system. Maize is a crop with higher market value and is traded extensively, locally and to supply urban centres. Tractor plowing enables some farmers to alter their production decisions to support a higher-effort but higher-return farming system.

The theoretical question of the paper has been whether mechanization in northern Ghana is being driven by a binding labour or a timing constraint. Agricultural machinery is considered a labour-saving technology by much of the literature (Pingali, 2007). Even when the distinction is made between power operations (i.e. land preparation, and harvesting) and control operations (planting, and weeding), mechanization of these operations is considered to lead to reduced labour intensity. However, the empirical findings of this paper appear to point in a different direction. Tractor use appears to increase, rather than decrease, the labour used in land preparation, and tractor use potentially also drive an increase in labour use for other operations due to use of tractor plowing.

A coherent explanation for this observed pattern is the following. Without machinery, farmers find it difficult to prepare their land in time to plant optimally. If planting is done late, the expected yield will be lower and the returns to subsequent investments in labour and other inputs for crop production are less. To the extent that tractor plowing enables earlier planting, it encourages a shift into more profitable crops and also generates higher physical yields. Both of these tend to crowd in the application of labour for crop maintenance, harvest, and post-harvest activities. A similar pattern was found in Ethiopia where the high consumption risk associated with fertilizer application was associated with much lower fertilizer use; farmers were trapped in low-risk and low-return production (Dercon & Christiaensen, 2011). The implication for these farmers in Ghana is that labour scarcity seems not to be a binding constraint - since farmers can apparently increase both family and hired labour when needed. Instead, the benefit of tractor plowing in this context seems to stem from its interplay with the timing of the rains in an environment where the planting window is very narrow (Ruthenberg, 1980).

Timely planting, thanks to tractor use, changes the expected returns for agricultural activities within the household, and therefore affects the intra-household decisions over labour use, which crops to cultivate, and which family members to take active control over which plots. Women, who may have been more labour constrained than men, cultivate more when the household uses machinery, although not necessarily of time-sensitive crops.

The gender dimension of mechanization has been little researched and it is by no means clear whether increased commercialization of production, evidenced by mechanization, pushes women out of agriculture, or whether the reduced drudgery associated with land preparation may enable women to farm more. Furthermore, gender differences in the ability to access family and hired labour, and other inputs, may well extend to engaging with the service market for machinery. Theis *et al.*, (2018) particularly demonstrate the importance of considering the changes in intra-household decision making in light of technology adoption, with the costs and benefits of technology adoption not borne equally by household members. The evidence is that women have control over cultivation of a greater area when the farm household is using tractor plowing on at least one plot. It is not clear whether the effect is due to women are using tractor plowing on their own plots, or the use of tractors on other household plots frees up labour for land preparation on female-controlled plots. Either way, the findings are consistent with qualitative discussion with farmers who frequently indicated that the use of machinery has enabled their wives and other female household members to farm more.

These results are specific to the instrument used. When a comparison is made between all surveyed households using tractor plowing and not, labour use is found to decrease for land preparation and field management, which is consistent with conventional theory which sees tractor use as simply labour-replacing. However, when we focus on those households which may struggle to access tractor services each year, the effects are more consistent with tractor plowing alleviating a timing constraint and actually crowding in labour use. For these farmers, it may be that labour and machinery are complements, due to the timing constraint. They may be operating at a lower equilibrium, which tractor use enables them to improve upon. When we consider all farmers including larger-scale farmers and those who more consistently secure tractor services each year, the effect of labour and machinery being substitutes is found (i.e. when estimating treatment effects using propensity score matching).

The methodological approach of the paper prevents any conclusions being drawn regarding the long term impacts of machinery use on agricultural production, household welfare, and the wider farming system dynamics. These results cannot speak to debates over whether mechanization is leading to expansion of agricultural land into pasture, virgin, or forest land, or to the reduction of fallowing practices. Over the long term, mechanization could be facilitating a mining of soil nutrients as farmers are able to increase production through land expansion, rather than intensification and maintenance of soil nutrients.

Mano, Takahashi and Otsuka (2017) consider similar questions in the context of rice intensification in Cote d'Ivoire. They find the uncertainty over access to tractor services prevented intensification of production. Tractor use in land preparation enhanced the adoption of input- and labour-intensive practices in subsequent farming activities, resulting in complementarity between machinery and labour use. Takeshima, Houssou and Diao, (2018) find that tractor ownership increases the returns to scale for maize production in northern Ghana. This paper adds to this literature in focusing on the input decisions of tractor users. There is consistent evidence across these papers to support the claim that tractor use, either through ownership or rental market, is not so much associated with changes in labour use, but instead generates increased return from the use of all inputs – labour, hybrid seeds, and chemicals.

## VII. Conclusions

Overall, this analysis provides evidence that tractor use leads some farm households to increase the area of cultivation, increase labour use for some operations, and to increase women's engagement in agricultural production. One implication of these findings could be that the short time window for land preparation in cereal-producing zones of Ghana is motivating farmers' use of tractor plowing. When mechanized plowing enables earlier planting, farmers change their production decisions over which crop to plant and how much labour effort to invest in crop maintenance and harvest. Furthermore, this difficulty over land preparation appears to particularly constrain women's engagement with farming. These effects of tractor use are more pronounced for farm households who are just-excluded from the tractor service market. This departs from literature which consider mechanization as labour-saving and a response to increasing labour costs. If this were the case, we might expect to see machines substituting for labour in other farm activities, and we would also expect to see total labour use per hectare falling (or at least remaining constant). If a timely planting is motivating mechanization, however, it is by no means inevitable that mechanization of other operations will immediately follow.

For policy, there are two key debates which these results contribute to. Machinery use in Ghana does seem to be facilitating a shift in the gender division of responsibilities for agricultural production. Further work would provide more evidence of these suggestive indications. A second debate this work contributes to is that over climate change mitigation. The conclusion that mechanization in Ghana may be driven by the short growing season could have implications for understanding the risks and responses of farmers to climate change. Tractor use may in some sense be a respone to the increased variability and unpredictability of rainfall patterns in this region. The use of machinery may be one means of mitigation for farmers to reduce the time required to carry out an activity, thereby reducing the risk of crop damage and lower yields due to rainfall variation.

## Paper 3: Rural institutions and agricultural technology adoption: a study of the tractor service market in Ghana

Abstract:

Uptake of modern agricultural technologies, such as machinery, has had a chequered past in Sub-Saharan Africa, with the vast majority of African farmers continuing to rely upon low-input technologies. In rainfed tropical agricultural systems, some farmers are excluded from access to productivity-enhancing machinery due to limited time for land preparation, synchronous timing of operations across farmers, and the fixed costs associated with service provision. Without a coordination mechanism, the spatial externality in a time-constrained market would lead to undersupply of tractor plowing services. This paper combines qualitative and quantitative data from the district of Yendi in northern Ghana to show that existing social norms in rural agricultural communities can improve the outcome of the market for both farmers and service providers. The flow of information through kin networks and norms of egalitarianism provide a means for coordination amongst farmers and service providers, and increases the probability of smallholder farmers preparing their land in time for optimal planting. Analysis of the gender differences and the use of out grower schemes in accessing tractor plowing services is also explored.

## I. Introduction

Agricultural mechanization is increasingly being advocated as the key to upgrading agricultural productivity and boosting economic growth in Africa. The narrative is that technology has the potential to improve productivity, enhance the quality of jobs in the sector, and strengthen the agricultural sector as the springboard for wider economic growth (African Center for Economic Transformation, 2017; Malabo Montpellier Panel, 2018). In line with this, imports of agricultural machinery through concessional arrangements between African governments, and those of India, China, or Brazil are providing the fiscal means for mechanization policies to resurge. However, the modalities of making such machinery available to the full spectrum of farmers in African farming systems are frequently left as an afterthought (Cabral, 2016).

Institutional innovations are required alongside the technological ones, in order to facilitate economically sustainable adoption. The lessons of the past demonstrate that government-sponsored and managed machinery services are more often than not mismanaged and reliant on considerable government subsidy. Programs of "tractorization" have been pursued from as early as the 1960s up to the present decade, and met with frequent failures (Amanor & Chichava, 2016; Mrema et al., 2008; Seager & Fieldson, 1984). In more recent times, the private sector is innovating. HelloTractor and TrotroTractor are social enterprises utilizing

GPS and mobile phone technology to match tractor service providers with farmer demand for services.[36] The long term success of these initiatives is still to be determined.

However, Ghana's mechanization story provides evidence of innovation within informal institutions that have been successful. Despite early mechanization being focused on large-scale state farms, a quiet revolution has taken hold in cereal-producing areas of northern Ghana where the majority of farmers, of all sizes, are found to be using mechanized technologies for land preparation (Diao et al., 2014; N. Houssou et al., 2013). A national household survey from 2009 found that 93% of farm households in northern Ghana had used tractor plowing on at least one plot in the last season.[37] How have the economic and social institutions which have supported this adoption succeeded? What lessons from their innovation and adaption can be learnt for the development of mechanization policies across the continent?

The distinctive agro-ecology of the region is undoubtedly important for the "success" of mechanization, but I will argue that another essential ingredient lies in the social structure of rural communities in northern Ghana (e.g. Goody 1975; Lyon 2003; Lambrecht & Asare 2016). Specifically, the existing social structure of rural Ghanaian communities provides strong social norms and kin-based networks which have facilitated the growth of the tractor service market. The coordination that is possible through these social relations has enabled

[36] https://www.hellotractor.com/ in Nigeria; and http://www.trotrotractor.com/ in Ghana.

[37] Economic Growth Centre and Institute for Social Science and Economic Research Socioeconomic Panel Survey 2009 (Yale / University of Ghana). Northern, Upper East and Upper West regions.

the market to overcome the substantial externality created by the spatial dispersion of farm plots and the short time window for demand.

Literature on technology access and adoption has often overlooked the social embeddedness of agricultural markets and exchange as it seeks to identify the aspects of farmer capability, risk management, and input costs which affect adoption of modern technologies. When social capital is considered, it is often a more individualistic understanding of social capital, rather than something which is vested in a group or community (Fafchamps & Minten, 2001). This paper aims to expand this literature on technology adoption and its barriers by taking a more socialized understanding of the service market.

The existing social structure has already been shown to be important for agricultural technology and exchange relations. For example, Lyon (2000a) identifies the variety of relationships which constitute the social capital required to create trust in exchange relationships, with the absence of formal enforcement mechanisms and in the context of tomato production and marketing in Ghana. In particular, norms of reciprocity in Ghana have been found to be important, alongside networks, for agents to determine whether to trust each other (Goody 1975; Lyon 2006). In a different context, Lewis (1996) considers the network of tractor owners, users, brokers and dealers in Bangladesh, in relation to the existing networks to which individuals belonged and operated. He discussed the particular role that kin networks can play in the organisation of economic activity and to increase the quality of tractor services received. In this paper, I draw from the approaches of Platteau, who emphasizes the role of social norms and institutions in technical change, and Granovetter who encourages the consideration of the social embeddedness of market institutions

(Granovetter, 2005; J.-P. Platteau, 2000). In this way, the paper addresses the puzzle of how an inefficient market is sustained, through incorporating analysis of the existing social structure of a rural Ghanaian community.

This paper draws on a case study of the farming systems and tractor services market in Yendi district of northern Ghana. By using a mixed methods approach, rich insights are brought from individual interviews and focus group discussion with farmers, service providers, and other participants in the market. A small-scale survey is used to confirm the representativeness of the qualitative findings. The resulting evidence indicates that internalized norms of reciprocity and egalitarianism are supporting cooperation within and across villages, in order to improve access to the tractor service market for farmers, although some market inefficiency remains due to unpredictable and localized rainfall patterns.

The rest of the paper is organized as follows. The next section elaborates the nature of agricultural production Ghana, the actors involved in the tractor service market, and the relevant aspects of the social structure. Section III provides a theoretical framing through which to explore the nature of market inefficiency and the aspects of the social structure which have potential to improve market outcomes. The combined methodology is explained in Section IV along with the basic characteristics of the district. The qualitative and quantitative results are presented together in Section V. The results and their implications for our understanding of farmer’s production decisions and the tractor service market are discussed in Section VI.

## II. Context

### *a. Agricultural production in northern Ghana*

As discussed in the introductory chapter, Ghana's agroecological conditions are loosely grouped into three zones (see figure A1). The forest zone is concentrated in the south and west of the country where the soils and higher annual rainfall support farming systems dominated by cocoa-production. Further north, the soil type and topography lend themselves to cereal and root crop production. The case study locale for this paper is in the savannah zone, where the rainfall patterns give a single growing season. The agroecological characteristics combined with evolving domestic food demand create both opportunity and restrictions for a tractor service market.

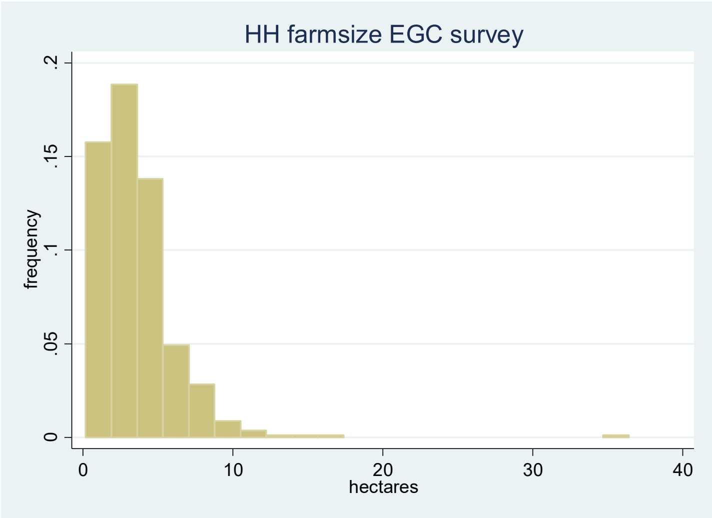
Total production of market-orientated cereal crops has increased in Ghana since the 1980s. There has been a relative increase in production of maize and rice, at the expense of millet and sorghum. In 1976, maize accounted for 36% of cereal production (by weight) in Ghana; this increased to 55% in 2014 (**Error! Reference source not found.**). Expansion of maize production has been particularly pronounced in the north of Ghana. By government estimates, total production of the Northern region more than doubled between 2002 and 2012.[38] Cultivation of yam and cassava have greatly increased in the same period. The growth of cereal production can be attributed to the growth of urban markets over the same

[38] Total production of maize in Northern region was 79,050 Mt in 2002, and 195,000 Mt in 2012. Source: Statistics, Research, and Information Directorate, Ministry of Food and Agriculture, Government of Ghana.

time period, as these foods are preferred by urban populations. As the country's urbanization rate increased from 31% to 51% between 1984 and 2013, the demand for these crops increased correspondingly (The World Bank, 2015). The uptake of machinery amongst farmers in northern Ghana should be seen in this context of increasing urban food demand for crops such as maize and rice, supported by improvements in transport infrastructure.

Cultivation of maize in the savannah zone of northern Ghana requires higher input use and earlier planting than more traditional crops, such as sorghum and millet. Maize should be planted in June with harvesting during August to October. In contrast, millet and sorghum can be planted over a longer period, from May to July, with harvest in October and November (Food and Agriculture Organization, 2017). Similarly, cassava and yam have a longer planting season which is at a different time of year. Maize cultivation in tropical environments poses a number of challenges that make the power and time saving advantages of machinery attractive to farmers. These issues have been well documented by agricultural researchers. There is high evapotranspiration in the off-season that leaves the land hard and difficult to turn over before the first rains of the new season. Rainfall variability is considerably higher in tropical areas, compared to temperate. Weed regrowth is considerable in the tropics and is a major reason for low potential yields. The short time window and difficult work for turning over the soil creates peak demand for labour once the soil becomes workable and, moreover, creates pressure to reduce the time required for land preparation. These factors combine to make the returns to mechanized land preparation relatively high in such areas (Ruthenberg, 1980). The increase in maize cultivation is strongly associated with the increased use of tractor plowing (M. Kansanga et al., 2018).

**Figure 3: Household farm size distribution**




Source: EGC/ISSER Socioeconomic Panel Survey 2009

The distribution of farmland amongst households is another characteristic of the farming system that will affect types of technology adopted. There are increasing returns to scale for machinery use as plowing a single large plot will be less costly than plowing many scattered small plots. The average farm size for households in northern Ghana is 3.86 hectares, with 50% of households cultivating less than 2.83 hectares.[39] Figure 3 illustrates that the distribution of farm sizes is skewed with most farmers maintaining relatively small cultivated areas. Households usually do not hold a single plot but their total farm land is divided into several plots. From the same survey of 2009, the average number of plots per households was 2.5. Therefore, in an area where 93% of farmers were found to be using tractor plowing on at least one plot, farmers were cultivating 2 or 3 plots of about 1 hectare. Based on the

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[39] Northern Ghana includes the three regions: Upper West, Upper East, and Northern.

individual farm scale alone, the economies of scale associated with machinery use are not easily achieved.

### *b. Tractor service providers and other actors in supply of services*

In Ghana, the majority of farmers access mechanized plowing technology through a market for tractor plowing services (Chapoto et al., 2014). This is true even though the farming system displays characteristics that might discourage investment in service provision (Pingali et al., 1987). The potential income from tractor service provision is limited by the short season for land preparation and low demand for the mechanization of other operations. The dispersion of small plots increases the fixed costs of service provision. Furthermore, farmers are constrained in access to credit and have low incomes, which limits their demand for purchased inputs. Even for tractor purchase, formal credit is only available for few investors through a government scheme. Houssou *et al.* (2013) calculate that the returns to machinery investment under these conditions are only positive when providers are able to take advantage of government support and are able to service a high number of acres each season.

In spite of the challenges, tractor use has taken off in northern Ghana. The tractors have come from multiple sources but are almost all privately owned. In the case study location of Yendi District, a listing of tractor owners carried out in 2012 showed that there were 178 tractors owners (Chapoto et al., 2014). The majority of these tractor owners rented out plowing services to other farmers. Most tractors in use are former government stock or imported from Europe via second-hand auctions. More recent government import and distribution of machinery has also brought newer machines into private use. Across the country, the government's mechanization program has included the import of over 500 tractors during 2007-2012 (Benin, 2015b). These machines have been distributed to private entrepreneurs at subsidized prices and through hire-purchase arrangements, with the intention that they be used to provide services to small-scale farmers. Currently, the government does not own and operate machinery itself. The majority of tractor owners are medium-scale farmers who have used their own income to invest in the purchase of a tractor, both for their own farms and in order to provide tractor services to other farmers (Diao et al., 2014).

### *c. Social structure in rural Ghana*

Given the vast literature on social structure and social capital across economic, sociology, and anthropology literature, it is important to clarify the intellectual roots of this paper in its use of these terms. In Granovetter's (2005) review of sociology literature on the interaction of social structure with economic outcomes, one of the core principles is the role of norms and network densities. The norms regarding acceptable behavior are enforced over dense social networks, which partly define the overall social structure. The understanding of social norms, relations, and networks in the paper are derived from Granovetter's view of social embeddedness (Granovetter 1985). Drawing on this idea of social embeddedness, Fafchamps (2017) questions the common argument in economics that informal institutions (i.e. the norms and networks which support trust and cooperation without formal enforcement) will disappear once formal institutions are developed. In his view, all market exchange takes place with a social context, even when formal institutions for enforcement exist. Farmers in Ghana and elsewhere in Africa have continued to access land, labour, and capital through social institutions as well as impersonal commercial transactions throughout the decades of development since independence (Berry, 1993). In the market for tractor services in Ghana, there are no formal institutions to enforce contracts of exchange between farmers and service providers, and so the focus of the paper will be to understand the informal institutions, to use one term, or the social structure in which the market and its actors are embedded.

Households in Ghana operate within a social structures which is dominated by family, kin, and clan relationships, with land rights being the most documented point of intersection between economic outcomes and traditional social institutions of Ghana (on land: Goldstein & Udry 2008; Lambrecht & Asare 2016; Ghebru et al. 2016). The allocation of land is complex and set within the traditional clan system. Access to land is linked to the kinship ties which are maintained, therefore social norms and relations are maintained not for their own sake, but in order to facilitate access to a key economic resource (Bugri 2008). The extent to which this has a de facto impact on land use and allocation varies by village and have been evolving and as Ghana develops. Land rights continue to be allocated through traditional tenure systems, particularly in rural areas of the north, despite increasing urbanization and commercialization pressures (Yaro 2010). The purchase and sale of agricultural land is rare.

Beyond land rights, the rich social structure in Ghana has been shown to play an important role in economic life, and particularly in agricultural activities. Hart (1975) finds that the norm of reciprocity held within kin groups in north-east Ghana can create tension between individual entrepreneurs who may accumulate wealth above that of the social group. The norm of reciprocity within kin groups is not limited to an individualized exchange, but has an expectation of equal exchange (Hart, 1975). Agricultural entrepreneurs attracted antagonism from their kin for what is seen to be concentration of agricultural surplus for the individual rather than the group, especially where unpaid or communal labour has been used in production. Urban entrepreneurs face fewer social expectations; their accumulation is not seen to have been at the expense of the group. Collective practices for agricultural production are therefore used as a means to allay conflict of this nature. Although this ethnographic work is somewhat dated, the importance for agricultural entrepreneurs to maintain good home-ties remains, i.e. to secure access to land (Bugri 2008).

