The determinants and spill-over effects of tractor adoption in Tanzania

by

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Declaration

I, Divan van der Westhuizen, hereby declare that this thesis, which I submit for the degree PhD Agricultural Economics at the University of Pretoria, is my own work and has not been submitted by me for a degree at any other tertiary institution.

Signature: Date: 2021/07/19

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Abstract

After decades of persistently low use of agricultural mechanisation, the proportion of African farmers using tractors has rapidly increased since 2005. The conventional perception is that tractor use in sub-Saharan Africa is confined mainly to large-scale commercial farms. However, there is mounting evidence of the rapidly increasing use of tractors by smallholder farmers, albeit through tractor rental markets in geographically concentrated areas. To date, evidence on the causes of rising use of mechanisation in the SSA region, and particularly on smallholder farms, remains limited. This has often attributed to state-led efforts to prematurely promote mechanisation, which is rarely considered to be a market-driven response to changing factor prices. However, the recent economic transformations in many regions in sub-Saharan Africa may be providing these incentives. This study contributes to the information gap by utilising four waves of data from the nationally representative National Panel Survey from 2009, 2011, 2013 and 2015 to identify the factors driving the use by Tanzanian smallholders of mechanisation, and by examining whether there is evidence of the potential role of larger-scale farmers in promoting a movement to more capital-intensive forms of farming. The study aimed to develop a conceptual framework that interprets the important interactions between the primary and secondary drivers of agricultural transformation change in sub-Saharan Africa and their respective implications for technology adoption, such as the use of mechanisation. Selective elements of these interactions will be empirically investigated in the context of agricultural households in Tanzania. For instance, the study examines the relevance of the

Hayami-Ruttan hypothesis of induced innovation in Tanzania and explores whether it upholds the importance of changes in factor prices. The research focuses on the changes in land dynamics, including farm size and land size distribution, and the corresponding tractor use in Tanzania by developing descriptive statistics over the period from 2009 to 2015. Generalised Linear Models (GLM) and Mundlak-Chamberlain Correlated Random Effects (MC CRE) models for tractor demand by households were formulated to empirically investigate important relationships, such as changes in factor prices, the role of medium-scale farmers in promoting a shift towards capital-intensive input use, and changing farm size and land size distribution. The demand model applications, through post-estimation analysis, were utilised to develop key policy principles. The results of the household tractor rental model, derived from the pooled GLM and MC CRE Probit estimation, indicated that land size is coupled with tractor use through rental services, particularly in the 5-9.99 hectare group. As wage rates increase, a shift towards renting a tractor would be considered. The opposite is true when the cost to rent a tractor is considered. These results uphold the importance of relative changes in factor prices, which is consistent with the induced innovation hypothesis. The study also found that the demands for mechanisation services through participation in rental markets have increased in areas with a higher density of medium-scale farms, which then enabled small-scale producers to rent tractors. In these higher density areas, there is an increasing number of small-scale farmers, cultivating less than 5 hectares, who make use of tractor rental services. This positive spill-over effect has the potential to reduce labour input requirements and facilitate a shift by small-scale farmers to non-farming activities that generate higher returns to labour, while still deriving income from farming. In the 21 regions of mainland Tanzania that are representative of a lower concentration of medium-scale farmers, only 3% of small-scale farmers have rented tractors. However, in the 5 regions with the highest density of medium-scale farms, 23% of smallholders have rented mechanisation services.

Keywords: Mechanisation, Tractor rental markets, Medium-scale farmers, Land Dynamics

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Acronyms

AGITF	Agricultural Inputs Trust Fund, Tanzania
AGRA	Alliance for a Green Revolution in Africa
ANOVA	Analysis of Variance
ASDS	Agricultural Sector Development Strategy, Tanzania
EA	Enumeration Areas
FAO	Food and Agricultural Organization
GLM	Generalised Linear Models
HS	Harmonized Commodity Description and Coding System
LOGIT	Logistics Regression Models
LSMS	Living Standard Measurement Surveys
MC CRE	Mundlak-Chamberlain Correlated Random Effects
NPS	National Panel Surveys
OECD	Organisation for Economic Co-operation and Development
POLS	Pooled Ordinary Least Squares
PROBIT	Probability Regression Model
SS	Sum of Squares
SSA	sub-Saharan Africa
WCO	World Customs Organization

The Determinants and Spill-over Effects of Tractor Adoption in Tanzania

Chapter 1:
Introduction

"Over the past 50 years, the normal structural decline in the share of agriculture in the economy and accompanying convergence of incomes in the agricultural and non-agricultural sectors, ***has not yet happened in sub-Saharan Africa****. The economy in terms of sector shares in total output has been practically frozen, as has the structure of production within agriculture itself,* ***its technology****, and its mode of growth primarily via area expansion. As a consequence, African agriculture remains extremely* ***under-capitalized****, and the number of poor and hungry has increased in both the rural and urban areas."*
(Binswanger-Mkhize, McCalla & Patel, 2010)

1.1 Background and Context

Historically, the use of mechanisation in sub-Saharan Africa (SSA) has been very low, and substantially lower than in other developing regions (FAO, 2008; Pingali, Bigot & Binswanger, 1988 and World Bank, 2016). However, after decades of persistently low use of agricultural mechanisation, the proportion of African farmers using tractors has rapidly increased since about 2005 (International Trade Centre, 2017). Conventional perceptions are that tractor use in SSA is confined mainly to large-scale commercial farms; however, there is mounting evidence of the rapidly increasing use of tractors by smallholder farmers.

To date, evidence on the causes of rising use of mechanisation in the SSA region, and particularly on smallholder farms, remains limited. Consequently, it is possible that limitations on the knowledge of supply and demand principles in agricultural mechanisation markets in SSA may have contributed to state-led efforts in the past, to prematurely promote mechanisation, which is rarely considered to be a market-driven response to changing factor prices.

There currently exists a renewed interest from governments and donor stakeholders in mechanisation in SSA, however, the underlying foundations that underpin demand growth in mechanisation remain limited and complex. Recent transformations in agricultural food systems in many parts of SSA may assist in explaining why the demand for labour-saving technologies, including tractors, has increased over the past decade which in turn, can inform policy.

Recent studies by Adu-Baffour et al. (2018); Agyei-Holmes (2014 and 2016); Chapoto, Houssou, Mabiso & Cossar (2014); Daum & Birner (2017); Diao, Takeshima & Zhang (2020); Diao et al. (2014); Mrema (2016); Sims & Kienzle (2016); and Takeshima, Pratt, & Diao (2013) have investigated the rising use of tractors in selected SSA countries. Some of these studies have highlighted the importance of government and development agencies in promoting tractor use, while others highlight the role of medium- to large-scale farms in driving tractor use and acting as nucleus change agents to promote a more commercialised smallholder sector (Takeshima et al., 2013; Chapoto et al., 2014 and Diao et al., 2020).

Generally, the topic of mechanisation in SSA has received limited attention over the past decades, which is likely correlated with the observation that, prior to 2005, the use of mechanisation was low and confined to certain geographical regions. As to the period after 2005, it is well documented that the region has experienced significant dynamism, with structural changes occurring in many countries. Examples of these changes include urbanisation, increasing demand for food- and food products, rising population, rising food prices and increasing rural wages (Diao, Hiroyuki, Takeshima & Xiaobo, 2020; Diao, Silver, and Takeshima, 2016 and Kormawa, Mrema & Mhlanga, 2018). This has reshaped how agriculture in the region is perceived and prompts the revisiting of historic literature that defined certain outcomes, patterns and projections. The structural shift that is caused by the interaction between these drivers (that facilitate agricultural transformation, intensification and growth) has the potential to reshape economies in SSA, as well as its institutional environment, its agricultural environment, and its value chains.

Hence, the corresponding impact of these drivers on agricultural food systems, for instance, increasing demand for food as a result of rising population, can promote and facilitate agricultural growth, intensification and development. Another example includes the changing landscape surrounding farm structures, such as land ownership, land distribution and farm sizes, where it is observed that the number of medium sized farms, largely funded from non-farm investment sources, is increasing. According to Jayne et al. (2016 and 2019), medium-scale farmers now control roughly 39% of farmland in Tanzania, 32% in Ghana, 20% in Kenya, and more than 50% in Zambia.