More recent evidence on habits of cooperation in agricultural production are consistent with this older work. The remoteness and lack of alternative livelihoods in northern Ghana explain the stronger participation in group activities observed in northern, compared to southern, regions (Porter & Lyon 2006). Lyon (2003) shows that culture-specific norms of reciprocity and group decision making continue to underpin the habitual trust observed amongst groups cooperating on agricultural activities such as manual and mechanized processing of oil palm. He finds cooperation to be highly dependent on personalized relationship, which in part are built upon garnering information on individuals' reputation through kin and community networks. These observations are consistent with the findings of this paper. Lyon particularly emphasizes that these norms are deeply internalized such that the motivation for sustained cooperation in these groups is due to habitual trust, rather than individual incentives.

Although not specific to Ghana, Berry's (1984) review of literature on agrarian change and food production in Africa argues that social processes have as much of an influence on agricultural activity as individual rational behavior. She points to the lack of responsiveness of agricultural output to price changes as evidence that farmers base their decisions on many factors other than simple economic incentives. Units of production and consumption rarely collapse onto the self-contained nuclear household, therefore research on changing agricultural and social structures need to take account of the diversity in forms of domestic organisation which exist. The analysis of this paper attempts to do just this.

## III. Theoretical understanding of the tractor service market

In order to explore the working of this service market, the following section draws on standard economic theory alongside understandings of social structures to develop a framework through which to analyze the empirical data which follows. The theoretical world which standard economic theory might describe, is one in which multiple obstacles would hamper the development of the market. By drawing upon perspectives related to the social embeddedness of markets, the theoretical framework opens up the possibility of non-market institutions playing a key role in supporting market functioning.

### *a. Why the service market is inefficient*

The characteristics of the farming systems discussed in the previous section create constraints on the supply and demand for tractor services. The following theoretical elaboration considers how the characteristics of the village economies of northern Ghana lead to an inefficient market for tractor services. In summary, these characteristics are likely to create a coordination problem of matching a few service providers with many dispersed small-scale farmers, whose demand for services reflects localized rainfall patterns. The resulting uncertainty over the timing of tractor service delivery would lead to sub-optimal production outcomes for farmers.

First, we consider the cost structure facing service providers in the market. There are fixed costs, which can be thought of as the cost of transporting the tractor from its base to the village and the specific plot. There are several dimensions of transport cost. There is transport cost of physically moving the tractor and operator to the village. Once that fixed cost has been incurred, the marginal cost for each additional plot that is serviced will be less for the provider already working in the village, than for a tractor provider situated elsewhere. A service provider will only decide to travel to a village if they will be able to cover their fixed transport cost through adequate demand in the village. In this context, there are few large-scale farms which would cover this fixed cost. Instead, the service provider relies on demand for services from a sufficient number of small-scale farmers in a village to make it worthwhile for them to travel to the village in the first place. This can be thought of as a positive spatial externality. Once a service provider travels to a village for one farmer, the marginal cost of service provision for the second farmer is much lower. Because of the externality, we would expect to find an undersupply of tractor services if the market forces are the guiding principle. There is also potential for service providers to extract some rents from the local village market for services. The high transport cost creates a cost of entry to the local market and a natural monopoly at the village level for tractor providers (Friedman, 1983).

In addition to this fixed transport cost, there are the variable costs which are associated with the fuel and labour costs of plowing a particular plot. Poor quality plots with waterlogged soil or many tree stumps are also more likely to damage the engine or plowing attachment.

Therefore the variable costs of fuel and repair costs may be higher for plots which (i) are waterlogged (often used for rice cultivation), (ii) have been previously used to cultivate yam (more energy used to break down the yam mounds), and (iii) have not been plowed before or have been recently fallow. Some of these characteristics are easily observable by tractor operators, while others will be difficult to capture before work begins.

The nature of demand for tractor services is also worth elaborating. The returns to mechanized plowing for farmers are driven by three factors. First, mechanized plowing is a substitute for manual hand-hoeing for land preparation, depending on the scale of cultivation. At a very small scale of cultivation, manual and mechanized land preparation will be perfect substitutes as either technology will ensure land is prepared for planting in a few hours or days. However, beyond an acre or two, the amount of time required to prepare the land manually increases far beyond the time required for doing the same work with a tractor.

The second driver of tractor service demand is the time window available for land preparation between the first rains and the optimal planting time. This time window varies by crop with maize requiring early planting, and crops such as yam, sorghum, millet, and soybean having a longer period in which planting can be done. Furthermore, all farmers in a given locale will be seeking to prepare their land at the same time, according to localized rainfall patterns, making it expensive or impossible to secure adequate hired or communal labour to do the work. Finally, crops with higher market value will also have higher returns to machinery use.

These factors together mean that the returns to tractor plowing are higher for maize than for other crops. The elasticity of demand for tractor services will depend upon the returns to machinery use. For farmers seeking to cultivate large areas of maize, their demand will be relatively inelastic compared to those cultivating smaller plots, and crops such as sorghum, soybean, and millet with both lower market value and later planting times. The planting time for yam is much longer and at a different time of year.

Wihtout some institutional structure that can solve the externality problem, these features of the tractor services market have the potential to create some significant market failures. One could easily imagine that without mechanisms for coordination, more isolated communities and small-scale farmers would find it difficult to access services from the market. Given the time delimited nature of the market, it would easily be possible for the plowing season to end before service providers have even reached all the farmers whose willingness to pay would exceed the cost of provision.

The high variation in costs of service provision could lead to price differentiation, driven by village location and plot-specific characteristics. If we had perfect competition, the variation in marginal costs would lead to variation in prices by village and by plot. If the monopolistic power of service providers was dictating the price, again we would expect to have variation in prices according to the degree of isolation of the local market. For more isolated villages, the cost of entry is higher and degree of competition lower, potentially resulting in higher rents for service provision. This parallels results from Hotelling's theory of a spatial duopoly, where firms supply identical products at different locations with transport cost (borne by consumer in that case), that the firm will have strictly positive profits in equilibrium (see discussion in Friedman 1983, chp 3). Either way, we expect the price to vary by village or plot, if market forces prevail.

Furthermore, the unpredictable and localized rainfall patterns will create uncertainty over the timing of machinery services. The onset and distribution of the first rains of the season are unpredictable and localized. Local knowledge held by farmers may give them some advantage in understanding the common patterns, but discussion with farmers indicated that the pattern and timing of the rains in the area is highly changeable from year to year. Without perfect information on that season's rainfall patterns, it is impossible for service providers to organize their work optimally. There will always be a more efficient ordering of villages and plots which are serviced under perfect information which cannot be achieved in reality.

The result of the inefficient market and localized rainfall patterns would be to create uncertainty for farmers over when and whether they will receive the tractor plowing services they demand. Given the time-sensitive nature of the returns to machinery use, this uncertainty has profound implications for farmers. The utility the farmer gains from consuming tractor service within the planting window, will be much higher than from consuming services late. The production decisions for farmers will therefore be constrained by this weakness in the service market. Farmers will plant at a sub-optimal time which increases the probability of low yield or crop failure. Subsequent production decisions over their crop choice and investments in fertilizer and other inputs will be adjusted to account for the delayed land preparation, and late planting. In addition to excluding some farmers from the market, the unpredictable rains create production inefficiency as farmers face uncertainty over the timing of rains and the timing of service provision.

*b. Existing social relations enable the market to function and reduce timing uncertainty*

The conceptualization of the market for tractor services leads to the question of whether the actors in the market use formal or informal mechanisms to solve the coordination problem. The central argument of this paper is that actors use the existing informal institutions of village- and kin-based social norms and networks to minimize inefficiencies and improve the market outcome. These informal institutions take the place of a set of alternative formal institutions that are generally lacking in northern Ghana, such as government regulation of service provision, formal brokerage of tractor services, or formal contracting subject to the adjudication of courts.

This market can be thought of as analogous to the market for postal services or other potential natural monopolies. There are similar spatial externalities and time constraints that make it efficient for the same provider to deliver services to adjacent consumers, rather than having multiple firms making deliveries to adjacent households. Some customers, such as businesses, have very different demand from others, so that costs vary by consumer. The timeliness of service delivery is also an important feature of the product. In most countries, the postal service is either government operated or subject to government regulation in order to protect consumers from monopolistic pricing, and to ensure universal coverage of regular postal services. Where markets are dominated by informality, government is unable to play the same regulatory role.

Furthermore, the history of mechanization programs in Ghana demonstrates that centralized coordination of machinery services is susceptible to political capture and defeated by poor state capacity. However, in the vein of Granovetter (2005), the following discussion will show that by considering the social embeddedness of the tractor service market, we gain a fuller understanding of how actors minimize the loss due to market inefficiencies. I suggest that the existing social norms and networks are acting in place of formal regulations to improve market outcomes.

For these purposes, it is important to make clear the nature and particular aspects of the social structure to which I am referring. I am interested in those social relationships which farmers (a) hold outside of the household, (b) have been created through non-economic processes (e.g. marriage), and (c) are used to serve both economic (e.g. agricultural production) and non-economic purposes (e.g. status). This perspective on the social embeddedness of economic actors draws upon those of Granovetter (2005) and Fafchamps (2017). This definition allows for the fluidity of social networks and the multiple purposes which social relationships can have. An individual's social relations are used both for social and cultural activities, as well as economic purposes. It is therefore futile to try to separate those relationships which are social and those which are economic. Furthermore, the introduction of a new technology can create new purposes for existing social relations (J. Platteau, 1994). For analytical purposes, my focus is on connections which were initially created through non-economic processes i.e. kin networks, but are now being utilized for the economic activities of agricultural production, as distinct from anonymous interactions for the sole purpose of market exchange.

Technological change is both supported by and disrupts these informal institutions as economies and communities develop. Social norms and institutions can be supportive of technical change by providing networks and reciprocity which protects agents from some of the risks associated with adopting a new technology (J. Platteau, 1994). Therefore, the consideration of social relations and norms can be particularly important where deviations from competitive market outcomes are observed (Granovetter, 1985, 2005).

My analytical approach is therefore to consider farmers and tractor owners not only as individuals seeking to maximize their private returns, but also as individuals embedded within a social context. In this way, the non-economic incentives (or obligations) associated with the social relations may help or hinder the functioning of the tractor service market. I focus on two specific aspects of the specific cultural context and will discuss how the associated social norms may be enabling the functioning of an inefficient market for tractor service provision.

### *Extended family networks*

Through kinship, extended family networks have strong social norms. Members of the same kin group have shared obligations that go beyond the single economic transaction for tractor services. Extended family networks have the advantage of reaching across villages, as opposed to other networks that operate among families within the same village. The importance of extended family networks in many contexts reflects their usefulness in reinforcing social norms of reciprocity and egalitarianism (Fafchamps, 2017; J. Platteau, 1994). This is the principle that if any of their member accumulates capital or increased income or opportunity, the benefits will be shared with the rest of the network. For example, if one farmer in the village does well and acquires a tractor, the expectation may be that the use of the tractor will be shared with village and family members first, before non-network members. Indeed, members of a family or extended family network might pool some savings to support a member of the network in purchasing a tractor. These ongoing social connections in extended family networks are characterized by generalized reciprocity, going beyond the direct transaction. For instance, a tractor owner may send his machine to help a cousin, and in return the cousin may assist with hospital expenses in the following year. The point is that any single transaction forms part of a larger web of transactions that reinforce trust and mutual dependence within the network (Fafchamps, 2017). By using these connections, it may be that farmer are able to counteract the monopolistic bargaining power of service providers to secure a more competitive price. They may also able to reduce the uncertainty over the timing of service delivery by calling upon service providers with whom there is some obligation or mutual interest. For service providers, the kin network may be a useful source of information about the pattern of localized rainfall and may generate additional demand for services, as well as the more general benefit of adhering to the social norms of the extended family.

This mutuality can also be considered in terms of risk mitigation. If farmers use the extended family network as a means of support when they experience an income shock, then members of the network also have an interest in reducing the risk of an income shock for other members in the network. Tractor service provision is a means to do this. By providing timely services to members of the network, the returns to the collective agricultural activities of network members will increase.

### *Informal farming groups*

Farming is not done as a purely individual or household activity. Neighboring households share labour through communal arrangements over the farming season, for activities such as weeding, land clearing, and maize shelling. Labour is shared within households, but also between households in the same village. These informal groups serve a mixture of economic and non-economic functions, which again can be described as a generalized, rather than balanced, reciprocity. The groups are not formalized, but are a dynamic and informal coming-together of farmers to support individual farming activities. Elsewhere in Ghana, such self-sustaining informal groups have been found to be held together by cooperation and trust rooted in strong kin networks and norms (Lyon 2006). In the Upper East, it was found that animal plowing was shared in exchange for communal labour days during the 1980s (Whitehead 2006). The argument of this paper is that these existing informal groups and their associated norms have been further extended to support the adoption of mechanized technology. By coordinating within the group, farmers are able to harness some of the economies of scale associated with machinery use, without requiring full land consolidation. Plots remain under individual farmer control but, as a group, farmers are able to improve their bargaining power to negotiate the price and timing of tractor service provision. For service providers, their fixed cost is covered when a group of neighbouring farmers can be plowed at the same time, thereby overcoming the spatial externality.

The proposed argument is that the social embeddedness of households provides a mechanism for coordination which enables the market to function. Farmers can secure access to services, even though no individual farmer could cover the full cost of hiring a service provider. By consolidating their demand through informal farming groups, and calling upon providers within their network, some of the economic constraints on the market are overcome. These social connections not only enable access to services, they also reduce uncertainty over the timing of service delivery. If the social embeddedness of households is irrelevant for the service market, we might expect to see no relationship between the timing of plowing and planting, and the type of social connection between the farmer and service provider.

## IV. Data and Methodology

### a. *Method*

Yendi district, in the Northern region of Ghana, was selected as a case study location due to a high level of machinery use recorded in the EGC-ISSER household survey. 61% of the plots covered by the survey in Yendi were cultivated using a tractor. As shown in Table 20, the district is amongst the more highly mechanized districts in the Northern region, although not the highest according to the survey data. The table also demonstrates that Yendi is similar to other districts in the region in many other dimensions. Population density and growth, as well as local agro-ecological conditions are important drivers of agricultural intensification and variation in farming systems. Yendi is similar to other districts in the region both in terms of population growth between the censuses of 2000 and 2010, and in terms of the average number of days in the growing period. The district as a whole is relatively densely populated, as district town is farily large. Yendi town is important in the traditional chief and clan systems.

Data collection for the case study involved two approaches over September and October 2016. The first was to collect qualitative data through individual and focus group interviews with farmers, tractor owners and operators in 21 villages (Figure A 9). These interviews were based on semi-structured questionnaires that covered farming activities, use of (and access to) tractor services, non-farm activities, and village characteristics. The focus groups ranged in size from 3-15 persons and the selection of participants was determined by discussion with an initial point of contact -- usually a village elder or chief. Details of the interviews and interview guides are provided in the appendices to the thesis. The aim was to include villages of varying distance from the district capital, and farmers with a mixture of (i) farm sizes, (ii) tractor users and owners, and (iii) men and women. Quotes from these focus groups discussions are provided in the results section. Most quotes are paraphrased translations of the original discussion, as most interviews were conducted in local languages (Dagbani, Konkomba, or Twi). Where directly translated wording from a participant is used, this is specified with the use of quotation marks.

**Table 20: Northern districts - key characteristics**

| District | Population (2010) | Population density (2010) | Population change (2000 to 2010) | Length of growing period (district median) | % tractor use by plot |
|---|---|---|---|---|---|
| **Saboba-Chereponi** | 120,580 | 174 | 29% | 200 | 60% |
| **Karaga-Gushiegu** | 194,110 | 116 | 54% | 189 | 77% |
| **West Mamprusi** | 167,770 | 42 | 50% | 181 | 90% |
| **Bole-Sawla-Tuna-Kalba** | 161,560 | 19 | 27% | 223 | 60% |
| **Savelugu Nanton** | 136,650 | 29 | 52% | 190 | na |
| **Tolon Kumbungu** | 113,680 | 33 | -15% | 202 | 67% |
| **Yendi** | 201,260 | 132 | 55% | 211 | 61% |
| **Zabzugu Tatale** | 122,290 | 37 | 56% | 214 | 25% |
| **West Gonja-East Gonja-Central Gonja-Kpandai** | 417,410 | 31 | 32% | 209 | 25% |
| **Bunkprugu Yonyo-East Mamprusi** | 242,220 | 100 | 39% | 193 | 84% |
| **Tamale** | 371,910 | 149 | 28% | 197 | 100% |
| **Nanumba South-Nanumba North** | 238,780 | 28 | 66% | 223 | 33% |

Source: Population data is from IPUMS database from Government of Ghana Population and Housing Census 2010. Length of growing period data is denoted as number of days and is derived from FAO's GAEZ database. Estimate of % of plots using tractor is from EGC/ISSER Socioeconomic Panel Survey 2009, these are unweighted estimates. Several districts are grouped together to account for changes to district boundaries between rounds of the census (2000 and 2010).

A second round of data collection was undertaken in order to gather quantitative data on the findings emerging from the qualitative interviews. A small-scale survey was administered in five of those villages (Adibo, Zakoli, Sunson, Gnani, and Wambung) to 250 households (Table 21). The villages were purposively selected to include a mixture of Dagomba and Konkomba households, and a range of village sizes. Extensive machinery use was found across all the villages in the first phase. Within each village, households were selected using a random walk until 50 households were interviewed. The sampling rate was relatively high within each village in order to attempt to capture variation in social capital indicators and farming practices, whilst rainfall patterns and transportation costs are common within village. A random walk was used because a list of all households in each village was not available and it was beyond the budget of the current project to carry out a listing exercise. Again more details of the survey instruments can be found in the appendices to the thesis.

As a check on the representativeness of the sample compared to the rest of the Northern region in Ghana, we can compare the land size distribution for households covered by the quantitative survey to the land size distribution for households in the EGC-ISSSER Socioeconomic Survey (2009), which was designed to be representative of the population for the region. The mean household farm size for this survey in Yendi was 5.82ha. For the EGC-ISSER Survey, this was 3.75ha for rural households. From this, we can see that the Yendi sample includes households with larger farm sizes than most of the northern region. The difference in means is significant and the distributions are compared in Figure A 10 (Appendix VII). However, most farm households in both samples own less than 8 hectares of farm land.

**Table 21: Village sampling information (quantitative survey)**

| Village | No. of surveyed households | No. of households (2010 census) | Electric grid connection | Type of road through village | Distance to Yendi (Euclidean) | Working tractor in community in 2016 |
|---|---|---|---|---|---|---|
| Adibo | 59 | 251 | yes | Dirt | 15.2 km | no |
| Wambung | 47 | 132 | yes | Tarmac | 16.1 km | no |
| Gnani | 52 | 131 | yes | Tarmac | 23.3 km | yes |
| Sunson | 42 | <112 | yes | Dirt | 16.8 km | yes |
| Zakoli | 46 | <112 | no | Tarmac | 6.4 km | no |

Source: Population and Housing Census 2010, Yendi District Report, Government of Ghana; Author's field observations.

A mixed methods approach was implemented with sequential use of data collection methods in order to allow one method to inform the other as conclusions of how the market functions were developed (Greene, Caracelli and Graham 1989). From the qualitative interviews, initial findings emerged regarding the functioning of the rental market and the role social relations play, along with a typology of the actors in the market. The quantitative survey approach was used to further explore these initial findings. Descriptive statistics and simple ordinary least squares regression analysis are used to investigate the patterns in the survey data. The theoretical framework has been informed by considering both data sources (Plano Clark & Creswell, 2008). For the empirical analysis, each data source will be utilized to provide evidence to support the theoretical argument of the paper.

This combined methodological approach has its advantages and limitations. The social capital which is of interest in this paper is that which rests within the group, and the ways in which existing social norms in those groups influence the individuals' decisions in the service market. Quantitative measures of the extent and quality of an individual household's social network are not estimated, nor are experimental methods used to gauge group-level aspects, such as trust. However, the quantitative work does give us a sense of whether the social connections between actors in the market are important for farming production and service provision. The social relations and the norms which govern the relationships are best analyzed through the qualitative data. The subject of this research is not the strength of an individual farmer or household's social capital (although indicators such as being a chief or elder, or the size of farming groups to which they belong are used), but the norms which are held collectively by the groups and networks to which they belong, which are garnered from the qualitative data.

### *b. Plot and household characteristics*

The quantitative survey covered a total of 1,202 plots, cultivated by members of 246 households in the main season of 2016. Table 22 provides a summary of the plot-level data. Overall, 75% of the plots were cultivated using tractor plowing. Only 8 of the households captured by the survey did not use tractor plowing for any of their plots. Tractor plowing was used for all the commonly grown crops, and over 90% of maize, rice, and soybean plots were plowed by tractor. This is consistent with previous discussion that the timing of planting for some more commercialized crops is more critical, making tractor use essential for those crops. This is exemplified by the higher rate of tractor use for maize and soybean, compared to yam. These are the main crops grown in the area; yam differs from the other two crops in that the window for planting yam is much longer. Also of note is that tractor plowing is complementary with both herbicide and fertilizer use. Application of herbicide, followed by tractor plowing, is a common method to clear and prepare land, and this combination was used on over half of the surveyed plots. Fertilizer was mostly used with maize and soybean cultivation. Finally, tractor use was proportionally the same for plots farmed by women as for the whole sample. There are likely to still be gendered differences in how farmers access tractor services, but at least this simple measure indicates that both men and women are both using mechanized plowing.

**Table 22: Plot Characteristics (quantitative survey)**

| Variable (by plot) | Total no. of plots | Tractor used for plowing on plot (%) No | Tractor used for plowing on plot (%) Yes |
|---|---|---|---|
| Total | 1202 | 24.79 | 75.21 |
| *of which…* | | | |
| Female controlled | 140 | 23.57 | 76.43 |
| Plot was fallow | 129 | 96.90 | 3.10 |
| *Main crop grown:* | | | |
| maize | 278 | 7.55 | 92.45 |
| rice | 25 | 4.00 | 96.00 |
| soybean | 247 | 6.07 | 93.93 |
| yam | 240 | 22.08 | 77.92 |
| groundnut | 74 | 22.97 | 77.03 |
| sorghum or millet | 103 | 24.27 | 75.73 |
| *Inputs used:* | | | |
| Inorganic fertilizer | 194 | 3.61 | 96.39 |
| improved seeds | 17 | 0.00 | 100.00 |
| pesticide | 12 | 33.33 | 66.67 |
| herbicide | 650 | 7.54 | 92.46 |

Source: Author's survey and calculations. Yendi, 2016.

Further household characteristics are presented in Table A 11. These data provide insight to the nature of land availability. A substantial majority (61%) of households reported having more family land available to them than they currently cultivate. This indicates that although only a small proportion of plots were left fallow during the season, farmers are not yet land constrained. However, farm land is fragmented. Average total farm area is 5.82 ha but on average this is split into approximately 5 separate plots. Most farms therefore have about 5 plots of 1-2 hectares each. Plots are not necessarily contiguous, and can be a considerable distance away from the homestead.

### *c. Land and social institutions in Yendi*

Yendi district, which is the case explored in this paper, has its own unique history of ethnic conflict that has some bearing on the allocation and access to land by farmers of different ethnicities. Yendi is the seat of the Dagbon chieftaincy, and it has been subject to disagreements over inheritance between sub-clans. Particularly relevant for understanding the land institutions and networks amongst farmers, is the conflict between the Dagbani and Konkomba communities that reached its peak in 1994 (Bogner, 2000). The Konkombas reside within the Dagbon chieftaincy, and although they have their own chief system, their overall land allocation has been determined by the Dagbani chiefs. The Konkombas are a marginalized group as a result. The two ethnic groups live in distinctive villages or parts of towns, and farm in separate areas. From qualitative interviews, it is clear than the boundaries of land between Konkomba and Dagomba communities were determined at some point in the past and as such they are relatively fixed. This has implications for land availability for agricultural production, as arguably the Dagomba communities are less land constrained than Konkomba, in part due to the history of land allocation and distribution. Data from the survey conducted in Yendi district provide evidence of this. The average plot size for Dagomba households in the survey was 3.12 acres compared to 2.41 acres for Konkomba households, with a significant difference in the means at 99% confidence level.

However, the system of land allocation within each clan is similar. Farmers who belong to the community are allocated family land. They are also able to access ‘stool’ land through consultation with the local chief. This ‘stool’ land is land which belongs to the village but has not been yet been allocated to individuals or households. This land is not bought or sold, but a small payment may be made to the chief as a sign of respect. Within both communities, farmers are able to access ‘stool’ land at very low cost, provided it is available and they are able to cultivate it. However, the history of conflict and the role land played in its resolution, demonstrates that overall access to land is restricted and becoming more competitive.

In the villages that were studied, most indicated that all the land for the village had been allocated to families. Farmers are not necessarily cultivating all the land that is allocated to their families, but it is clear and known to all in the village that the land is theirs. The land can be cultivated by another (non-family) member of the village, with permission from the family. However, these boundaries cannot be permanently changed. Farmers were asked whether they could exchange land with a neighbor in order to consolidate their plots (and improve the efficiency of tractor use). Farmers found this idea laughable and would emphasize that the land is already allocated.

In conversations with farmers, it was apparent that adults within a household engage individually in farming activities, although labour and other agricultural inputs are shared within the household. Farming rights over the land are held by the family head, but they will allocate plots to their spouse or young men in the household to make decisions over cultivation of the plot. Beyond the household, neighbouring households within the village will take part in communal labour arrangements in addition to reproductive and cultural activities. For example, one farmer explained that he sends one of his children around to neighbouring households to request help for weeding the next day. When such a request is made, it is expected for the household to send at least one family member to assist, on the understanding that farmers can expect the same assistance in return.

## V. Results

### *a. Evidence of time sensitivity of plowing and its impact on farm incomes*

Key to the theoretical model of the hiring market is the underlying assumption that demand for tractor services is time-dependent. This timeliness constraint is evidenced by farmers directly reporting this, as well as their discussion of problems which arise when plowing services are late or difficult to secure. The benefits of tractor use for farmers are dependent upon the timing of when they receive tractor services.

[1] *"When it rains, the tractor will be farming for someone [else]…by the time they plow for you the season is over and so you will not get any good harvest."*

(Focus group discussion, Gnani, 19th Sept 2016)

Quote [1] indicates the stakes at play with regards to plowing services. If plowing services are delayed, their agricultural output is diminished. Another farmer stated a similar problem with his perception that at a certain scale of production, it is impossible to cultivate without use of tractors [2].

[2] *"If you want to do 5-10 acres, you can't do it yourself without machinery."*

(farmer in focus group discussion, Wambung, Sept 14th 2016)

This illustrates that farmers consider machinery use essential to their production beyond a certain scale. If they fail to secure tractor services, they may reduce the area cultivated to what is manageable with family and hired labour. Although the machinery and manual labour are substitutes, the timeliness benefit of machinery is considerable.

As part of the quantitative survey, farmers were asked whether they had been able to plant at the time they wanted to. From discussions with farmers, they indicated that plowing services and the timing of the rains are the key factors that will impact whether they are able to plant on time. For those plots which farmers reported planting late, 40% of these instances were attributed to problems in accessing tractor services.

Table 23 indicates that for maize production, in particular, timely planting is significantly and positively correlated with yield outcome, after controlling for other yield-enhancing inputs. The data here is limited and so we cannot say much about the relative effectiveness of other modern inputs such as fertilizer (only a dummy variable is used). These results confirm the qualitative findings that the timing of plowing services is important for agricultural output. Often arguments around mechanization presume that labour and machinery are directly substitutable, with no implications for yield. While this may be true in a technical sense, once weaknesses in the hiring market are accounted for, a farmer's choice to use machinery introduces a risk of late planting and lower yield.

**Table 23: Correlation of yield with key production variables**

| | Dependent variable: yield in maxi bags per acre (yam measured in pan) | | |
|---|---|---|---|
| | maize | yam | soybean |
| Planting was done on time (dummy) | 0.63** | 0.33 | 0.2 |
| | -0.23 | -0.29 | -0.24 |
| Fertilizer used on plot (dummy) | -0.15 | 0.87 | 2.31 |
| | -0.27 | -0.91 | -1.76 |
| Hired labour used on plot (dummy) | 0.21 | 0.86* | 0.09 |
| | -0.26 | -0.37 | -0.22 |
| plot area (acres) | -0.10* | -0.26** | -0.05 |
| | -0.04 | -0.08 | -0.03 |
| constant | 2.26*** | 2.00*** | 2.29*** |
| | -0.28 | -0.3 | -0.19 |
| Adjusted R squared | 0.04 | 0.05 | 0.05 |
| N | 249 | 181 | 225 |

Note: * indicates significance at 10%, ** is 5% significance, and *** is 1% significance. Standard errors are in parentheses and clustered at village level. Sample is restricted to plots on which each crop was grown, and for which tractor plowing was used. Standard OLS regression is used. Sample is all plots for which tractor plowing was used.

It is not simple to assess whether or not farmers plant "on time," as timeliness is conceptually complex. Timeliness cannot easily be disentangled from farmers' decisions about what to plant, and in turn this depends on weather and the timing of rains. When rains come late, a farmer may switch from maize to another crop, in which case the planting may be perceived as "on time". Although it is difficult to quantify, timeliness is captured in the quantitative survey by asking farmers whether they used tractor plowing on each plot and whether they planted early, late or on time. Farmers were also asked in which month they planted and the reasons why they planted late (due to tractor services being late, lack of working capital, or due to rainfall patterns). The measure is therefore based on farmer's perception of whether planting was done on time.

Taking the qualitative and quantitative evidence together, it is clear that the timing of plowing services is a critical factor in determining whether the farmer is able to plant on time – and also what crops the farmer can plant and ultimately what profits are earned. Farmers clearly indicated that they would reduce the area cultivated, plant different crops, or choose not to cultivate a plot if they fail to secure tractor services on time [3, 4].

[3] *They had wanted to plow more in the last year but … couldn't get the services in time.*

*(focus group discussion, Sunson, Sept 16th 2016)*

[4] *"I couldn't farm this season because I couldn't secure a tractor to go to my farm on time."*

*(farmer in focus group discussion, Adibo, 19th Sept 2016)*

Another strategy adopted by farmers was to cultivate different crops which were either more resilient to late planting, or required fewer inputs (e.g. inorganic fertilizer or manual weeding) [5, 6]. Maize and yam are prioritized when plowing is done on time. Maize yield is more sensitive to planting time and also requires inorganic fertilizer use. Yam plots are more laborious to prepare due to the mounds left from the previous season. Soybean, millet, and sorghum cope better with late planting and also do not require investment in fertilizers.

[5] *They also discriminate as to which fields were plowed on credit and which ones were plowed with cash. Yams and maize fields usually are plowed with cash while soya bean field plowing for instance is done on credit. The crops that are cultivated first are those whose fields are plowed with cash.*

*(focus group discussion, Adibo, Sept 19th 2016)*

[6] *Delays in plowing affected which crop they cultivated. They would have preferred to plant groundnut and also maize. When delayed service, they also plant less.*

*(focus group discussion, Tunu, Sept 16th 2016)*

One farmer in Yangu particularly highlighted the constraints facing farmers. He was discussing why farmers may choose not to cultivate maize [7]. Maize cultivation still requires investments in fertilizer. This extra investment may only be risked if farmers are able to plant maize on time.

[7] *Sometimes they have money to plow, but then won't have money to fertilize.*

*(focus group discussion, Yangu, Sept 16th 2016)*

The empirical data does support the idea that depending on the crop and scale of production, the use of mechanized technology is the only feasible means for land preparation. This has the potential to afford some market power to service providers. Farmers consistently indicated that a major challenge in their farming is securing tractor services on time. The cost to farmers of unpredictable timing of services is lower income from agricultural production, either due to reduced scale of production, cultivating lower value crops, or poorer yield from late planting.

### *b. Timing of service delivery and social relations*

In this section, I consider whether social norms and networks are used by farmers and providers to improve the functioning of the service market – namely to increase the farmers' probability of getting services and getting them on time. The quantitative survey confirms a strong relationship between the type of connection between a farmer and service provider, and the probability of that farmer planting on time (Table 24). The qualitative data then enables us to understand the nature of that social connection and the norms which guide the interaction.

Table 24 uses the quantitative survey to explore the partial correlations between farmers planting on time, and the social relationship between the farmer and the tractor owner/operator who provided plowing services to them. Columns 1 and 2 show that plots which were planted on time are more likely to have been plowed by a tractor owned by someone in the village, a friend or relative from outside the village, or through an out grower scheme. This is a considerable effect. Farmers are 32-34 percentage points more likely to plant on time if they get tractor services from someone they know, rather than an unknown service provider from elsewhere, and 41 percentage points more likely when accessing tractor service through the out grower scheme. The variables that are significant are those that indicate farmers have some existing social relationship with the tractor service provider either through being neighbours in the village, or being friends or family from outside the village. Although not reported, the regression was also estimated including household controls (plot area, number of separate plots held by the farm household, gender of the plot manager, and the type of crop cultivated), none of which were significant nor did their inclusion affect the coefficients on the variables of interest.

Once unobserved household-specific variation is controlled for, through fixed effects, households which include chiefs or elders and hosted a tractor owner are significantly associated with timely planting (column 3, Table 24). There is little variation in which type of tractor service provider is used across plots within the same household, therefore the significance on those coefficients is lost when household fixed effects are included, although their magnitude is little changed. This is noteworthy confirmation of what we might expect

– that leaders of the village community are more likely to be at the front of the queue when the tractor service provider comes to the village.

**Table 24: Determinants of timely planting**

| Dependent variable: Dummy for planting on time (OLS) | (1) | (2) | (3) |
|---|---|---|---|
| Used own tractor~ | 0.29 | 0.38* | 0.34 |
| | (0.19) | (0.19) | (0.34) |
| Used tractor owned in village~ | 0.32** | 0.32** | 0.37 |
| | (0.10) | (0.10) | (0.34) |
| Used tractor via out grower scheme~ | 0.41** | 0.42*** | 0.23 |
| | (0.13) | (0.12) | (0.38) |
| Used tractor owned/operated by a friend~ | 0.34*** | 0.32*** | 0.35 |
| | (0.08) | (0.08) | (0.32) |
| Household hosted a tractor operator | -0.02 | -0.02 | 0.74* |
| | (0.09) | (0.09) | (0.42) |
| Household includes a chief or elder | 0.04 | 0.06 | 0.74** |
| | (0.07) | (0.06) | (0.34) |
| No. of farming group members | 0 | 0 | 0 |
| | (0.00) | (0.00) | (0.01) |
| Plot level controls | yes | yes | yes |
| Village fixed effects | yes | no | no |
| Household fixed effects | no | no | yes |
| adjusted R2 | 0.07 | 0.05 | 0.58 |
| N | 867 | 867 | 859 |

Note: ~ indicates the reference category is using a tractor that is unknown to the farmer from outside the village. Standard OLS regression results are reported. Regression model was also run using probit and logit techniques with same results for coefficient significance. Standard errors are clustered at village level. There is little variation in the source of tractor services within households, therefore the inclusion of hh fixed effect cancels out the effect. * indicates 10% significant level, ** 5%, and *** 1%.

From qualitative interviews, tractor owners had a variety of profiles in terms of how they related to the farmers they served. The first to be considered are those tractor owners who are based in their village. The responses of some tractor owners strongly suggested a sense of loyalty to their home communities, which indicates that the norms of egalitarianism and reciprocity are guiding the way in which these tractor owners organize the ordering of service provision. One tractor owner in Zang explicitly stated that he prioritizes his home community during the plowing season [8].

[8] *He also provides services outside the community and goes depending on the rains. This community gets priority, so if he has gone out, he comes back when the rain comes.*

(tractor owner in focus group discussion, Zang Sept 15th 2016)

In two of the villages which were visited, farmers described the organisation of services within the community in order to ensure all farmers are able to take advantage of the rain [9]. This was a case where the local chief formerly owned a tractor and provided services for the local community, but the machine was not functional in the most recent season.

[9] *The operator said that as a sign of commitment, he would plow an acre each for all the customers who came. This, he said, would enable each one of them [farmers] to take advantage of the first rains because if he used all the time to plow all of an individual's holdings, another individual may have to wait, during which the rains may be missed.*

(tractor operator for local chief, Zakoli, Sept 13th 2016)

In this particular case, the tractor was owned by the local chief who saw it as his duty to share the use of the tractor equally with the farmers in his community. This pattern was repeated in another village also. Elsewhere, farmers also indicated that they were better able to secure timely tractor services through tractor owners based in their local community [10].

[10] *"Before a tractor was owned in the village, it used to be hard to get service."*

(farmer in focus group discussion, Zang, Sept 15th 2016)

This was a recurring theme in focus group discussions that a tractor owned by member of the village, or family members close by, would be a common source of tractor service provision, as quotes [11, 12] demonstrate.

[11] *"Sometimes we send to Saboba [to provide tractor services]. [I] serve here first, then we go there. We farm early, they farm late…because of the rain and the land. They don't farm yam. We have some family over there, they will call us and we will stay with them. Our operator is from that place [Saboba]…we are in the same family."*

(Tractor operator and farmer, Bakpaba, Sept 20th, 2016)

[12] *In the village, there are two tractors, one is broken. The one tractor is not enough to serve all their farms, so they also get services from outside. Two additional tractors came to provide services last season. One came from Yendi, this one comes every year, the operator is from the village. The second came from Tamale to plow for soybeans, he is also a brother.*

(focus group discussion, Sunson, Sept 16th 2016)

These quotes convey the weight which is put upon tractor owners and operators providing services to extended family members. Equally, farmers clearly see benefit in the habitual use of tractor providers within their family network.

However, only 3 of the 21 villages have the benefit of a tractor owner (with a functioning tractor) based in the community. In this instance, farmers cooperate with neighbouring farmers in order to secure tractor services. Furthermore, farmers' responses indicated that these informal institutions for cooperation on agricultural production are not new, but an adaptation of well-established norms. There are strong social norms within village communities, which drive the sharing of labour and coordination of farming activities. Communal labour has been an established means of cooperation among farmers for many generations. In Yendi, the protocol that was described was that a farmer will call round to neighbouring households to ask for assistance for a particular agricultural task that day (e.g. weeding, maize shelling). Households have some obligation to send a representative from their household to provide free labour, with the understanding of reciprocity in due course. Communal labour continues to be an important component of agricultural labour, despite increasing commercialization of agricultural practices in more recent decades. From the survey of households, 49.59% of households used communal labour on at least one of their plots.

These same informal farming groups and means of cooperation are being used to coordinate tractor service provision, as described by farmers in Kpalba [13]. This pattern was described similarly across several villages.

*[13] The farmers group themselves and organize to call a tractor for services together. The tractor operators also prefer this as it saves them costs. The group is formed by proximate farms. The group will also use each other's labour for weeding, harvesting, and beating the crops.*

(focus group discussion, Kpalba, Sept 16th 2016)

Farmers often described the situation in which there is a 'host' farmer in the village who provides food and accommodation for the tractor operator while they work on all the farms in the village [13, 14]. The host is usually connected to the tractor owner/operator in some way through family ties. The host will get tractor services for free in exchange for hosting. The host will also play some role in organizing the sequence of the tractor provider's work in the village. If any farmers have arranged to pay in kind, the host farmer will be the one to keep track and facilitate repayment. This further emphasizes that how a farmer is connected to others within and beyond the village, has potentially considerable bearing on the timing with which they receive tractor-plowing services.

*[14] They reach out to friends and family within those areas that are known to have tractors. The group leaders were usually the ones tasked to seek tractor services.*

(focus group discussion, Adibo, Sept 19th 2016)

This shows that it is the interaction of kin networks across villages and the social institutions for coordination within villages that farmers draw upon to improve their outcomes from the tractor service market.

### c. *Price for tractor services across villages*

The qualitative evidence also offers insights into the spatial externalities discussed above, which have particular salience in a time-constrained market. If market dynamics were exclusively what guided the market, we might expect to see considerable price variation for tractor services. Under both perfect competition and monopolistic price-setting, we would see price variation across farmers. The empirical observations, however, indicate that these conceptualizations of the market dynamics alone do not explain the resulting price variation. This subsection will explore the evidence.

Table 25 shows the variation in the price of tractor services per acre across the quantitative survey villages. There is little variation in the mean or median cost of tractor plowing services per acre, despite differences in geographic location and land availability in each village. The median cost is the same across all villages at 50GHC per acre. The mean cost of tractor services per acre is higher in Gnani village than the other smaller villages. Gnani is a larger village with more densely populated area, reflected in only 34% of surveyed households having uncultivated land available to them. A higher level of demand may drive up the mean price for this location. In all but 3 of the 21 villages which were visited, farmers in the focus groups and service providers quoted the price for tractor services to have been 50GHC for the last season.

**Table 25: Price of tractor plowing services**

| | Cost of tractor services per acre | | | | |
|---|---|---|---|---|---|
| Surveyed village | Median | Mean | Standard Deviation | % yam plots | % hh with uncultivated family land available |
| ADIBO | 50 | 49.77 | 17.42 | 0.33 | 0.78 |
| GNANI | 50 | 52.78 | 17.50 | 0.23 | 0.34 |
| SUNSONG | 50 | 44.43 | 21.45 | 0.13 | 0.51 |
| WAMBONG | 50 | 48.44 | 19.54 | 0.16 | 0.61 |
| ZAKOLI | 50 | 45.46 | 15.53 | 0.18 | 0.73 |
| Whole sample | 50 | 48.36 | 18.89 | 0.20 | 0.60 |

Almost all individual farmers also faced the same price of 60GHC. There were a few deviations from this price which farmers reported [15]. The first was if more than a single pass with the plow is required or requested for the plot. This is typical of fields that were previously planted with yams. Yam fields and plots with many stumps, often need more than one round of plowing, compared to other fields which ordinarily are just plowed once. A few farmers, particularly in Adibo, did both plowing and harrowing which increased the cost per acre of tractor services. The survey asked for the total cost of tractor services on each plot, and this has been divided by the reported plot size. Second, farmers reported that in some cases they are able to negotiate to pay after harvest and in kind, rather than paying with cash at the time of plowing. Third, the standard price was reported as 'per acre' but plot sizes are not homogenous. Few plots are precisely one acre in size, so there would be some negotiation to deviate from the standard price if the plot is judged to be more or less than the usual acre.