Apart from the changing land dynamics, there is evidence of structural changes in various areas, such as in rural and urban population dynamics, accelerated economic growth, a temporary end of declining agricultural prices, increasing regional and domestic demand for food, a rising middle-income consumer segment, positive agricultural growth, transformation, and investment (AGRA, 2020; Binswanger-Mkhize et al., 2010; Diao et al., 2020, Malabo Montpellier Panel, 2018; Ousmane & Makombe, 2014, Traub, Yeboah, Meyer & Jayne, 2014 and Tschirley, Bricas, Sauer & Reardon, 2020).

This changing landscape, such as with the evolution of land dynamics, often creates divided opinions about the impact on national policy goals, especially on the welfare of rural households, including small-scale farmers, in terms of technology adoption, access to inputs and market access.

The influential theory behind agricultural transformation, growth and intensification of farming systems, developed by Boserup (1965) and Ruthenberg (1980), argued that Africa was not ready for widespread mechanisation during the 1980s and 1990s (Diao et al., 2014). Binswanger-Mkhize and Savastano (2014) have argued that the Boserup-Ruthenberg model for intensification is often conditional upon the occurrence of rapid population growth and improving market access conditions that could encourage higher utilisation of inputs and higher investment in mechanisation and irrigation infrastructure.

One of the study's conceptual anchors is based on the induced innovation hypothesis, developed by Hayami and Ruttan (1970). This is used to explore how changes in factor prices in agriculture, coupled with economic transformation and rapid change in the demographic landscape, have affected the demand for mechanisation and the possible spill-over effects of tractor availability on the rise of tractor rental markets utilised by small-scale farmers (van der Westhuizen, Jayne & Meyer, 2017).

Recent studies have documented changes in farm size distributions in a number of African countries, and it is possible that the rise of larger-scale farmers, who own tractors, has promoted the development of tractor rental markets that are utilised by nearby smallholders. The increased profitability of medium-scale commercial farmers normally boosts the demand for mechanisation technologies, which, through them, strengthens the supply of tractor hire services to small-scale farmers (Misra, 1991; Byerlee & Husain, 1993, and Singh, 2013 quoted in Mrema, 2016). The availability of tractor rental markets in some areas may have altered relative factor prices in ways favourable to the introduction of mechanisation by smallholders.

This study addresses the apparent information gap by identifying the factors behind the recent rise and adoption of mechanisation use by farmers in SSA using Tanzania as a case study. Although the focus will be on tractor adoption in Tanzania, the study has to rely on the broader mechanisation adoption principles and evidence from many parts of SSA. The reason for this approach is to assist in the development of a conceptual framework to investigate farm-level analysis on tractor adoption in Tanzania where the results in turn, may be relevant to inform the complexities of mechanisation adoption in other parts of the continent.

The findings of the study provide evidence about the potential role of larger-scale farms in promoting a movement to more capital-intensive forms of farming, not only on large farms but on smallholder farms as well. Sims & Kienzle (2016) stated that farm power and agricultural mechanisation are agricultural production inputs that will be crucial for raising labour and land productivity if the Sustainable Development Goals to end poverty and hunger are to be achieved. In order to stimulate product value chains and active input supply, the demand for mechanisation by the smallholder farm sector needs to be raised (Sims & Kienzle, 2016). The substitution of capital for family labour on smallholder farms may release labour from farming to other activities that provide higher returns to labour. It also promote the alleviation of child- and woman use in manual labour activities.

The findings can also contribute to the broader policy debate regarding agricultural development in SSA and whether policies related to agriculture should be positioned towards small-scale vs. larger-scale producers (Wineman, Jayne, Isinika-Modamba and Kray, 2020).

While the recent rise of larger farms in SSA may pose important challenges[1] to smallholder farmers, it is also possible that large-scale farms may contribute to diversification of income sources off the farm (e.g. wage employment) and thus lead to alternative sources of labour productivity growth for rural households. However, evidence on wage employment effects for small-scale neighbours is not always positive (Wineman et al., 2020).