[15] *"Everyone is charged the same price - 50-60 GHC depending on the size of the plot. This is the same for virgin land [land that has not been plowed before]."*

(tractor operator, Kpalba, Sept 14th 2016)

There are some deviations from the standard price reported by farmers. The standard price, however, was well known, and farmers insisted that apart from the reasons mentioned, they paid the standard price. This is consistent with the quantitative survey where the price variation is minimal, given the dispersion of plots and seasonal peak demand for services.

To further investigate, for the household, the relationship between the price of tractor plowing and the theorized factors which may affect the price negotiation, partial correlations between the price and variables affecting (i) connection with the tractor provider, and (ii) strength of family/group social capital, (iii) plot-specific characteristics, as shown in Table 26. There is a marginally significant and negative relationship between the area of the plot and the cost per acre for tractor services, once other factors are controlled for. This is consistent with the theorized cost structure that tractor service providers will have higher marginal cost for smaller plots and therefore charge more per acre. However, the magnitude of the effect is very small – less than 1GHC difference in the cost per acre between a one acre and two acre plot.

Those using their own tractor or accessing services through the soybean out-grower scheme pay significantly less for tractor services than other farmers. Otherwise, there is remarkable homogeneity in the cost per acre across households. Even households which include a chief or elder do not systematically pay more or less for tractor services than others.

**Table 26: Determinants of tractor plowing price**

| **Dependent variable: Price of tractor plowing paid per acre** | (1) | (2) |
|---|---|---|
| Used own tractor | -17.46*** | -17.50*** |
| | (3.57) | (3.98) |
| Used tractor owned in village | 1.28 | -0.23 |
| | (2.92) | (2.95) |
| Used tractor via out grower scheme | -29.89*** | -29.96*** |
| | (4.45) | (4.39) |
| Used tractor owned/operated by a friend | 1.78 | 1.68 |
| | (2.59) | (2.63) |
| Household hosted a tractor operator | -0.02 | -0.27 |
| | (1.95) | (2.07) |
| Household includes a chief or elder | -0.35 | -1.56 |
| | (1.61) | (1.56) |
| No. of farming group members | -0.01 | 0 |
| | (0.09) | (0.10) |
| Area cultivated (acres) | -0.78* | -0.86* |
| | (0.36) | (0.37) |
| No. of plots farmer cultivates | 0.16 | 0.12 |
| | (0.35) | (0.34) |
| Female (dummy) | -2.12 | -2.91 |
| | (1.58) | (1.68) |
| Main crop on plot is yam | 3.05 | 3.81 |
| | (2.04) | (2.07) |
| Main crop on plot is maize | 2.27 | 2.56 |
| | (1.36) | (1.33) |
| constant | 49.33*** | 49.96*** |
| | (5.33) | (5.80) |
| Village controls | yes | no |
| adjusted R2 | 0.11 | 0.1 |
| N | 847 | 847 |

Note: ~ indicates the reference category is using a tractor that is unknown to the farmer from outside the village. Standard errors are clustered at village level. Standard OLS regression estimation used.

The resulting price in the market is not linked to those transportation and plot-specific costs which might be expected under purely market forces. The uniform median price, which is observed from quantitative (Table 25) and qualitative responses, provides evidence that the existing social relations and norms are just as important as market forces in determining the price. Discussions with farmers and tractor operators confirmed that there is an agreed price each season which is known by all. There was very little debate or discussion over that season's price for services amongst focus group participants when this question was asked. Farmers indicated that even if there was a shortage of tractor services, the result was that they wait for tractor services. Those who don't have cash to pay upfront may have to wait longer and then pay by credit if the service provider agrees. No one who was interviewed indicated that they paid a higher price in order to get tractor services sooner, or to secure a service provider to come to their village. In fact, there is no significant difference in the mean tractor cost per acre for plots which were planted on time compared to those that were not.[40] The same norms that guide the organisation of tractor services are likely to also be enforcing a standard price for all households and plots, and discouraging exploitative pricing.

In discussions with farmers, it is clear that information on the price of tractor service for that year is quickly shared amongst all farmers within and across villages. Furthermore, where groups of farmers are organizing themselves and negotiating services from a provider together, a uniform price that is known by all in the groups is part of this coordination. Finally, farmers also indicated a strong preference for calling upon service providers from within their existing kin networks.

Perhaps the most compelling evidence regarding the price-setting is that there is no evidence of 'surge' pricing at the point in the plowing season when demand is high due to the arrival

[40] Mean tractor cost per acre for plots planted on time was 48.42 GHC, versus 48.19 GHC for those plots planted late. P-value for two-sided difference in means was 0.86.

of the first rains, or the end of the season approaching. When farmers were asked what the effect of a lack of tractor services was, the response was that they get services late. None of the farmers responded by saying that service providers charged them more when there was a shortage of providers.

Qualitatively, it is clear that the pressures on supply and demand create a spatial externality, as well as opportunity for monopolistic pricing. However, given the heterogeneity in plots, their locations, and the timeliness premium, there is relatively little variation in prices across plots, farmers, or villages. Although a wider study would provide more confirmatory evidence on this, the evidence from these villages indicates that the social structure in which the market is embedded is enforcing a single price for all farmers and plots.

### *d. Out-grower scheme as an alternative coordination mechanism?*

Some farmers, however, opt to take part in a formal out-grower scheme for soybean production. The scheme is run by a private company which contracts with farmers in a range of locations across northern Ghana for the production of maize and soybean. In Yendi, they are active in a handful of villages, where the company focuses on soybean production. The company provides farmers with a package of inputs, including seeds, fertilizer, and tractor services. The cost of these inputs is deducted from the total value of the harvest that is sold to the company at the end of the season. Therefore, farmers are not involved in negotiating the price for tractor services. Farmers reported that the tractor services available via the out-grower scheme would be limited to 1 or 2 acres per farmer, although in some cases they could pay the tractor service provider directly to plow more of their land. In this way, it could be that the out-grower scheme works as an alternative, and more formal, mechanism to secure timely tractor services, rather than relying on the social norms and networks as argued above.

Is the farmer's choice to participate motivated by improving their access to timely tractor services? And relatedly, is it farmers who have weaker social capital that are more likely to choose the out grower scheme? To investigate this further, Table 27 shows the difference in plot and household characteristics for plots that are cultivated by households participating in the out grower scheme, and those that are not. The sample focusses only on those villages where the out-grower scheme is active and farmers therefore had some opportunity to participate.

Plots cultivated by households participating in the out-grower scheme are more likely to be planted on time. 84% of plots cultivated by out grower households were planted on time, compared to only 56% of those cultivated by non-out grower participants (Table 27). This could be due to timely tractor services, but some of the difference could be due to improved supply of other inputs and better knowledge about good practices. Participating in the out-grower scheme changes whom the farmer gets tractor services from, as expected, although it is not associated with the probability of the plot being plowed with tractor or not. For out grower households, 42% of their plots are plowed directly by the out-grower scheme, whilst 56% of plots were plowed by a friend or relative. Interestingly, the composition of crops cultivated between out grower and non-out grower participating households is very similar. The participating households are more likely to include a chief or an elder, to be better educated, and to generate income from other sources, such as migration, rearing animals, or self-employment. These would all indicate that these farmers may have better economic and social status, and wider networks.

### Table 27: Characteristics of out-grower participants

| | Not out grower households | | Out grower households | | P-value for t-test difference in means |
|---|---|---|---|---|---|
| | mean | N | mean | N | |
| Planting done on time | 0.56 | 184 | 0.84 | 43 | 0.00 |
| Used tractor plowing | 0.77 | 236 | 0.69 | 62 | 0.21 |
| Used tractor via out grower scheme | 0 | 186 | 0.42 | 43 | 0.00 |
| Used tractor owned/operated by a friend | 0.9 | 186 | 0.56 | 43 | 0.00 |
| Price of tractor plowing paid per acre | 50.61 | 182 | 39.25 | 43 | 0.00 |
| Area cultivated (acres) | 3.09 | 236 | 3.73 | 62 | 0.24 |
| No. of plots in household | 7.44 | 236 | 7.06 | 62 | 0.33 |
| More family land is available to household | 0.58 | 226 | 0.75 | 40 | 0.04 |
| Maize cultivated | 0.17 | 233 | 0.24 | 62 | 0.21 |
| Rice cultivated | 0.02 | 233 | 0 | 62 | 0.25 |
| Soybean cultivated | 0.24 | 233 | 0.26 | 62 | 0.77 |
| Yam cultivated | 0.15 | 233 | 0.21 | 62 | 0.26 |
| Groundnut cultivated | 0.08 | 233 | 0.06 | 62 | 0.74 |
| Sorghum or Millet cultivated | 0.11 | 233 | 0.05 | 62 | 0.16 |
| Hh includes a chief or elder | 0.19 | 236 | 0.58 | 62 | 0.00 |
| No. of farming group members (hh) | 10.08 | 236 | 14.02 | 62 | 0.00 |
| Plot cultivated by female hh member | 0.12 | 235 | 0.05 | 62 | 0.11 |
| Land is borrowed | 0 | 230 | 0.05 | 62 | 0.00 |
| Highest education level of household | 2.91 | 232 | 3.42 | 62 | 0.01 |
| no. of household members | 12.04 | 236 | 18.19 | 62 | 0.00 |
| Hh member migrated for work in last 12months | 0.36 | 236 | 0.66 | 62 | 0.00 |
| Hh received remittances in last 12 months | 0.02 | 236 | 0.08 | 62 | 0.02 |
| hh generated income from rearing animals | 0.41 | 236 | 0.73 | 62 | 0.00 |
| hh generated income from self-employment | 0.11 | 236 | 0.19 | 62 | 0.08 |
| main dwelling has aluminium roof | 0.91 | 236 | 0.53 | 62 | 0.00 |

Note: Sample restricted to villages where out grower scheme was active.

The conclusion from this simple analysis is that participation in the out grower scheme is associated with improved probability of getting timely tractor services, although not whether a farmer uses tractor plowing or not. Participants in the out-grower scheme are in general better connected socially than their neighbours. A plausible characterization – though not one that can be concluded for certain – is that farm households with lower social status who draw upon the informal networks and norms to access machinery services, whereas those with higher social status are able to participate in the out-grower scheme and improve their access to timely service through that route.

### *e. Gender and the tractor service market*

Some interesting differences emerge from the analysis in relation to the gender of the farmer. In both Table 26 and Table 28, the price for plowing services and the probability of timely planting are uncorrelated with whether the plot is controlled by a male or female household member. From the qualitative discussion with farmers, a major improvement that they attributed to tractor use is that women are able to farm more, compared to when tractor services were unavailable. Women have always had rights over farmland through their husband or family and have been involved in farming. The difference which was reported by farmers in the focus groups is that, due to tractor plowing services, women are able to cultivate a larger area.[41] Frequently, it was reported that the income women get from farming is used to pay school fees for children. This is consistent with Dietz et al. (2013) who also

[41] Men and women were both invited into focus groups discussions. However, there were more men than women who participated, which might introduce a bias in the responses.

found perceptions in northern Ghana that women are able to access and own land more easily now than in the past.

Tractors alleviate the labour constraint for both men and women farmers at plowing time. However, farmers seemed to indicate that this constraint was greater for women and so the proliferation of tractor services has had a greater effect on women's agricultural activities, evidenced by some of the focus group discussions [16]. Some women who were interviewed indicated that they had to wait for all the men in the village to use the tractor before the women would then be able to access services. However, others indicated that the tractor would plow all the plots for the household at the same time.

[16] *All the people present [indicated that the] coming of the tractor has been of immense benefit to the whole community because now there are plowing services all year round and the women said now they are able to do early farming to get more yield and are able to farm twice. The women also said the tractor has reduced hunger in the community. They are now able to rest more and they are able to get money to take the kids to schools.*

(focus group discussion, Nambongani, 13th September 2016)

The quantitative survey yields useful insights here. It includes data on tractor use and the gender of the household member in charge of each plot. Unlike other studies that can only look at male-headed and female-headed households, I am able to look at plot level and therefore capture women within male-headed households. In fact, only three of the households in the survey have no plots managed by men. The majority of women captured are in households with both male and female household members involved in agricultural production. As discussed in other technology and gender studies, the negotiation within households over the use of and control over modern technologies is lacking in the literature (Theis et al., 2018).

**Table 28: Characteristics by gender of plot cultivator**

| | Male plots | | Female plots | | P-value for t-test difference in means |
|---|---|---|---|---|---|
| | mean | N | mean | N | |
| Planting done on time | 0.57 | 793 | 0.64 | 103 | 0.16 |
| Used tractor plowing | 0.75 | 1053 | 0.8 | 130 | 0.25 |
| Used tractor via out grower scheme | 0.03 | 808 | 0.04 | 102 | 0.49 |
| Used tractor owned/operated by a friend | 0.63 | 808 | 0.69 | 102 | 0.26 |
| Price of tractor plowing paid per acre | 48.8 | 775 | 45.11 | 99 | 0.07 |
| Area cultivated (acres) | 3.11 | 1053 | 1.59 | 130 | 0.00 |
| Maize cultivated | 0.26 | 1046 | 0.04 | 128 | 0.00 |
| Rice cultivated | 0.02 | 1046 | 0.01 | 128 | 0.26 |
| Soybean cultivated | 0.17 | 1046 | 0.49 | 128 | 0.00 |
| Yam cultivated | 0.23 | 1046 | 0 | 128 | 0.00 |
| Groundnut cultivated | 0.04 | 1046 | 0.24 | 128 | 0.00 |
| Sorghum or Millet cultivated | 0.1 | 1046 | 0.02 | 128 | 0.00 |

Note: Only 3 households in the sample had all female-only plots, implying these are female-headed households. These households are excluded from the sample so all plots are in households with both men and women engaged in agricultural production.

Table 28 presents various plot-level variables by the gender of the household member in charge of the plot, from the survey in Yendi. Women are slightly more likely to plant on time; this is partly due to the difference in area and crops, compared to men. Women are far less likely to cultivate maize and yam. Only 4% of the 128 plots cultivated by female household members were cultivated with maize. Women concentrate on cultivating soybean and groundnut. They also cultivate much smaller plots compared to men, on average. The average plot size for female plots is 1.59 acres, to 3.11 acres for male plots. Women are cultivating smaller areas, and planting crops which do not require as early planting as maize. Therefore, planting on time is less dependent upon the timing of tractor services.

There is a marginally significant difference in the cost of tractor services for male and female controlled plots. However, the difference is small in magnitude and may reflect difference in the crops which are cultivated – men are more likely to cultivate yam which requires multiple plows. This supports indications from qualitative interviews that tractor use is negotiated by the household together, rather than by individual plot holders [17].

[17] *She has never called a tractor to come before but she gets it when the men bring in the tractors.*

(Chief's wife, Zakoli, 13th September 2016)

As regards gender differences in tractor use through the service market, we can conclude three things. First, women are just as likely to use tractors for land preparation as men. Second, women undertake agricultural activity which is less dependent upon timely tractor use, and have lower returns to machinery use. We cannot say whether these production choices are the result of weaker access to tractor services and other inputs. Third, communal bargaining over price of tractor services seems to ensure that women do not pay more or less than men.

## VI. Discussion

The collection of evidence from the case study of this particular district in Ghana provides support for the ideas that the agro-ecological and land tenure characteristics of agricultural systems in northern Ghana have shaped the social and economic institutions that govern tractor use. Many of the farmers in the study area depend upon tractor plowing technology for cultivation, particularly for maize cultivation, in order to take advantage of a narrow window of time after the onset of the rains. The reliance on the tractor service market has the potential to create a major uncertainty for farmers and their communities, since the timing of plowing has substantial implications for the profitability of farming. Finding institutional structures that can assure timely plowing is a matter of real importance for farmers and farming communities.

On the other side of the market, tractor owners and operators organize their work to concentrate on serving many farmers within a few villages. This gives some indication of the cost structure which was theorized --namely, that there is a fixed cost of travelling to a village. Conditional on coming to a particular village, tractor owners can maximize their profits by serving as much area as possible in the same location. If transport costs were negligible, we might expect to see tractor owners serving large farmers across many villages with more concern for minimizing the on-plot costs of service provision. The underlying economic problem is to cover these fixed costs of getting a tractor to each village. There is some competition among tractor operators that limits market power (and hence limits the ability of a tractor operator to charge high prices to farmers). But where villages are remote, plots are fragmented, and the fixed costs are high, there may be no decentralized solution to covering the fixed cost. If the tractor operator comes to the village speculatively, absorbing the fixed cost in hopes of recovering it through monopolistic pricing, he will lack bargaining power – in the sense that once he is there, it is in his interest to plow for any price above marginal cost. If the tractor operator does not come, there may be no single farmer who can offer to pay the fixed cost. A coordination failure is a likely outcome, in which no tractor operator considers it worthwhile to go to a particular village, and no fields get plowed.

By drawing on local institutions and norms, in which collective decision making is common around land management and farming, villages are able to coordinate on hiring a tractor operator. By effectively sharing the fixed cost across a large number of farmers, they can create surplus; they can make it profitable for tractor operators to come to the village and still earn positive profits. This should hold for all but the most remote villages, where the fixed cost exceeds the aggregate surplus that can be generated through timely plowing. Farmers and service providers are drawing upon the social context in which they operate to find ways to reduce the costs of these inefficiencies. Neighbouring farmers are using their existing ways of working to share labour and other resources, in order to consolidate their demand for tractor services. Although the land tenure system limits the consolidation of land ownership and use, through the informal groupings, farmers are consolidating their demand for services in order to share the fixed cost which would otherwise discourage service provision.

The preference among farmers to use service providers from within their networks is evidence that there is some benefit to farmers to draw upon these social institutions. There is at least the perception that this means of accessing services can improve the timeliness of service delivery. Moreover, we have shown that there is a significant correlation between whether a farmer is socially connected to their service provider and the probability of planting on time. The way that these social connections are described by both farmers and service providers indicates that there are social norms at play which attribute responsibility to tractor owners and operators to prioritize those farmers in their kin network. The economic advantage of this arrangement seems to not only be for farmers. Service providers avoid the costs associated with searching for customers during the season by getting information from their extended kin network on rainfall patterns. Here, we have considered the economic costs and benefits of drawing upon these social networks. However, it would be an interesting further study to understand the social benefit for tractor owners and operators of serving their kin members well.

By relying on existing social relations, there is the danger that those with weaker bargaining power or status within those social institutions may be disadvantaged. The paper investigated whether women are disadvantaged in accessing tractor services either in terms of the price they pay, or the timing of service delivery. The evidence does not indicate there to be any difference in neither the price that is paid, nor the likelihood of getting tractor services. However, there is a difference in the scale and types of crops which women cultivate. Women may be making production decisions based on delayed access to tractor services, or the nature of their production (due to other constraints) may require less time-critical tractor services in the first place. It is therefore difficult to conclude whether women are able to access services equitably with men, given inequity in access to other resources and production activities.

## VII. Conclusions

Northern Ghana faces many of the same agricultural characteristics as other savanna zones in West Africa, where there is little use of machinery in land preparation or other farm activities. As in much of the region, farm size is quite small, and farmers are poor, with little access to credit or insurance. Technology adoption and diffusion are widely seen as slow. Across the region, repeated efforts by governments to promote agricultural mechanization have had mixed success, and frequently have not lead to sustained use after government funding ends. Yet northern Ghana stands out as a striking example. Government programs over several decades have facilitated an increasing stock of tractors, but previous iterations of government-managed tractor service provision in the 1980s did not lead to widespread and sustained machinery adoption by smallholders. This paper has shown that the widespread adoption observed in more recent years is partly due to the social context and adaptation of existing informal institutions to the organisation of tractor services. It could be argued that in the absence of direct government intervention in the tractor service market and increasing private ownership of secondhand tractors, institutional innovations have emerged which are enabling widespread access to tractor services.

This paper asks how the use of tractors for land preparation has become so widespread. Part of the answer appears to be that the agricultural characteristics of this locale imply that tractor plowing is essential to take advantage of the narrow temporal window for planting maize – an increasingly profitable crop thanks to growing urban demand. But the profitability of tractor plowing would not by itself lead to widespread adoption without solving the spatial externality and the time-constrained market. Farmers are dependent on tractors that must travel to their locations – often from relatively distant towns. The fixed cost of travel may outweigh the profitability to service any one farmer. But when farmers can organize collectively in a community, the fixed costs are shared across many plots and the group can arrange for a tractor to come and plow a number of closely proximate farms.

This empirical case study has demonstrated the crucial role that the existing social relations play in overcoming and minimizing the costs associated with this inefficient market. Farmers coordinate service requests through their existing informal farming groups and call upon service providers within their kin networks. The strength of existing relationships and the strong social norms of cooperation in farming appear to facilitate these cooperative solutions, without any formal role of state planning or organisations such as official farmer groups or cooperatives.

This case study has important implications for the academic and policy discussions of scale economies in farming in Africa. Much literature in agricultural economics has argued that mechanization will only be used when farm size is sufficiently large and/or when labour costs get sufficiently high. An extreme conclusion from this would be that land needs to be consolidated in ownership in order for economics of scale from machinery to be harnessed. This example shows that the cooperation of neighbouring farmers can substitute for consolidation of ownership, at least in the context of plowing. The land ownership is not changed, but the decision over plowing becomes a group decision and neighbouring plots are plowed together, by the same tractor. Therefore, some of the benefits from economies of scale are accrued through reducing the transaction costs for tractor service providers.

Finally, the key contribution of this paper is in showing how the social norms and networks which exist in rural agricultural communities are facilitating access to mechanized plowing services for farmers in Ghana. The importance of agents' social embeddedness in supporting trust and market exchange has been noted and theorized by others (Fafchamps & Minten, 2001; Granovetter, 2005; J.-P. Platteau, 2000). This paper shows some specific ways in which these norms and networks have been applied to support adoption of a modern, capital-intensive technology alongside more traditional norms of land and labour sharing. Recent policy reports promoting mechanization for Africa have specifically made note of the need for institutional innovations to facilitate access to the technology for all farmers (African Center for Economic Transformation, 2017; Malabo Montpellier Panel, 2018). The findings of this paper provide a pertinent example where these innovations can emerge from smallholder farming communities.

# Thesis Conclusion

*Understanding agricultural mechanization for theory and policy*

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In this concluding chapter, I will discuss some of the key themes which have emerged across all three papers, and elaborate the contribution of the thesis as a whole. These findings will be considered in light of recent literature and their potential implications discussed. As well as pulling together the key themes from across the thesis, I will also reflect upon the research process and further work which would strengthen the evidence base. The final section will consider the emerging policy attention to agricultural mechanization, and contribution this thesis can make to the direction of policy.

## I. Overall themes.

### *a. Adaptive social institutions*

The emergence of machinery use in Ghana has relied upon the social norms and institutions in agricultural communities. The service market and coordination of demand by neighbouring farmers enables economies of scale for service provision, whilst farm sizes remain small. This thesis has shown that these social institutions have adapted to facilitate access to capital technology for small-scale farmers (Paper 3). The first paper sets the scene in demonstrating the importance of exogenous drivers relative to individual farmer characteristics in explaining patterns of technology adoption. All farmers in a local community are facing the same external conditions which affect the returns to machinery use. The local social institutions then provide the context for farmers to coordinate in order to secure access to machinery for themselves and their neighbours. The substantial effects of machinery use on agricultural production that is found (Paper 2) demonstrates that farmers have considerable incentives to adopt tractor-plowing, and as a consequence are motivated to coordinate with their neighbours and relatives to secure access to services. This collection of papers demonstrates that the adoption of mechanization is as much an individual decision as it is a communal one, at least in the context of many small-scale farmers and strong social norms.

The role of social institutions and capital in agricultural development has been viewed as both helping and hindering. The norm of egalitarianism can discourage investment and accrual of wealth, as benefits must be shared with family and kin. However, the flow of learning and risk-sharing amongst social networks can facilitate experimentation with new agricultural technologies. The empirical case examined here is one where social networks and norms are improving access to machinery, over what the market incentives would enable. Alternative private sector solutions to the coordination problem in the market for tractor services are being developed. Companies such as HelloTractor[42] use GPS and mobile technology to match service providers with farmer demand. It will be interesting to see whether these new technological solutions replace the role of social institutions in the tractor service market, for all farmers or for certain sub-groups.

However, the challenge of time-limited demand and limited supply of tractors means that there will likely always be some farmers excluded from the market at the market price – i.e.

[42] https://www.hellotractor.com/

farmers who would want to purchase services at the market price but because the season has ended, their plots are not plowed. It is beyond the scope of this thesis to consider which farmers and plots are excluded, but different outcomes may have different implications for social equity. Certainly, a market outcome that draws upon actors' social embeddedness has the potential to avoid reinforcing the economic inequality arising from land endowments and geographic isolation but may instead reinforce the economic inequality arising from the existing social relations and associated status. Whilst the current study raises this question, it is unable to provide evidence one way or the other.

### *b. Mechanization that eases timing constraints rather than saving labour*

Theories of agricultural mechanization tended to assume that the farmer's decision over technology adoption depends simply on the relative abundance or prices of land, labour and capital. However, the findings of this thesis have found that viewing mechanization as labour-replacing is a simplification which masks the motivations of farmers and the impact of its use on local rural economies. The first paper found weak evidence that areas with shorter growing periods are more likely to adopt tractor-plowing, which was not true of mechanizing transport or maize-shelling. Farmers put substantial effort into coordination and appealing to tractor owners in their social networks in order to secure timely tractor plowing services (Paper 3). The impact of tractor use revealed that mechanization of plowing was not leading to a reduction in labour intensity, but in fact to increased labour use for other operations for some farmers (Paper 2). This is not to say that labour availability is an irrelevant constraint for farmers, but it may be less consequential than the importance of timely land preparation in order to plant on time is considerable for farmers.

Underlying existing theories is the assumption that agro-ecological conditions in a particular location are fixed. It is these agro-ecological conditions which determine, by crop, the timing for agricultural operations and the length of the growing season. However, neither the choice of crop, nor the agro-ecological conditions are necessarily fixed.

Urbanization and changing diets have increased demand for particular crops such as maize and soybean. Maize, in particular, relies on earlier planting to optimizing the growing period in Ghana. This shift in demand is driving the adoption of tractor-plowing, arguably more than constraints in access to agricultural labour. Furthermore, this timing constraint is more acute for certain operations in the production process. Technologies which facilitate early planting are critical. The precise timing of weeding and harvesting is less critical and therefore the returns to mechanizing those operations are lower for farmers.

Having said that, there are broader patterns of seasonal migration from areas of northern Ghana to provide labour for cocoa-production and urban centres in the south, which are likely to play a part in the mechanization story. Of the households interviewed in Yendi, 36% had a household member who migrated for work in the last year (Table A 11). The increasing availability of tractors may be enabling farm households in the north both to shift into labour-intensive and timing-sensitive maize production, and also to allow some household members to migrate for employment elsewhere at peak times.

Changes to the agro-ecological conditions are not as immediate as changing diets, but are evolving as a result of climate change pressures. For West Africa particularly, projections indicate considerable temperature increases due to anthropogenic climate change which will considerably reduce potential yields for cereal crops, with maize most affected (Niang et al., 2014; Schlenker & Lobell, 2010). The volatility of rainfall is expected to increase and number of rainfall days to decrease in Ghana over the long term, with rural communities responding to such pressures already (Codjoe & Owusu, 2011). These changing climate pressures have the potential to increase the returns to mechanized plowing. It is a technology which has the potential to enable farmers to respond quickly to unpredictable rainfall and to turn over hard soil from extended dry seasons. This thesis has by no means provided conclusive evidence of this link, but it is conceivable to see that mechanization could be play a current and increasing role in farmers' response to changing climatic conditions.

However, if the objective is to support sustainable intensification of Africa's farming systems in the context of climate change, the maintenance of soil fertility must be considered. Land degradation in northern Ghana where soils are shallow is a serious problem (Akudugu, Dittoh, & Mahama, 2012; Yiran, Kusimi, & Kufogbe, 2012). Tractor plowing has the potential to exacerbate land degradation through facilitating the conversion of more land to annual cultivation, and through compaction of the soil structure. The extent to which mechanization is playing a role in the mining of soil nutrients has not been explored in the literature, except alongside other technologies through extensification (Erenstein, 2006).

### c. *Gender and technology in agriculture*

The findings of the thesis provide a substantive contribution in understanding the gender differences in access to (and use of) agricultural mechanization technology. The second paper showed that tractor use disproportionately increases women's engagement in agriculture both through increasing the farm area over which they exercise control, and the number of labour days used by women in production. Furthermore, the case study from Paper 3 shows that female farmers are able to access tractors alongside male household heads. In fact, farmers indicated that a major consequence of their adoption of mechanized plowing was that female household members were able to farm more. In keeping with this, the study found no evidence that women are disadvantaged in accessing tractor services.

These findings are notable for their consistency across both quantitative analysis of survey data, and in the mixed-methods case study. It implies that the difficulty in securing labour for land preparation either from within the family or through the labour market was previously preventing women from cultivating their own land. Women tend not to cultivate the most timing-sensitive crops; this suggest that it may be the labour constraint which is motivating their use of machinery. This is a question of women having weaker bargaining power over family or communal agricultural labour. By using tractor plowing, negotiated at the community level, the weaker bargaining power of women is neutralized. The impact on their agricultural activities of tractor use is greater than for men, because securing labour is all the more difficult.

It has been noted in the literature on gender and agriculture that differences in agricultural productivity and input use in Ghana can be attributed to differences in access to inputs, such as land and labour, between men and women (Doss & Morris, 2000). Furthermore, intra-household bargaining power is an important component in understanding who is adopting technology and for what agricultural activities (Haider, Smale, & Theriault, 2018; Theis et al., 2018). This thesis adds to this understanding to see that mechanization disproportionately increases female engagement in agricultural production, by reducing their demand for family or hired labour. It is also encouraging to find evidence that men and women are both using tractor services. This question may warrant further investigation, but at least from what the methodologies of these papers can show, women are not disadvantaged in accessing tractor services.

The Women's Empowerment in Agriculture Index considers five domains to capture women's access and control over agricultural activities, namely production, resources, income, leadership, and time use (USAID, IFPRI, & OPHI, 2012). The evidence of this thesis seems consistent with a view that mechanized technology in this context is enhancing women's empowerment across these domains. As farmers described qualitatively, their wives are taking more control over agricultural production and are using the income from that activity to help pay school fees for their children. This implies improvement in both women's empowerment over production and the use of income. In terms of time use, there is evidence of women's time spent in agriculture increasing. However, the analysis does not allow any conclusions on whether this is an improvement in overall time use for men or women, or whether women have increased agency over their time use.

Long-term impacts on intra-household time use and bargaining power have not been captured by the papers in this thesis. Nor has there been a separate consideration of women within male-headed household and female-headed households in terms of access and impacts of tractor use. Extending the work to include analysis of panel data, and repeat visits to the site of qualitative work could probe into some of these intriguing further questions.

## II. Reflections on the research process

As discussed in the introduction, the methodological approaches of the thesis papers have been inevitably constrained by the administrative, household survey, and geospatial datasets which are available. The analysis of farming systems is constantly challenged by the heterogeneity of soils and climate; infrastructure; social and family systems; economic opportunities and urban connectivity; implementation of government support; as well as individual farmer preferences and capabilities. Many of our methodological struggles reflect the challenges of isolating the relationships of interest from the multitude of other factors influencing the observed farming systems. Moreover, analysis in the context of heterogeneity is all the more a challenge where comprehensive data is limited. The methodological approach was designed in order to make the most of the various data sources and types, as well as methods, in order to build a fuller picture of agricultural mechanization in Ghana, whilst being aware of the limitations in data and methods with the scope of a doctoral thesis project. The subsections which follow will reflect on the limitations in the data with the implications for the success of the methods used, as well as discussion of further work which would overcome some of these limitations.

### *a. Data and method limitations*

The inevitable drawback of using secondary household surveys is that the sampling and questionnaires have been designed for different purposes. This is particularly evident in Paper 2, where the sampling and matching with administrative data left a relatively small sample size in terms of districts. The results of the instrumental variable analysis were weaker because of the limited sample size, which reflects the fact that "treatment" was effectively at the district level, whereas impact is assessed at rural household level. The identification would potentially be more convincing if the matched sample of districts were larger. If there were better information on the operations of the government-provided tractors in the particular season, the instrumental variable could have been implemented at a finer resolution i.e. by village or enumeration area, or by distance of the farm household from the tractor service provider. Administrative data on the current stock and location of government-supported service providers is not available. Obviously, the ideal situation would have been a randomized roll out of the government program ex ante, with the survey planned accordingly.

As is discussed above, a key theme arising from the thesis is the importance of timing in motivating farmers' demand for tractor services. However, timeliness is a difficult concept to capture in terms of farmers' production decisions. Whether planting has been done at the optimal time is dependent upon the crops which are cultivated, and often farmers decide which crop to cultivate on the basis of whether they will be able to plant at the right time for that season. The 'right time' is dependent upon the particular rainfall patterns of that season. It is not directly captured in either of the secondary datasets used. The primary quantitative survey which I designed attempted to capture this factor by relying upon farmer's own opinion on whether they planted early or late. Given the difficulty in objectively capturing this factor, subjective farmer-reporting was a reasonable second-best approach.

The geospatial datasets which were used in the first paper provided proxy information on key factors. These datasets are based on geospatial models which estimate population density, travel time, and growing periods at a relatively fine resolution, but based on observed data at a coarser scale. Inevitably, using this data at a fine resolution also includes a greater measurement error between the model and the true value, were it observed. However, rainfall data is not available at a local scale for Ghana. The emerging work on weather-based index insurance and credit facilities in SSA are increasing the availability of local rainfall data, but these data are sometimes limited to a certain project area (Chantarat et al., 2013; Dercon & Krishnan, 2000; Greatrex et al., 2015).

Population density data was used to proxy for pressures on land and labour availability at the local level. An even better measure of this would be land prices or rents, or agricultural wages. However, agricultural land is rarely bought, sold, or rented formally in Ghana. Agricultural labour is hired frequently which could provide some data on labour costs. However, the labour exchange is also done through communal and family systems. There is also rarely good data in household surveys on how the cost and availability of labour varies during the season, which is the data that would be most relevant for questions of peak demand for labour or machinery. Therefore, population density data becomes a useful, if imperfect, proxy for these dynamics. Finally, survey responses on travel time to the nearest village or market town are inevitably correlated with farmer characteristics, and so a geospatial model provides a measure which is somewhat independent from farmer characteristics.

Finally, the case study data collection which was collected by the student for Paper 3 provides rich insights, but in hindsight, perhaps better quality data could have been gathered. An inductive approach was taken, which allowed freedom to adjust fieldwork methods after qualitative interviews were completed. However, more time to test and plan the quantitative survey would likely have benefited the quality of the data. Specifically, social connectedness and geographic remoteness are likely to be correlated. Capturing the geographical remoteness of both farmsteads and individual plots would have enabled the factors of remoteness and dispersion of plots to be analyzed, and therefore convincingly isolate the social and marginal costs factors.

### *b. Potential future work to build on these findings*

The first potential extension of the thesis work is to take advantage of the second round of the ISSER-EGC Socioeconomic Panel Survey, of which the first round was used for the analysis in paper 2. With this additional data, panel regression methods could be used, such as fixed effects, to control for the plot, farmer, and household specific characteristics which are unchanging over time. Alternative pseudo-experimental methods such as estimation of difference-in-difference effects would enable research into questions of the longer term impact of agricultural mechanization that was not possible with a single cross-section dataset. Questions which could be investigated more thoroughly include (i) the productivity impact of mechanized plowing and its interaction with technologies, (ii) opening up understanding of women's participation in agriculture and the impact on intra-household time use, (iii) long term effects of machinery use for smallholder farmers and the welfare outcomes of different household members, (iv) impact on farm and off-farm labour, and (v) the interactions between urbanization, rural infrastructure, and machinery use.

The third paper of the thesis raised interesting questions regarding the means through which farmers and other participants in the wider agricultural system coordinate, in order to overcome some of the spatial externalities inherent in this farming context. The paper primarily considered the informal social norms and networks maintained in rural farming communities, as well as the role private out grower schemes may play, in coordinating tractor users and service providers. Further innovations are being offered by the private sector to use mobile and GPS technologies to support Uber-style applications which enable machinery owners, service providers, and farmers to manage and coordinate demand for service provision. This provides opportunity to investigate the effectiveness of different coordination mechanisms in supporting the tractor service market in terms of market efficiency and in terms of the equity of access to timely machinery services, i.e. which farmers are excluded or at the back of the queue for tractor services at peak time.

The interest in this strand of research is to examine the interactions between modern technology, market transactions, and non-economic relationships (in the style of Ganovetter and others). As such, data collection methods could be improved in order to better capture both the social relationships and the economic costs underlying the externality. The type and strength of the social connections between farmers and service providers could be better understood. Similarly, more information could be gathered on the marginal costs associated with each plot, such as its distance from a good road.

## III. Emerging mechanization policies in Africa

This research endeavour has primarily been focused on understanding empirical experience of mechanization in Ghana, and developing our theoretical understanding of the role mechanization plays in agricultural development. It does not directly address the increasing policy enthusiasm for mechanization which often assumes that machinery adoption is an unequivocally good thing which should be promoted for development and food security (African Center for Economic Transformation, 2017; Malabo Montpellier Panel, 2018;

Mrema et al., 2008). This resurgence has the danger of repeating the mistakes of the 'tractorization' schemes of the 1980s.

Indeed the pressures of urbanization and population growth which have driven changes to Ghana's farming systems, are similarly being felt across the continent. Agricultural food imports have been rising, as increased domestic production has failed to keep pace with population growth, and particularly increasing food demand from urban middle-classes. The policy advising institutions of the Malabo Montpellier Panel, the African Centre for Economic Transformation, and the Food and Agriculture Organisation have all begun touting mechanization as the means to increase agricultural productivity, create improved job opportunities for the growing youth demographic, and to drive broader economic development in Africa (African Center for Economic Transformation, 2017; Malabo Montpellier Panel, 2018; Mrema et al., 2008).

The claim that agricultural machinery will increase productivity seems to be consistent with my findings. My results suggest, however, that the increase in productivity in northern Ghana takes the form of a shift to higher value crops rather than an increase in the yield levels that are achieved. Achieving yield growth will require a package of additional agricultural technologies which maintain and sustain agricultural yields for the long term. Mechanization which leads to expansion into poorer quality soil, without the availability or affordability of yield-supporting technologies, will potentially lead to declines in productivity.

In addition, the third paper of this thesis demonstrated the importance of the coordination and institutions which manage access to machinery. Without timely access to machinery services in northern Ghana, the productivity benefits of machinery use are lost. This is an important lesson for those mechanized technologies which meet a timeliness constraint for farmers. By the very nature of the problem tractor plowing solves, there will be peak demand for tractor services and therefore challenges in determining who gets access and when.

At first glance, it can seem contradictory to promote mechanization for job creation. Indeed, in some contexts, mechanization will reduce local employment opportunities. As with tales of structural change in history, without providing opportunities for skill development, a skill mismatch can arise between the new employment roles created by technological change and the skills of the existing workforce, with unemployment an inevitable consequence. This thesis has shown that the impact of mechanization is not simply to reduce labour activity in agriculture. In fact, the time spent working in agriculture increased in total, but with a shift in the type of work that was being undertaken. Mechanization may in fact create new employment opportunities in the agriculture sector, but policies will need to bear in mind the investment in skill development required to support technological change. The case considered here is a mature technology for which the skills and knowledge for adoption have been established; more advanced mechanized technologies and sophisticated production systems would require investment in education, skills, and other institutions which support technology transfer and adaptation.

The Malabo Panel report particularly advocates for institutional innovation alongside technological innovation (Malabo Montpellier Panel, 2018).[43] The emphasis is often on

[43] "Mechanization is also not just about technology; its success depends on organizational innovations, such as reliable services and cooperation arrangements for and with farmers." – Ousmane Badiane, Foreword to Malabo Panel Report: Mechanized.

formal government or private sector institutions, whereas the story of Ghana's mechanization relies upon innovation in the social institutions which underpin rural life. The Malabo Panel report's final recommendation to 'support smallholder farmers and women's groups' is welcome, and will hopefully not be left as an afterthought as governments press ahead with subsidized machinery imports. Designing policies which are sensitive to the existing capacity within communities for coordination will be important for both public and private sector to successfully include farmers of all scales in this mechanized revolution.

Debates over appropriate technology began in the 1980s and have resurfaced with the increasing influence of BRIC actors, such as Brazil's Embrapa, in Africa's agricultural development. There has been a particular focus on the transfer of agricultural machinery technologies from Brazil to Ghana, Mozambique and elsewhere (Cabral, 2016). Despite the range of agricultural technologies for small, medium and large scale farming available in Brazil, it is large-scale tractors which governments in Ghana and elsewhere have chosen to import. Given the continued small-scale of tractor-using farmers in Ghana, as well as the power of social institutions to facilitate technology adoption, the government may be failing to support the transfer and adaptation of technologies which match not only the agro-ecological needs of Ghana's farming systems, but the characteristics of farm sizes.

My final thoughts regarding agricultural mechanization and the inevitable juggernaut of machinery imports, public-private partnership, and social enterprises which will jump upon the emerging policy trend are as follows.

1. Mechanization policies should reflect the diversity of farmers and farming systems in Ghana, and elsewhere. A good government may be able to manage this, but partnership

with private sector and rural institutions is likely to work best. The example of Ghana shows that almost despite failed government policies, private and social institutions took up the job of facilitating a service for tractor services which benefits a whole range of farmers.

2. As mechanization has taken off in Ghana, there is little sign that warnings regarding long-term soil sustainability have been heeded. Tractorization should be considered in tandem with a package of technologies to support sustainable intensification goals.
3. Policies to promote technology adoption should be aware of the benefits for both men and women of mechanization, and the impact on intra-household time-use in smallholder family farms. There is potential for the technology to enable women's empowerment in agricultural production, income generation, and as a consequence the welfare of households.

## Appendices



List of Tables and Figures in Appendices

## Appendix I: Guide for focus group discussions with farmers

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*Consent* – read out the consent script in local language. Ask for consent for their responses to be used for PhD research, all will be kept anonymous. Ask if the interview can be recorded.

*Respondent information* – complete table/excel sheet for key info ('Fieldwork Respondents')

*Intro question*: "Tell me about the kind of farming that you do, and how it has been changing in recent years." Then use questions below to cover key topics.