1.2 Problem Statement

The problem statement will be covered in three distinct sub-categories. Firstly, it will focus on the slow adoption rate of mechanisation in SSA followed by highlighting the uncertainties regarding the determinants that drive increased tractor use and spill-over effects in Tanzania. It will conclude by also considering the broader developmental challenges in SSA.

1.2.1 A Slow Adoption Rate of Mechanisation in SSA

It is said that the Green Revolution in Asia has created a shift to profitable commercial farming, easing poverty in rural areas, preserving large areas of fragile land from conversion to extensive farming, and aiding in avoiding potential hunger threats in the face of an increasing world population. In Asia, according to FAO (2008a), the number of four-wheel tractors, as an indicator of advancement in mechanisation over the past 40 years, increased fivefold, from 120 000 to 600 000 units, between 1961 and 1970. By 2000, the number of units had increased to 6 million. Subsequently, tractor utilisation and units continued to increase and it is estimated that in 2008, in India and China alone, the number of units had increased to 2.6 million and to more than 2 million, respectively. Similarly, in Latin America and the Caribbean region, tractor units increased from 383 000 to 637 000 from 1961 to 1970, and thereafter tripled to 1.8 million units by 2000.

In SSA, however, the Green Revolution and mechanisation trend was different to that in Asia and Latin America. Mechanisation and intensification levels, the use of fertilisers, and the use of modern technologies have remained low (Table 1). In 1961, the numbers of tractors in use in SSA were more than those in Asia and the Near East, by a total of 172 000 units. A marginal

[1] E.g. the displacement of small-scale agricultural households, employment and rural-urban migration

increase was observed towards the 1990s, when the units increased to 275 000. Towards 2000, it is estimated that the number of tractors actually declined to 221 000 units.

Table 1: Agricultural intensification, input use and capital investment indicators in 2007

Region	Yield of cereals (kg/ha)	Fertiliser use (kg/ha)	Tractors per 1000 ha
Africa[2]	**1040**	**13**	**28**
Average of 9 selected countries[3]	**3348**	**208**	**241**

Source: FAO (2013)

The continued low levels of mechanisation in the relatively land-abundant SSA have posed a long-standing mystery in the agricultural mechanisation literature (Pingali et al., 1988). More specifically, these authors questioned why the process of mechanisation had been so slow within a region that is characterised as land-abundant. Why has this process been substantially slower, as compared with countries such as China, India and Pakistan that are associated with abundant labour and low wage rates? Why was it the case that the use of animal traction and tractors had spread fairly rapidly in restricted pockets in Africa, but had left bordering agro-climatic regions unaffected? Furthermore, why had certain cattle farmers failed to use their oxen for land cultivation, and lastly, why had efforts made by governments and donor agencies to bypass the animal traction stage to direct mechanisation through motorised tractors repeatedly failed? Diao et al. (2020) argued that supply of mechanisation has failed to meet demand due to market failures and improper government interventions.

According to Pingali et al. (1988), the evolution of farming systems is closely correlated with the transition from the hand hoe to the animal-drawn plough, and cannot be understood by using a simple choice of technique analysis that is familiar with modern economic theory.

Farm power in SSA relies mainly on human muscle power, based on operations mainly conducted by hand hoes and other hand tools, which essentially limit operational output. According to the FAO (2008a), 65% of farm power in SSA relies on manual labour, as opposed

[2] Africa less Egypt and Mauritania
[3] Bangladesh, Brazil, China, India, Korean Republic, Pakistan, Philippines, Thailand and Vietnam

to only 25% in selective developing regions. Only 10% of engine power is utilised as a main power source in SSA.

AGRA (2016) has analysed levels and trends in agricultural productivity by using three indicators – yield (cereal) defined as output per hectare, which is considered a measurement of land productivity; value added per agricultural worker as a proxy for labour productivity; and total factor productivity. The AGRA conclusions were in line with other sources in the literature, that both land and labour productivity in SSA has remained low, compared with other developing regions. Yields were substantially lower and indicated a stagnant growth trend, over time. Despite contrasting results in regional value-added per worker and total factor productivity in Africa, levels remained low, compared with developing regions such as Latin America and Asia. These trends are indicative that investment in the agricultural sector and agricultural value chains in SSA has remained low.