*Main topics*

I. Agricultural production and technology use (machinery, chemical inputs, improved seeds)

- How has this changed? Why were the changes made (family circumstances, land tenure, non-farm income, training/interventions)
- What is the order of production decisions – area, crop, machinery, inputs? What determines these decisions?
- How have your costs of production, or need for working capital, changed with machinery use?
- How does the farmer decide on which plots to use machinery? Do you use machinery every year? How has your machinery use changed over the last 10-15 years?
- How is the price and time of machinery services determined? How long do you have to wait for machinery services? How do you organize access? Has this changed over the years? Do tractor service providers try to charge you more, why? Does this vary by plot? How does it compare to neighbouring farms?
- How does the cost of machinery use vary by operations, plot, crop, time of year?
- What technologies did your parents use for agricultural production?
- Where does farmer get working capital to pay for seeds/inputs/machinery services at the start of the season?
- What other economic activities are you and your family involved in?

III. Institutions and their evolution with machinery use.
Social capital and quality of networks

- how often do you consult with the local chiefs?
- How often do you see district agricultural staff, or attend trainings?
- Who do you discuss farming with regularly? How often? What do you talk about?

<table>
<tr><td>

- Which clan group do you belong to? Do you or any of your close family hold any positions of responsibility – official or traditional?

Labour use and allocation

- Who works on the plot, and for which operations? How is employment organized and has this changed over time?
- How has this changed over time?
- What is the division of labour within the household for different plots/crops? How does this vary over the year/seasons?
- How have the ways of labour exchange evolved with increased machinery use? How has the skill and organisation of labour demand changed with technology?
- What training and education did you, your children, and your parents have? What skills or trades did/do they have?

Land availability and security of tenure

- how were the various plots obtained? Any plots which you no longer farm?
- How far are your plots from the house, and from accessible roads?
- How does security of tenure relate to production decisions?
- How has competition over land use evolved? Has the way in which land is allocated and exchanged changed? Who owns land now, has there been consolidation? Has the rental cost of land, or the 'kola' required for land access changed?
- What are the farmers' perceived rights and tenure security over each plot? What is the history of the plot in terms of use and ownership?
- Has the role of government, NGOs, and traditional chiefs changed with respect to land, labour, farming systems?

</td></tr>
<tr><td>

III. Perceived impact of increased machinery use on labour, land, education, health, incomes, quality of life and opportunity.

- How is life different for you compared with that of your parents?
- What do you attribute this change to?
- Gather perceptions on how increased use of mechanization has affected
    a. labour wages, type, and exchange,
    b. farming systems (crops, frequency of cultivation, techniques, input use),
    c. land allocation, availability ,and exchange,
    d. intra-household labour use,
    e. migration and non-agricultural economic activities.

</td></tr>
</table>

*Closing* - Thank the farmer for their time. Check that phone number has been recorded correctly. Ask if it would be okay for us to come back tomorrow or the day after to visit their farm.

## Appendix II: Interview questionnaire – tractor owners

*Consent* – read out the consent script in local language. Ask for consent for their responses to be used for PhD research, all will be kept anonymous. Ask if the interview can be recorded.

*Respondent information* – complete table/excel sheet for key info ('Fieldwork Respondents')

Main topics

| |
|---|
| I. Tractor stock and entrepreneur history<br>• What machinery is owned and operated? For what agricultural operations are they used?<br>• What is hired out for machinery services, or used on own farm?<br>• What other economic activities is the tractor owners involved with?<br>• How has tractor ownership evolved over time? How has farming or other economic activities changed alongside tractor ownership?<br>• Does the tractor owner hold any positions of responsibility in the community (official or traditional)? What is their education level? Which clan group do they belong to? Are they indigenous to the local community?<br>• How as the tractor stock changed in the last 10-15 years – in numbers, the type of machines, the number of owners, the type of owners?<br>• Do you know of any government, NGO or other intervention related to mechanization in the local area? Have you benefited from any of these?<br>• Why did you buy a machine? What benefit has it brought you, apart from income of machinery services? E.g. networks, access to finance, working capital for other businesses, access to training/services. |
| II. Labour and skills for tractor service provision<br>• What labour does the owners use for tractor operation and service provision?<br>• What kind of contracts or arrangements are made?<br>• What education and skills did the labour have? Has the owner made any investments in their skills?<br>• How was the labour found? Is it difficult to find labour for this work? What does the labour do throughout the year? |
| II. Organisation of services provision<br>• How do you decide which farmers to serve and when?<br>• Are there any farmers which you serve every year? |

| |
|---|
| • Which locations do you provide services to (villages)? Does this change each year? How has this changed over the last 10-15 years?<br>• How many farmers in each of these villages? What farm size do these farmers have?<br>• Do you know all the farmers you serve? What proportion are from the same village, or clan group?<br>• Do you coordinate with other tractor owners? Or share information with them? |
| III. Price-setting for machinery services<br>• How do you determine the price for machinery services? It is done per acre/ha, or for the whole plot/farm?<br>• How does the price vary across villages? Why does it vary?<br>• Does the price you charge vary by farmer within the village, or by plot? If yes, why?<br>• What is the most profitable type of farm/farmer for you to provide services to? What is the least profitable? |

*Closing* - Thank the farmer for their time. Check that phone number has been recorded correctly.

**Appendix III: Small-scale Survey – enumerator guide**

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**Plan for small-scale survey**
*Yendi district, Ghana*

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**Research objective**: to understand variation within villages of the timing and cost of tractor services, and how this relates to household and farm characteristics. The focus is on access to tractor services within the village.

- Is the mode of payment for services linked to early/late planting, and to yield?
- Is timing of services linked to farm size, belonging to a farming group, social capital, ability to pay upfront?
- Does this relationship vary across villages due to institutions (proxied by ethnicity), or population density (proxied by land availability, or population).
- What affects a village's the distribution in access to tractor services? Large scale farmers, existing institutions for collaboration, access to out growers scheme?

**Scope:** The survey will cover 200-250 households in 4-5 villages in Yendi and Mion districts. The unit of analysis will be the household, although questions will be asked of individual plots and individual household member (of working age, involved in farming). Survey questions will cover the following areas:

i. tractor services
ii. hh characteristics
iii. land
iv. crops
v. labour and agricultural inputs
vi. wealth indicators
vii. farming cooperation and social connectivity.

**Sampling:** The villages will be selected from the first round of focus group discussions that were conducted in 21 villages of Yendi and Mion districts. Villages form only Yendi district will be selected. Rather than a random sampling of villages in the district, this will be purposive sampling. The sub-set of villages in the first round of focus group discussions were selected via a random walk. There may be a slight bias towards communities located by roads which can be accessed by 4x4, but I don't believe this is significant. The selection of villages for the 2$^{nd}$ round of quantitative survey will be purposively selected based on (i) variety of konkomba, dagomba, and mixed communities, and (ii) whether there is a locally owned tractor.

The alternative would be to randomly select 5 villages from either the district list of villages, or the sub-set of villages for which focus group discussion were carried out. The IFPRI survey already provides a sample that is representative at the district level for Yendi. For the purposes of this survey, it is adequate to do purposive sampling to capture the variety of institutions (mostly determined by ethnic group), and means of tractor access (locally owned, soybean out growers scheme).

The villages selected are the following. Adibo may also be added if necessary – largest community (250 households).

Day 1/2: Then start with Zakoli, followed by Wambung. There are other neighbouring villages we can be included if necessary

Day 3: Start with Gnani (call the contact you have there), and possibly other neighbouring villages as required for the no. of respondents.

Day 4/5: Start with Nagani, then Sunson. Similarly, consider other villages nearby if necessary.

| | dagomba | konkomba | mixed |
|---|---|---|---|
| large population | wambung | | Gnani(, Adibo) |
| small population | sunson | nagani | Zakoli no.1 |

The sampling of households will be done using a random walk, starting from a random point in the road, the enumerator will select every 3rd house as they walk away from the road. In this way, there will be a random sample that is representative of the village.

**Community Entry**: The researcher and enumerators will meet with the assemblyman/chief, as appropriate, of the village to inform them of the work that will be carried out in their village. The researcher and enumerators will work together spending one day in each village. One enumerator will also assist the researcher to gather village data and conduct qualitative interviews (see key informant interviews). A total of 5 enumerators will be used.

**Consent**: Oral consent will be requested from each household as the interview is carried out. A script for this will be provided by the researcher. It is important for the enumerators to inform participants that their participation in the survey is voluntary and anonymous.

**Enumerator training**: 1 day training will be carried out with the team of enumerators at Mafara Hotel, Tamale. The training will go over oral consent, the survey questionnaire, the process of recording the data, logistics, and ethical conduct in the villages.

**Enumerator contract**: The enumerators will be paid for 6 days work that includes 1 day of training and 5 days of data collection. A per diem will be paid to cover accommodation, communication, and food costs during data collection, in addition to the daily rate. Enumerators will be responsible for arranging their own accommodation. Per diems will be paid on a daily basis, with the full payment to be paid at the submission of completed paper questionnaires.

**Key informant interviews**: The researcher, with assistance from the co-supervisor, will conduct key informant interviews with leaders of each village. This will follow up from the preceding focus group interviews, and focus on the historical changes to the village. The researcher will review the previous focus group discussion, and undertake follow-up interviews.

**Materials:** Each enumerator will be provided with 50 paper copies of the interview questionnaire, and a printed copy of survey plan. Enumerators will also be provided with notebook, folders, and pen/pencils.

## Appendix IV: Small-scale Survey – Survey questionnaire

**Survey Questionnaire – Tractor usage in Yendi district**

| | |
|---|---|
| Village name: | |
| Enumerator name: | |
| Interview number: | |
| Date of interview: | |
| Time of interview: | |

****READ ORAL CONSENT SCRIPT****

*This research is being conducted on behalf of Frances Cossar who is a PhD student at the University of Oxford. Her research is on agricultural technology use. We have a set of questions that we would like to ask you related to your household and farming activities. The answers you give will be the basis for a PhD thesis.*

*The personal information you will share will not be passed to any third party. This research is independent of any government, international, or aid organisation. This research is anonymous, which means that in my publications, your name will not be used. Your participation is completely voluntary and we can stop any time you like. I am not able to compensate you in cash or in kind for your time or cooperation.*

*If you would like to talk directly to the researcher, she can be contacted at +233 507095012 or frances.cossar@qeh.ox.ac.uk. This research project has been reviewed and approved by the university's ethics committee. If you would like to speak to the University directly, their email is ethics@socsci.ox.ac.uk.*

*Do you have any questions? Do you give your permission for me to interview you? Do you give your permission for me to re-contact you to clarify information?*

**Oral consent script read: yes / no**

**Interview subject consented: yes / no**

Contact phone number for participant: ____________________

<u>At the end:</u>

- Verify the contact phone number for the participant
- Thank the participant for their participation.
- Provide my business card.

**Household Characteristics**

1. How many of the following are in the household?

| | |
|---|---|
| Married men (over 16) | |
| Married women (over 16) | |
| Unmarried men (over 16) | |
| Unmarried women (over 16) | |
| Children (under 16) | |

2. What is the highest education level completed of the most educated in the household? *Circle one answer*.

| | |
|---|---|
| 1 | No formal education |
| 2 | Primary school |
| 3 | JHS education |
| 4 | SHS education |
| 5 | Technical/Vocational education |
| 5 | Tertiary education |
| 6 | Non-formal education |

3. How many of the children in the household currently attend school?

__________________

4. From which of the following activities do the household members receive income? *Multiple answers applicable.*

| | |
|---|---|
| 1 | Crop cultivation |
| 2 | Animal rearing |
| 3 | Agricultural labour |
| 4 | Trading/marketing (agriculture) |
| 5 | Trading/marketing (non-agriculture) |
| 6 | Formal employment |
| 7 | Other self-employment |

5. What type of material is the roof on the main house made from?

| | |
|---|---|
| 1 | Thatch |
| 2 | Aluminium |

6. How many animals are owned by the household?

| | |
|---|---|
| Cattle | |
| Sheep | |
| Goat | |
| Guinea Fowl | |
| Chicken | |

7. Does anyone in the household own a motorbike/tricycle? 1. Yes 2. No

8. Does anyone in the household hold any positions of leadership or responsibility in the community? *Multiple answers allowed. Write NONE if no position held*

| | |
|---|---|
| 1 | Chief / sub-chief (*not land*) |
| 2 | Tendana / land chief |
| 3 | Elder |
| 4 | Religious leader |
| 5 | Assemblyman / Chairperson |
| 6 | Best Farmer |
| 7 | Local political party position |
| 8 | Government official |
| 9 | Other, specify: |

9a. Has anyone in the household migrated outside the region to work in the last 3 years? 1.Yes 2. No

9b. If yes, which district did they migrate to?

________________________________

9c. If yes what kind of work did they do?

| | |
|---|---|
| 1 | Agricultural labour |
| 2 | Non-agricultural informal work |
| 3 | Formal employment |
| 4 | Other, specify: |

10a. Do you farm in a group? i.e. do you coordinate with a group of farmers the work of plowing, planting, weeding, harvesting? 1. Yes 2. No

10b. If yes, how many farmers are in the group?

______

11. Does the household get access to credit or assistance to pay for farming inputs (apart from own resources)? *Multiple answers allowed*.

| | |
|---|---|
| 1 | No farming credit |
| 2 | Informal loan from another farmer |
| 3 | Out growers scheme |
| 4 | Agricultural bank |
| 5 | Remittances from family |
| 6 | Other, specify: |

**Table 1: Agricultural plots**

Please list all agricultural plots cultivated by all members of the household. Ask all questions for 2015 main season.

12. How many plots do you have? _________

| Plot ID. | 13. Area cultivated (acres) | 14. Gender of household member responsible for the plot?<br>1. M<br>2. F | 15. Is the land<br>1.family<br>2.skin<br>3.borrowed<br>4.sharecropped /rented? | 16. If this plot was fallowed in the last 10 years, for how many years was it left uncultivated? (enter 0 if not fallowed) | 17. Main crop grown on the plot (refer to table).<br>*List up to three.*<br>*Add code of 99 for fallow.* | 18. Quantity harvested for main crop (in maxi bags)<br>OR in "pans" for yam. 1 pan = 110 yams. | 19. What labour did you use on this plot?<br>1. household<br>2. communal<br>3. hired<br>*Multiple answers allowed.* | 20. What inputs did you use for this plot? *Multiple answers allowed.*<br>1. manure<br>2. compost<br>3. inorganic fertilizer<br>4.improved/hybrid seeds<br>5. pesticide<br>6. herbicide | 21. Was the harvest you got from this plot as you would expect for a good year?<br>1. as expected<br>2. below average<br>3. above average |
|---|---|---|---|---|---|---|---|---|---|
| | 2015 | | | | 2015 | 2015 | 2015 | 2015 | 2015 |
| 1 | | | | | | | | | |
| 2 | | | | | | | | | |
| 3 | | | | | | | | | |
| 4 | | | | | | | | | |
| 5 | | | | | | | | | |
| 6 | | | | | | | | | |

22. Is there more family land available to you that is not yet being cultivated? 1. Yes 2.No

**Table 2: Tractor use**

Ask these questions for the 2015 main season

| Plot ID. | 23. Did you use machinery for these operations?<br>1. Yes<br>2. No | | | | 24. How much did you pay **at the time** of plowing/harrowing for tractor services?<br>*Enter 0 if paid nothing.* | | 25. How much did you pay **after harvest**, for plowing/harrowing? | | 26. In which month did you get tractor services?<br>*Record as number e.g. 1=Jan, 2=Feb. 0 if did not use machinery* | 27a. Was this the time you wanted to plant?<br>1. Too early<br>2. on time<br>3. too late | 27b. If planted too late, why?<br>1. lack of money to pay tractor in cash<br>2. unable to secure tractor services (but had money)<br>3. lack of money for other inputs<br>4. unpredictable rains<br>*Enter 0 if planted on time or early* | 28. If you got tractor services late, what did you do differently?<br>1. planted less<br>2. planted different crop<br>3. didn't plant<br>4. No difference<br>*Enter 0 if services on time* | 29. How did you access tractor for plowing/harrowing?<br>*See Qu 29 codes* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1st plow | 2nd plow | Harrow | Harvest | In cash (GHC) | In kind (no. of maxi bags) | In cash (GHC) | In kind (no. of maxi bags) | 2015 | 2015 | 2015 | 2015 | 2015 |
| 1 | | | | | | | | | | | | | |
| 2 | | | | | | | | | | | | | |
| 3 | | | | | | | | | | | | | |
| 4 | | | | | | | | | | | | | |
| 5 | | | | | | | | | | | | | |
| 6 | | | | | | | | | | | | | |

30. Did you use machinery for any other operations? 1. Yes 2. No If 'yes', please list: ______________________

31. Did you host a tractor operator? 1. Yes 2. No

32a. How many tractors do you own? ________ 32b. If you own a tractor, when did you first buy a tractor (year)? __________

## Appendix V: Tables and Figures for Paper 1

### Table A 1: Summary Statistics

| | N | Mean | Standard deviation | 10th percentile | 90th percentile |
|---|---|---|---|---|---|
| Hh tractor use on at least one plot (dummy) | 1843 | 0.64 | 0.48 | 0 | 1 |
| HH Hired in mechanized plowing | 1843 | 0.43 | 0.50 | 0 | 1 |
| Hh hired in mechanized shelling | 1843 | 0.25 | 0.43 | 0 | 1 |
| hh hired in mechanized transport (from plot to homestead) | 1843 | 0.23 | 0.42 | 0 | 1 |
| Population density (EA, 2012, pers/km$^2$) | 1606 | 116.32 | 155.67 | 14 | 231 |
| No. of days in growing period | 1606 | 214.91 | 45.26 | 167 | 285 |
| Travel time to nearest 50,000 populous town (hours) | 1606 | 2.86 | 1.56 | 1 | 5 |
| No. of household members | 1843 | 0.37 | 0.48 | 0 | 1 |
| No of household member per ha of owned land | 1843 | 1.55 | 2.25 | 0 | 3 |
| Female headed household | 1843 | 0.12 | 0.32 | 0 | 1 |
| Current or former formal employment | 1843 | 0.20 | 0.40 | 0 | 1 |
| Highest education level of hh members | 1843 | 3.47 | 5.03 | 0 | 12 |
| Hh received government or NGO assistance in last 5 years | 1843 | 0.10 | 0.30 | 0 | 0 |
| Land owned by household (ha) | 1843 | 17.37 | 33.44 | 2.03 | 37.67 |
| Largest plot is grassland (not forest) | 1843 | 0.65 | 0.48 | 0 | 1 |
| Population growth 2000-2010 (%) | 1843 | 1.95 | 2.04 | 0.52 | 4.34 |
| Population growth 1989-2000 (%) | 1843 | 3.15 | 1.77 | 0.25 | 6.12 |

### Table A 2: Non-linear regression models

| | *Dependent variable: dummy for tractor use* | | | |
|---|---|---|---|---|
| | Probit | | Logit | |
| | (4) | APE at means | (4) | APE at means |
| Population density (EA, 2012, pers/km$^2$) | -0.00*** | -0.0011*** | -0.00*** | -0.0012*** |
| | (0.00) | (0.00) | (0.00) | (0.00) |
| No. of days in growing period | -0.00 | -0.0017 | -0.01 | -0.0019 |
| | (0.00) | (0.00) | (0.01) | (0.00) |
| Travel time to nearest 50,000 populous town (hours) | -0.93*** | -0.3715*** | -1.60*** | -0.4003*** |
| | (0.21) | (0.09) | (0.39) | (0.10) |
| Travel time (squared) | 0.11*** | 0.0448*** | 0.19*** | 0.0483*** |
| | (0.03) | (0.01) | (0.06) | (0.01) |
| District population growth controls | yes | | yes | |
| Household characteristics | yes | | yes | |
| N | 1587 | | 1587 | |
| F statistic | 11.79 | | 9.60 | |
| Count R-Squared | 0.81 | | 0.84 | |
| Adjusted Count R-Squared | 0.49 | | 0.57 | |

NB: Standard errors are in parentheses. Significance level is indicated by: * p<0.10 ** p<0.05 *** p<0.01

### Table A 3: Regression of tractor use on EA and District dummies only

| *Dependent variable: dummy for tractor use (OLS)* | | |
|---|---|---|
| | (1) | (2) |
| Enumeration Area fixed effects | yes | no |
| District fixed effects | no | yes |
| District population growth controls | no | no |
| N | 1827 | 1827 |
| R-sq | 0.67 | 0.42 |
| F statistic | . | 165.07 |
| Count R-Squared | 0.87 | 0.87 |
| Adjusted Count R-Squared | 0.64 | 0.62 |

### Table A 4: Regression of tractor use as no. of hectares plowed

| | *Dependent Variable: No. of hectares for which mechanized plowing was used.* | | | |
|---|---|---|---|---|
| | OLS | OLS | Tobit | Tobit |
| | (1) | (2) | (3) | (4) |
| Population density (EA, 2012, pers/km$^2$) | -0.00*** | -0.00*** | -0.02*** | -0.01*** |
| | (0.00) | (0.00) | (0.00) | (0.00) |
| No. of days in growing period | 0.00* | -0.00 | 0.01 | -0.01* |
| | (0.00) | (0.00) | (0.01) | (0.01) |
| Travel time to nearest 50,000 populous town (hours) | -0.54** | -0.47*** | -1.71*** | -1.39*** |
| | (0.22) | (0.16) | (0.57) | (0.38) |
| Travel time (squared) | 0.06** | 0.04** | 0.18*** | 0.14*** |
| | (0.03) | (0.02) | (0.07) | (0.05) |
| Total number of household members | | 0.04* | | 0.13*** |
| | | (0.02) | | (0.04) |
| No. of hh member per ha of owned land | | -0.06 | | -0.33*** |
| | | (0.04) | | (0.10) |
| Female headed household | | -0.11 | | -0.06 |
| | | (0.16) | | (0.41) |
| Current or former formal employment | | -0.47** | | -0.66 |
| | | (0.22) | | (0.53) |
| Highest education level of hh members | | 0.05*** | | 0.13*** |
| | | (0.02) | | (0.04) |
| Hh received government or NGO assistance in last 5 years | | 0.56** | | 1.00** |
| | | (0.23) | | (0.46) |
| Land owned by household (ha) | | 0.11*** | | 0.11*** |
| | | (0.03) | | (0.04) |
| Largest plot is grassland (not forest) | | 0.32 | | 0.55 |
| | | (0.20) | | (0.55) |
| Constant | 2.12*** | 3.08*** | 3.14* | 7.43*** |
| | (0.51) | (0.61) | (1.61) | (1.98) |
| District population growth controls | no | yes | no | yes |
| N | 1609 | 1587 | 1609 | 1587 |
| R-sq | 0.044 | 0.296 | | |
| F | 21.61 | 38.65 | 9.00 | 10.49 |

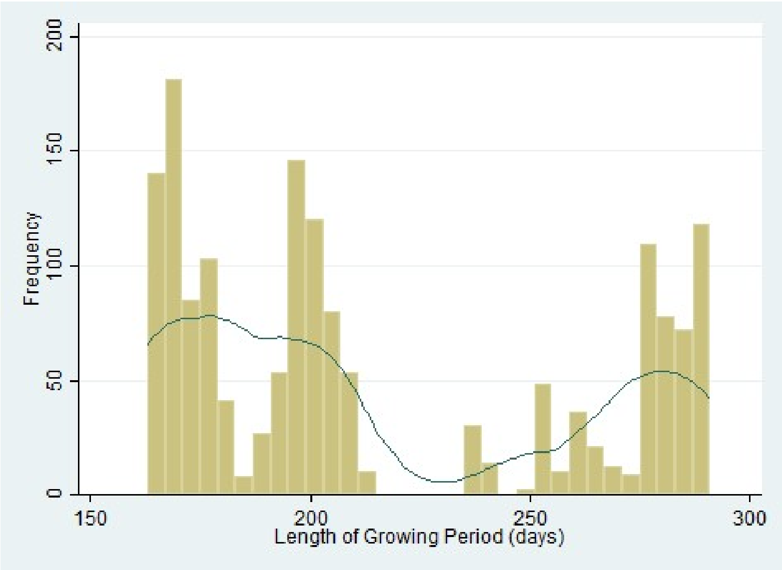



**Figure A 1: Histogram and Density plot of average Length of Growing Period (days)**

Source: HarvestChoice

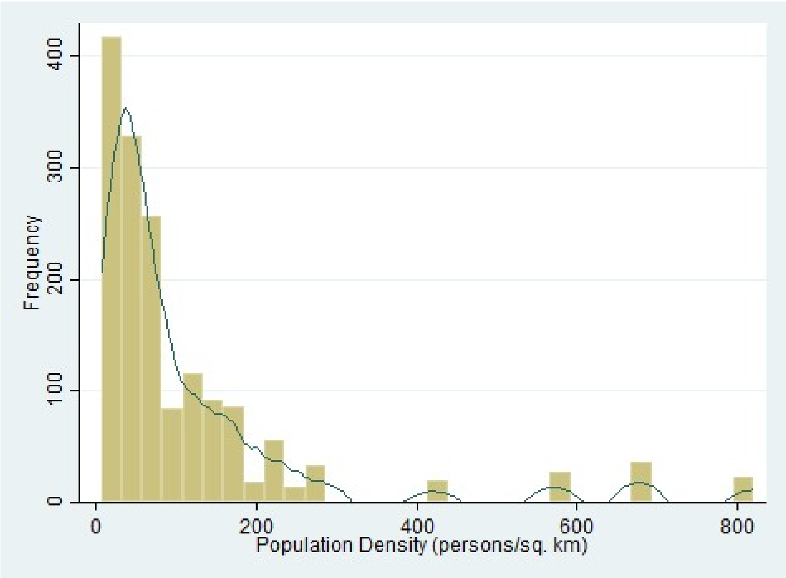



**Figure A 2: Histogram and Density plot for Population Density (2012, by enumeration area)**

Source: LandScan 2012 (HarvestChoice, 2015b)

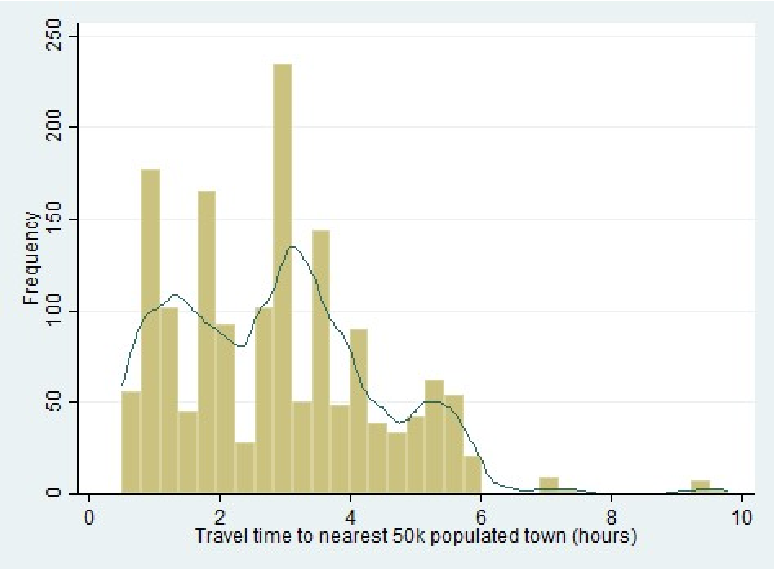



**Figure A 3: Histogram and Density plot for median Travel Time (hours) to settlement of 50,000 people**

Source: HarvestChoice.

## Appendix VI: Tables and Figures for Paper 2

### Table A 5: Treatment effects estimation using propensity score matching only

| | Productivity | | | | Scale of production | | |
|---|---|---|---|---|---|---|---|
| | Yield (kg/ha) | Labour productivity (kg/day) | Output value per ha (cedis) | Output value per person day (cedis) | Area cultivated (ha) | Area cultivated - maize (%) | Area cultivated - female (%) |
| Tractor use | 145.65*** | 8.06*** | 11.88 | 3.05*** | 0.78*** | 22.20*** | -4.14 |
| | (51.77) | (0.93) | (25.63) | (1.14) | (0.22) | (2.35) | (8.18) |
| N | 233 | 256 | 418 | 256 | 407 | 252 | 407 |

| | Labour days per ha | | | | Total labour days | | | |
|---|---|---|---|---|---|---|---|---|
| | land preparation | field management | harvest | post-harvest | Female family | Male family | female labour share of family labour | hired share of total labour |
| Tractor use | -18.79* | -6.15*** | 0.67 | -0.09 | 29.56* | 14.75 | 4.84 | -2.05 |
| | (10.23) | (2.03) | (2.52) | (1.48) | (15.46) | (39.75) | (2.98) | (3.42) |
| N | 394 | 393 | 383 | 398 | 418 | 418 | 388 | 408 |

Note: Propensity score is calculated from logit regression of tractor use on land area owned by household, motorbike ownership, inward migration in last 5 years, main dwelling has a cement floor, household size, urban EA, age of household head, female headed household, district population density in 2000, length of growing period (district mean), travel time to nearest 50,000 populous town (district mean), and welfare index from 2003 (district mean). The sample is restricted to households in districts which were allocated government machinery before and after 2009 to keep comparable samples, although the instrumental variable is not used in this estimation.

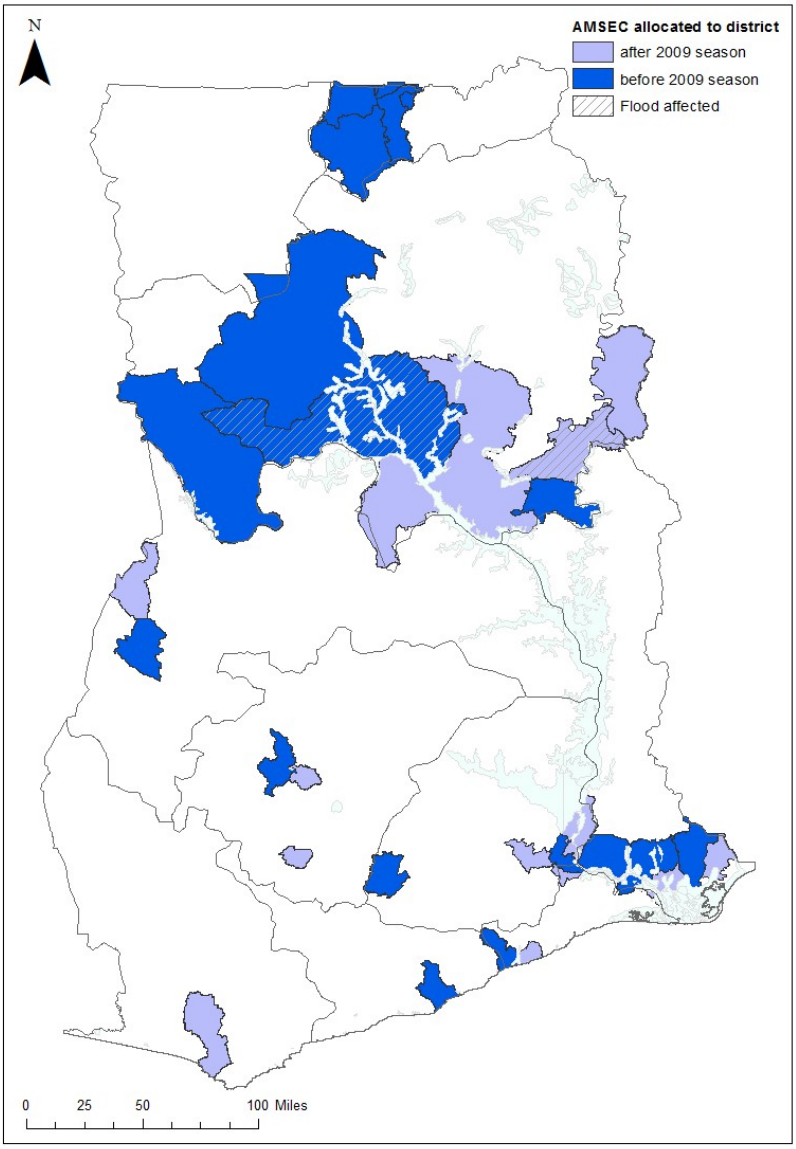



**Figure A 4: Map of treated and control districts**

Source: IPUMS 2010 district boundaries; MOFA administrative data on AMSEC program; UN OCHA information on 2009 floods.

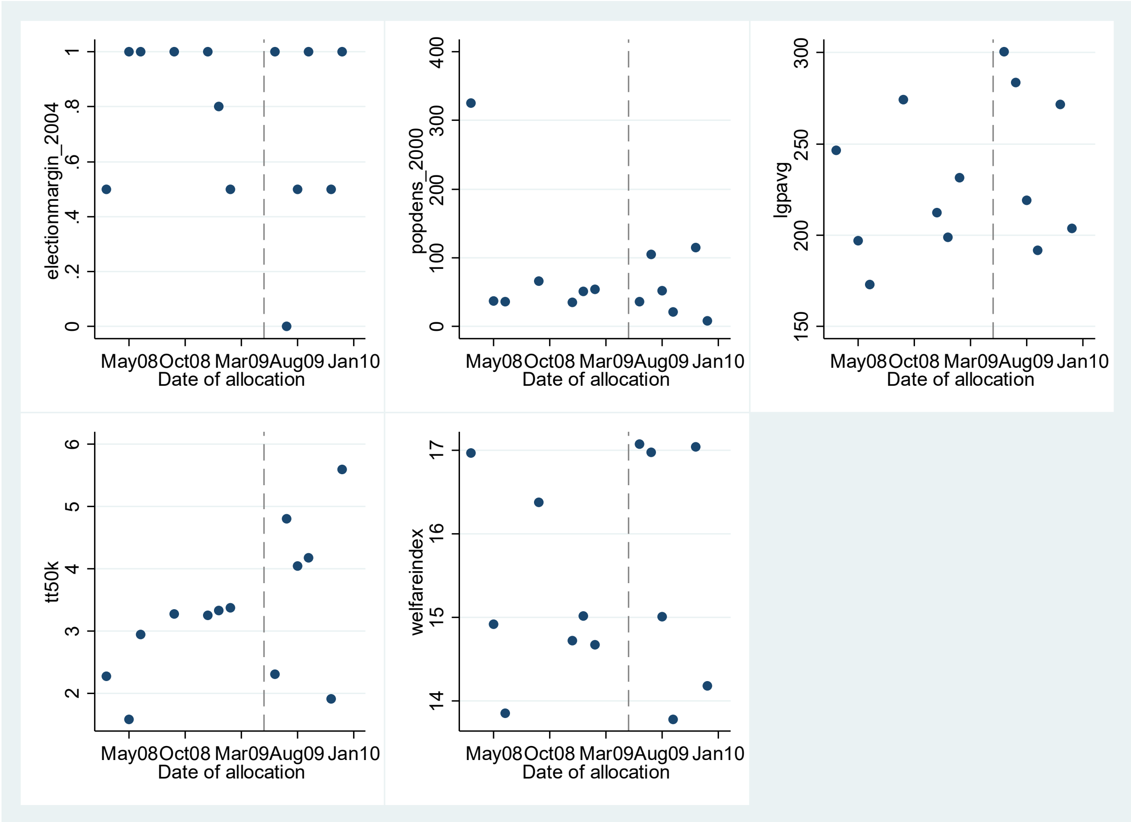



**Figure A 5: Scatter plots of district variables by date of government allocation**

Note: Vertical dashed line indicates May 2009 which marks the end of the plowing season. Each scatter point represents the mean value of the district variable for district which received government allocation in that month.

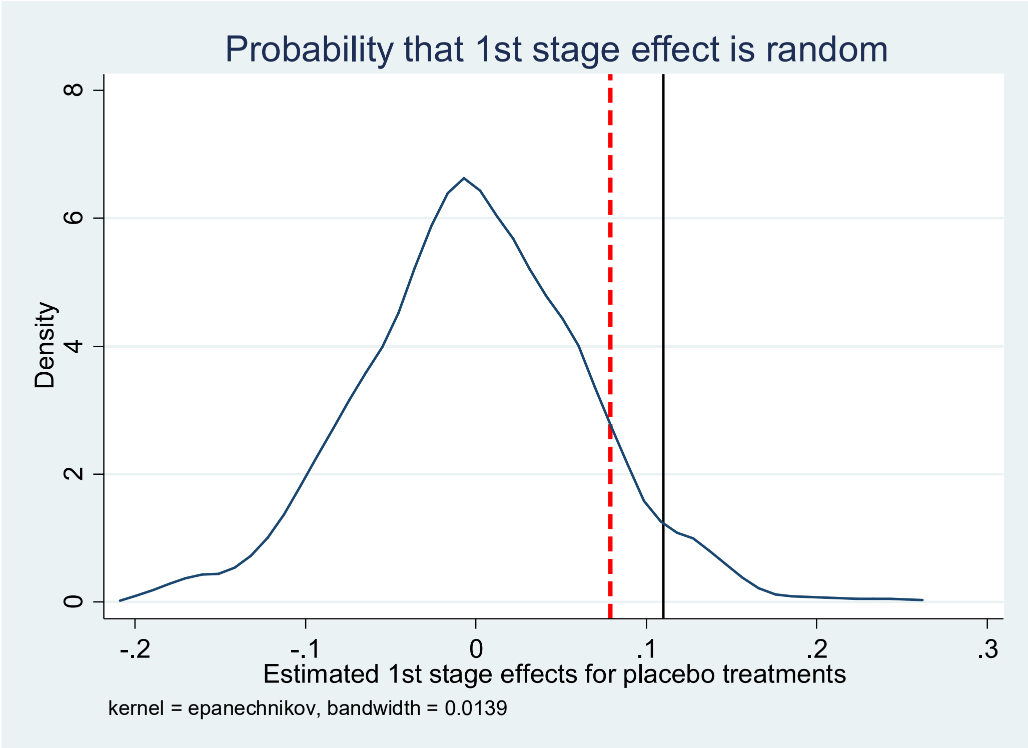



**Figure A 6: First stage regression using placebo treatment and control groups**

Notes: Placebo treatment is created by generating a random variable between (0,1), then assigning districts with random number greater than 0.5 to a placebo treatment group. 1,000 random draws were used to estimate the coefficient of treatment dummy from the first stage regression (same as model (3) from Table 11). This was done for the same 28 districts as in the main sample. These first stage effects are plotted as a density function. The red dashed line indicates the 90$^{th}$ percentiles of the distribution. The solid black line is 0.11 which is the estimated effect from Table 11 (model 3).

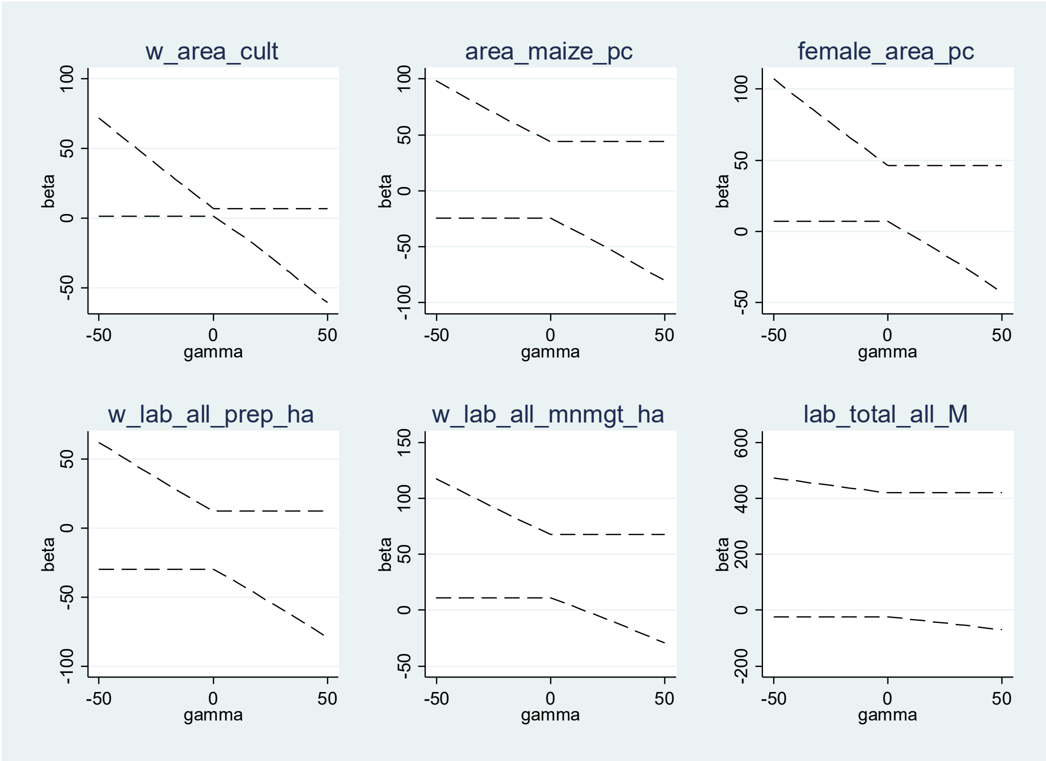



**Figure A 7: 90% Interval Estimates for treatment effect, with some endogeneity of instrument**

Note: The figure represents the 90% confidence interval for the effect of tractor use on key outcome variables of interest (*beta*): area cultivated (ha), proportion of cultivated area with maize, proportion of cultivated area under female hh member control, labour person days per ha for land preparation and field management, and the total male labour person days for agricultural activities. The x-axis is different values of *Gamma* $(\gamma)$, the potential values from the following model: $y = \beta T + \gamma Z + \alpha X + \varepsilon$ where T is tractor use, Z is the instrument, and X are exogenous covariates. If the exclusion restriction is valid, then $\gamma = 0$. See Conley, Hansen and Rossi (2012) for details on the method. Graphs were generated using *plausexog* stata command, with the *uci* method and a specified range of values for $\gamma$ between -50 and 50. The stata command was developed by Damian Clarke, University of Oxford.

*Plot-level differences due to tractor use in Yendi district*

A major drawback of the methodology in paper 2 is the assumption that farm households in treatment and control district are on average the same once observable characteristics are controled for. This is a problem if some unobservable characteristics are biasing the estimated treatment effects. In order to check whether the main results are robust once unobservable differences between household are controled for, an alternative data set and methdology is presented in this appendix, which exploits plot level data for households in one district of Ghana.

The data is a primary survey dataset which was collected by the author as part of a mixed methods case study, which makes up the empirical content of the third paper. More details on the data collection is provided there. In summary, 246 farm households in Yendi district were surveyed in October 2016. For each household, data was collected for each plot including machinery and other input use. This structure of the data enables analysis of the differences in machinery and input use across plots within the same household, thereby controling for household fixed effect and allowing some attribution of any differences of output or input use to differences in machinery use. The dataset whilst detailed, is limited. The survey only asked whether certain inputs were used or not (dummy variables), rather than the amount that was used of labour, fertilizer etc. Similarly, the majority of households did not have mechanized and unmechanized plots cultivating the same crops, making comparison of yield problematic.