By the mid-2000s, the use of tractors had shown barely any increase over the previous 40 years, and compared with other world regions, currently tractor use remains almost negligible (UN Department of Economic and Social Affairs & Development 2009). The low levels of productivity, including land and labour productivity, is therefore a growing concern and the question therefore arises as to why these low levels of productivity persist, leading to low agricultural intensification.

1.2.2 Causes and Spill-over Effects of Increasing Tractor Use in Tanzania

Nearly 70% of Tanzanian farmers are small-scale resource-poor subsistence producers, cultivating between 1 to 3 hectares of land (Agyei-Holmes, 2014). Innovation and technical change is key to address the situation and move them up the commercialisation continuum.

Historically, investment in capital goods was discouraged due to liquidity constraints and the cost of these goods. Low agricultural growth in Tanzania is underpinned by weather-related unpredictability, minimum use of improved seeds and fertiliser and the reliance of manual labour (MAFAP, 2013 quoted in Agyei-Holmes, 2014). For every 100 farms in Tanzania, only 16% made use of power tillers (Agyei-Homes, 2014).

However, although at a slow rate, there has been a steady growth in agricultural mechanisation over the past few decades (Mrema, Kahan and Agyei-Holmes quoted in Diao et al. (2020). Over the period from 2006 to 2010, the country saw a decline in the use of the hand hoe. Agyei-Holmes (2014) stated that in 2006, 68% of all farms in the country used the hand hoe as the main tool for tillage and has decreased to 64% in 2010. Similarly, the use of animal power has reduced by 20%. The speed of mechanisation growth varies across regions with areas such as Arusha, Manyara, Mbeya and Kilimanjaro reaching 50% share of cultivated area plowed by tractors opposed to only 14% for the whole country.

The development of machinery markets in Tanzania was often led by the private sector and service providers to meet mechanisation demand which include emerging medium-scale farmers that serve as custom hiring service providers (Mrema et al. quoted in Diao et al., 2020). Despite this progress, there still exists several knowledge gaps regarding the factors that drive mechanisation in Tanzania, including how governments can support the private sector through appropriate policies.

Agyei-Holmes (2014) has highlighted the importance of appropriate technologies with competitive prices and new origins of imports, like China and India. Although the supply of cost-effective tractors and tillers from non-traditional sourcing countries, like Japan and the European Union, have contributed to a positive shift in tractor adoption, this study identify and investigate other potential drivers that could assist in the understanding why the use of tractors has increased since roughly 2005. This investigation, however, shifts the attention to the demand-side and thus, adopts a market-led approach underpinned by farmer responses. Diao et al. (2020) stated that where the demand side factors are in place, agricultural intensification and adoption of mechanisation occurs. Van Loon, Woltering, Krupnik, Baudron, Boa & Govaerts (2020) stated that challenges for smallholders to access mechanisation include a mismatch between economies of scale of machines and farm size, cost of machinery, technocratic attempts to "leapfrog" mechanisation without addressing farmer's capacity and educational needs and the observation that many mechanisation initiatives are centrally planned and failed to reach smallholders.

Governments in SSA increasingly regard mechanisation as a vehicle for effective rural transformation (Mrema, Peeyush & Rolle, 2014). However, efforts to improve mechanisation on smallholder agriculture are not consistently successful. It was stated earlier that state-led efforts to accelerate mechanisation in the past has largely failed. This could have been due to governments involvement in the supply of mechanisation without regarding market-driven principles such as changing factor prices and/or changing land dynamics.

For instance, medium-scale farms are more prevalent than large-scale farms in many SSA countries which have increased rapidly in recent years. However, much less is known about their interactions with, and influence on small-scale producers (Wineman et al., 2020). It is more likely that medium-scale farms will use modern techniques and inputs and more actively engage in the marketing of their produce. Farmers will expand their farm size once a tractor is acquired, but cannot fully use the capacity on their own farms (Mrema et al. quoted in Diao et al., 2020).

There remains limited evidence regarding the impact of medium-scale farmers on rural communities, their ability to attract inputs suppliers, markets and generally, whether there exists positive spill-over effects to neighbouring small-scale producers that could contribute to effective transformation of rural economies?