The methodology is borrowed from Shaban (1987). Shaban used regression analysis to consider the difference in output and input intensity on sharecropped and owned plots by the same household. Differences in output and input intensity across plots, are regressed on the differences in plot-level variables which may explain these differences, other than the type of sharecrop or ownerships. The same method is applied here, to compare mechanzed and unmechanized plots of the same household. Mechanized plots are those for which tractor plowing has been used for land preparation.

Following Shaban (1987), the estimated model is:

$$\Delta x_i = \alpha + \sum_m \beta_{mi} \left(D_m^t - D_m^h\right) + \varepsilon_i$$

Where:

$\Delta x_i$ is the difference in output or input use between tractor-plowed and hand-hoed plots within cultivated by the same household

$\alpha$ is a constant which will equal zero if there is no difference in $x_i$ between mechanized and unmechanized plots

$D_m^t - D_m^h$ is the difference in the number of years the plot has been left fallow (to capture soil quality), and the probability of plot being controled by female hh member (to capture differences in access to resources). On average, mechanized plots have had fewer fallow years than unmechanized.

$\beta_{mi}$ is the coefficient for relationship between the difference in plot variable, $m$ , and the difference (between mechanized and unmechanized plots) for output/input intensity variable $x_i$. If β is non zero, then differences in $x_i$ are partly explained by differences in plot-level characteristics.

The results are presented in the following tables. In reading the tables, the reader should keep in mind that both left and right hand side variables are the difference in values (or probability for dummy variables) between mechanzied and unmechanized plots within the household. Overall, the results are consistent with the main results of paper 2.

There is no significant difference in yield either in terms of weight or value between mechanized and unmechanized plots ( Table A 6 ). The value of output is greater on average on mechanized plots, but the differences is not significant. In terms of weight, the yield is lower. Although not significant, the direction of these signs is consistent with the main findings. In terms of scale of production, the number of plots and area of farmland which is mechanized is greater than unmechanized. This is a simple finding that farm households are using tractor plowing on the majorty of their land.

There is a significant difference in the crops which are cultivated on mechanized and unmechanized plots ( Table A 7 ). Maize and soybean are more likely to be cultivated on plots which have been prepared with tractor plowing, which is not explained by differences in soil quality. This difference may be due to a gendered difference in which crops are cultivated. The coefficient for female plots is significant for several crops. This implies that som eof the difference in crop cultivated between mechanized and unmechanized plots is due to differences in the crops which men and women cultivate. An increased likelhood of cultivating groundnut on a mechanized plot is due to women being more likely to cultivate groundnut, rather than mechanization itself. Finally, differences in the likelihood of planting sorghum is due to poorer soil quality (shorter fallow period), rather than mechanization.

Farmers of either gender are more likely to use family, communal, or hired labour on the cultivataion of mechanized plots ( Table A 8 ). These differences are partly explained by differences in soil quality. Where the fallow period for mechanized plots has been shorter, farmers are more likely to use labour. The labour input variables are simple dummy variables for whether the farmer used this type of labour or not. Therefore there is a limit to what can be concluded. Finally, chemical use is significantly more likely on mechanized plots than unmechanized, both for fertilizer and herbicide use.

The key findings from the main paper were that mechanized plowing led to an increase in labour use, due to a timeliness constraint being overcome. The evidence here supports this. A further finding was that farmers switch to cultivating maize and other higher value crops with machinery use. Again, this data from Yendi district supports the idea that farmers are more likely to cultivate maize on mechanized plots. The complementarity of tractor plowing and herbicide is supported by both approaches. Output value per ha is higher on mechanized plot, which again is consistent with the main findings, albeit in neither approaches is the effect significant.

### Table A 6: Productivity and scale of production

| | Output per ha (kg, all cereals) | | | Output per ha (USD, all cereals) | | | Total area cultivated (ha) | | | Average plot size (ha) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Constant | -33.51 | -53.91 | -53.91 | 78.81 | 50.48 | 41.53 | 1.95*** | 1.83*** | 1.69*** | -0.46*** | -0.15 | -0.03 |
| | (32.80) | (34.08) | (34.29) | (40.93) | (40.63) | (40.69) | (0.25) | (0.29) | (0.28) | (0.14) | (0.15) | (0.15) |
| No. of years fallow in last 10years | | -35.75 | -34.61 | | -64.06* | -58.35* | | -0.08 | -0.13 | | 0.21*** | 0.22*** |
| | | (19.28) | (19.66) | | (24.78) | (24.84) | | (0.11) | (0.10) | | (0.06) | (0.05) |
| Female-controlled plot | | | 35.71 | | | 190.45 | | | -0.71 | | | -1.10* |
| | | | (99.33) | | | (129.29) | | | (0.91) | | | (0.47) |
| r2_a | 0 | 0.03 | 0.02 | 0 | 0.09 | 0.1 | 0 | 0 | 0 | 0 | 0.08 | 0.14 |
| N | 73 | 73 | 73 | 61 | 61 | 61 | 150 | 150 | 146 | 150 | 150 | 146 |

Note: Output in USD was calculated using FAO prices for the main food crops and farmer-reported harvest in kg.

## Table A 7: Crop choice

| | Planted maize | | | Planted yam | | | Planted soybean | | | Planted groundnut | | | Planted sorghum | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Constant | 0.32*** | 0.34*** | 0.34*** | 0.02 | -0.02 | -0.01 | 0.22*** | 0.19*** | 0.19*** | 0.03* | 0.02 | 0.01 | 0.01 | -0.03 | -0.04 |
| | (0.02) | (0.03) | (0.03) | (0.04) | (0.04) | (0.04) | (0.02) | (0.03) | (0.03) | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) |
| No. of years fallow in last | | 0.01 | 0.01 | | -0.03 | -0.03 | | -0.02* | -0.02 | | -0.01 | -0.01 | | -0.03*** | -0.03*** |
| 10years | | (0.01) | (0.01) | | (0.02) | (0.02) | | (0.01) | (0.01) | | (0.01) | (0.01) | | (0.01) | (0.01) |
| Female-controlled | | | -0.21* | | | -0.31* | | | 0.17 | | | 0.25*** | | | -0.01 |
| plot | | | (0.09) | | | (0.14) | | | (0.09) | | | (0.06) | | | (0.08) |
| r2_a | 0 | 0 | 0.04 | 0 | 0.01 | 0.04 | 0 | 0.02 | 0.04 | 0 | 0.01 | 0.1 | 0 | 0.08 | 0.07 |
| N | 146 | 146 | 144 | 146 | 146 | 144 | 146 | 146 | 144 | 146 | 146 | 144 | 146 | 146 | 144 |

### Table A 8: Labour use

| | Used hh labour | | | Used communal labour | | | Used hired labour | | |
|---|---|---|---|---|---|---|---|---|---|
| Constant | 0.40*** | 0.32*** | 0.30*** | 0.20*** | 0.14*** | 0.15*** | 0.32*** | 0.25*** | 0.25*** |
| | (0.04) | (0.04) | (0.04) | (0.03) | (0.03) | (0.04) | (0.04) | (0.04) | (0.04) |
| No. of years fallow in last 10years | | -0.05** | -0.06*** | | -0.04** | -0.04** | | -0.05*** | -0.05** |
| | | (0.02) | (0.02) | | (0.01) | (0.01) | | (0.01) | (0.02) |
| Female-controlled plot | | | 0.09 | | | -0.2 | | | 0.06 |
| | | | (0.14) | | | (0.11) | | | (0.14) |
| r2_a | 0 | 0.06 | 0.07 | 0 | 0.05 | 0.07 | 0 | 0.07 | 0.06 |
| N | 150 | 150 | 146 | 150 | 150 | 146 | 150 | 150 | 146 |

### Table A 9: Chemical use

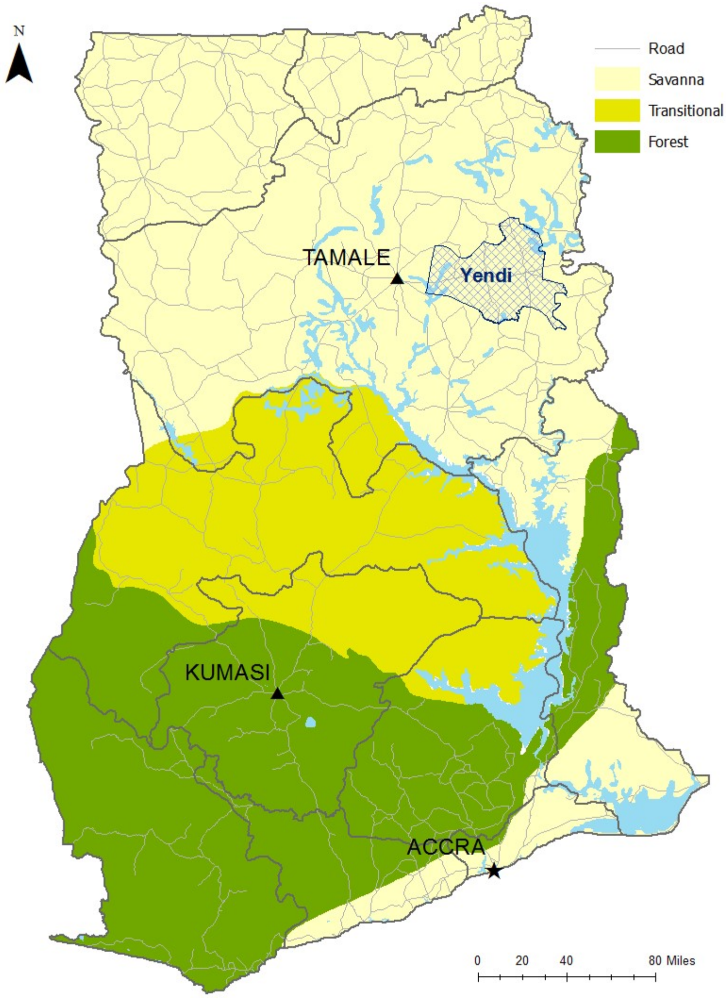
| | Used inorganic fertilizer | | | Used herbicide | | |
|---|---|---|---|---|---|---|
| Constant | 0.24*** | 0.25*** | 0.25*** | 0.52*** | 0.45*** | 0.42*** |
| | (0.02) | (0.03) | (0.03) | (0.04) | (0.04) | (0.04) |
| No. of years fallow in last 10years | | 0 | 0 | | -0.05** | -0.05** |
| | | (0.01) | (0.01) | | (0.02) | (0.02) |
| Female-controlled plot | | | -0.24** | | | 0.17 |
| | | | (0.09) | | | (0.13) |
| r2_a | 0 | -0.01 | 0.03 | 0 | 0.05 | 0.07 |
| N | 150 | 150 | 146 | 150 | 150 | 146 |

## Appendix VII: Tables and Figures for Paper 3

### Table A 10: Record of qualitative data collection

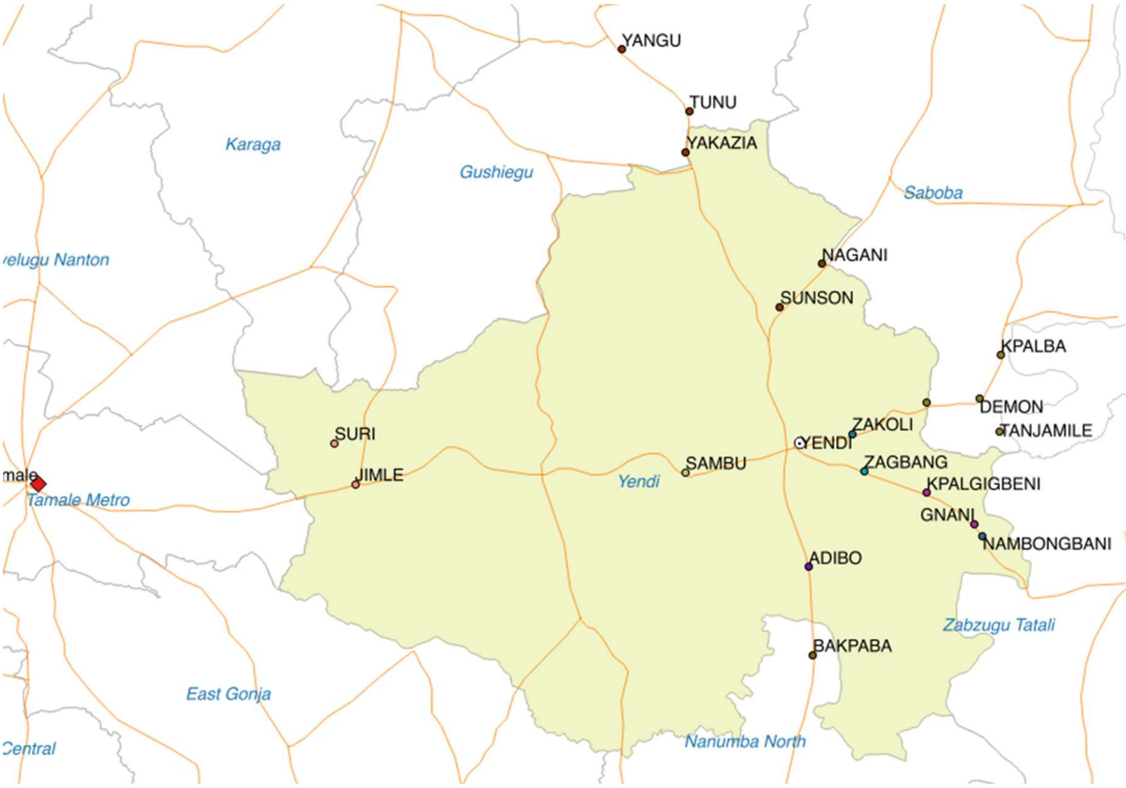
| Village | District | Type of interview | Gender of participants | Distance to district capital (Yendi town) |
|---|---|---|---|---|
| Nambungani | Yendi | focus group discussion | Mixed | 24.72km |
| Demon | Saboba | focus group discussion | Mixed | 22.9km |
| Kpalba | Saboba | focus group discussion | male only | 26.48km |
| Tanjamile | Saboba | focus group discussion | Mixed | 24.06km |
| Wambung | Yendi | focus group discussion | Mixed | 16.14km |
| Zagbang | Yendi | focus group discussion | Mixed | 8.45km |
| Zang | Yendi | focus group discussion | Mixed | - |
| Tunu | Gushiegu | focus group discussion | Mixed | 42.7km |
| Yangu | Gushiegu | focus group discussion | Mixed | 52.65km |
| Nagani | Yendi | focus group discussion | Mixed | 22.1km |
| Sunson | Yendi | focus group discussion | male only | 16.8km |
| Gnani | Yendi | focus group discussion | Mixed | 23.3km |
| Kpalgigbeni | Yendi | focus group discussion | Mixed | 16.4km |
| Bakpaba | Nanumba North | focus group discussion; tractor operator interview | Mixed | 25.9km |
| Adibo | Yendi | focus group discussion | male only | 15.2km |
| Gbungnalaga | Yendi | focus group discussion | male only | - |
| Zakoli | Yendi | tractor owner interview; individual farmer interview | Mixed | 6.41km |
| Yankazia | Yendi | tractor owner interview | male only | 38.1km |
| Salankpang | Mion (formerly Yendi) | focus group discussion | male only | - |
| Sambu | Mion (formerly Yendi) | focus group discussion | male only | - |
| Suri | Mion (formerly Yendi) | focus group discussion | male only | - |
| Yendi (town) | Yendi | tractor owner interviews (2) | male only | - |

**Figure A 8: Map of Ghana's agro-ecological zones**



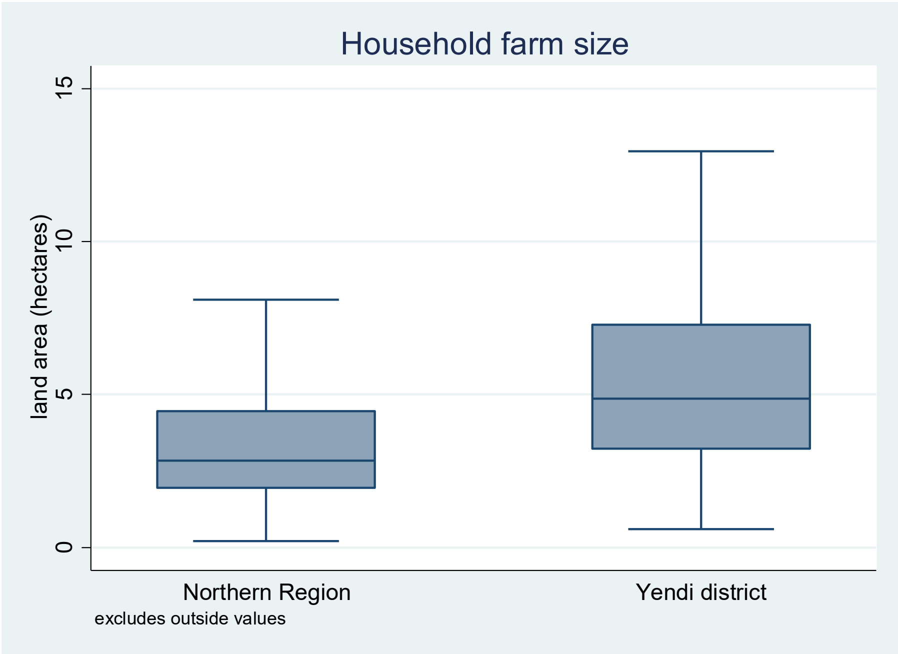

Source: Harvest Choice (2016)

## Figure A 9: Map of surveyed villages




Source: IPUMS International; Author's GIS coordinates for villages.

**Figure A 10: Comparison of farm size distributions**




Source: Data on the northern region is from EGC-ISSER Socioeconomic Panel Survey 2009-10. Data for Yendi district is from the author's quantitative survey of villages from 2016. Both data are farmer-reported measure of total farm land owned by the household, measured in hectares.

### Table A 11: Household characteristics (quantitative survey)

| Variables (by hh) | type | mean | standard deviation | N |
|---|---|---|---|---|
| No. of hh members | *count* | 11.95 | 6.87 | 246 |
| No. of children in hh | *count* | 5.44 | 3.64 | 246 |
| Education level of hh head | *see code* | 2.86 | 1.34 | 245 |
| Total area of farmland | *hectares* | 5.82 | 4.44 | 246 |
| More family land is available | *dummy* | 0.61 | 0.49 | 242 |
| Number of farm plots | *count* | 4.91 | 2.27 | 246 |
| hh income from own agriculture | *dummy* | 0.99 | 0.11 | 246 |
| hh income from rearing animals | *dummy* | 0.50 | 0.50 | 246 |
| hh income from agricultural labour | *dummy* | 0.03 | 0.18 | 246 |
| hh income from agricultural trade | *dummy* | 0.14 | 0.35 | 246 |
| hh income from non-agricultural trade | *dummy* | 0.13 | 0.33 | 246 |
| hh income from formal employment | *dummy* | 0.03 | 0.18 | 246 |
| hh income from self-employment | *dummy* | 0.13 | 0.34 | 246 |
| Roof of main house is aluminium | *dummy* | 0.72 | 0.45 | 246 |
| No. of cattle owned by hh | *count* | 1.85 | 5.45 | 244 |
| Motorbike owned by hh | *dummy* | 0.47 | 0.50 | 241 |
| Chief in the hh | *dummy* | 0.23 | 0.42 | 246 |
| hh member migrated for seasonal work in last year | *dummy* | 0.36 | 0.48 | 244 |
| hh participates in informal farming group | *dummy* | 0.67 | 0.47 | 245 |
| hh participates in out grower scheme | *dummy* | 0.11 | 0.31 | 246 |
| hh received remittances in last year | *dummy* | 0.08 | 0.27 | 246 |
| hh used tractor for maize shelling | *dummy* | 0.05 | 0.22 | 246 |
| hh used tractor for transport | *dummy* | 0.19 | 0.39 | 246 |
| hh used tractor for threshing | *dummy* | 0.07 | 0.25 | 246 |

Note: education code: 1=no formal education, 2=Primary school, 3=JHS education, 4=SHS education, 5=technical/vocation education.

**Table A 12: Indicators of social capital and timely planting**

| Group | No. of plots in group | No. of plots out of group | Probability of timely planting for group | Probability of timely planting for outside group | P-value for t-statistic of diff. in means |
|---|---|---|---|---|---|
| household includes a village chief | 316 | 965 | 0.54 | 0.40 | 0.00 |
| household includes a village chief or elder | 400 | 781 | 0.52 | 0.40 | 0.00 |
| household hosted a tractor operator | 185 | 989 | 0.48 | 0.43 | 0.12 |
| used own tractor | 8 | 890 | 0.63 | 0.57 | - |
| used tractor owned by someone in village | 180 | 718 | 0.61 | 0.56 | 0.09 |
| used tractor owner or operated by a friend outside the village | 577 | 321 | 0.60 | 0.50 | 0.00 |
| used tractor via out grower scheme | 26 | 872 | 0.69 | 0.56 | - |
| used tractor unknown to them | 107 | 791 | 0.25 | 0.61 | 0.00 |

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