To date, evidence on the causes of rising use of mechanisation, not only in Tanzania, but in the broader region of SSA remains limited. Uncertainty exists regarding the spatial representation of mechanisation, the profile of tractor users and adopters, the role of changing farm structures and the evolution of the medium-scale farmers in promoting agricultural transformation in rural areas. This include the interrelationships between structural changes and the adoption of technology, as well as regarding whether changes in factor prices have led to labour-savings technologies? Although Mrema et al. quoted in Diao et al. (2020) have investigated the landscape regarding tractor hiring services in Tanzania, the study has focused on four supply-side case studies and evidence from other regions is important to contribute to the debate.

It is important to note that mechanisation is only one agricultural input and cannot be observed in isolation. For instance, mechanisation in isolation cannot correct the productivity and yield gap challenge in SSA. It should rather be observed in combination with other inputs used in the context of best farm practice.

It is important to understand the potential benefits of mechanisation. In developing economies, such as in Asia and Latin America, investment in agricultural mechanisation has enabled producers to engage in more intensified production levels that augment the quality of life, as well as contribute to prosperity in the region (FAO, 2008a). It has the ability to transform rural economies by enabling increased output (either through expanding the area under production or increasing the yield due to timely operations), integrate small-scale producers into the value chain and generate more income (FAO, 2013 and 2014 and Diao et al., 2020). Tractors can provide multi-functional utilisation, such as for transportation, thus addressing the shortfall in seasonal labourers caused by long walking distances. Lastly, it reduces the drudgery that is associated with the use of manual labour, especially in the use of child and female labour.

1.2.3 Developmental Challenges in SSA

The broader food systems challenge, not only in SSA, but globally, relates to the provision of food, feed and fibre to a persistently increasing global population. This is considered as a key development challenge (AGRA, 2016) in an agricultural environment characterised by limited natural resources, including land and water. The global demand for animal feed, for example, is projected to increase by more than 60% by 2050, which is an indication that rapid productivity growth in agriculture is essential to meet future demand (IFAD, 2016). In many regions across the world, the ability to increase yields is limited, as opposed to other regions, such as SSA, where vast potential exists to boost growth in agricultural productivity. Evidence to date suggests that yields, and in particular productivity growth, in SSA have remained low, as compared with the rest of the world. Transforming the agricultural sector in Africa is imperative to unlock growth and reduce poverty (Diao et al., 2020).

Undernourishment and food insecurity in SSA have constituted an enduring challenge, with uneven progress across the region. Despite a reduction over the past two decades, the proportion of undernourished people still remains the highest among developing regions (OECD/FAO, 2016). Over the period from 2014 to 2016, the number of undernourished people in the world amounted to 794.6 million, mostly located in developing countries, with Africa having almost 30% of that total. The proportion of SSA accounts for 95% of undernourishment in Africa, which is an unacceptable reality that implies that a substantial number of people still lack the basic food required for an active and healthy life (FAO, 2008b).

Key factors contributing to the slow progress in achieving food security and the eradication of extreme poverty and hunger have been ascribed to high population growth rates and low productivity of resources in agriculture (OECD/FAO, 2016). The total population of SSA is estimated at 1.07 billion people, 14% of global population, and projected to increase to 2.12 billion (22% of global population) by 2050 (World Bank, 2021). The population growth is accompanied by rural to urban migration to such an extent that in the next two to three decades, it is projected that the amount of urban dwellers will exceed those residing in rural areas (FAO, 2009). The population growth in African cities shows a substantial increase over the past 10 years and it is projected to maintain this growth over the next decade. According to the African Agricultural Status Report (AGRA, 2016) cities like Dar-es-Salaam in Tanzania and Nairobi in Kenya indicated percentage growths of 85% and 77%, respectively, over the period from 2010 to 2015. From 2015 to 2025, it is estimated that another 2 million people, on average, will be added to each city. Hence, it is critical to ensure food security and reducing undernourishment for the population at large.

However, the ability to feed a rising urban population cannot be guaranteed by agricultural and food systems that are characterised by predominantly low levels of productivity, low input use, and lack of technology adoption. This include the use of improved seed varieties, appropriate fertilisers and lime and farm power that is still dominated by manual labour. Quoted in Binswanger-Mkhize et al. (2010), the InterAcademy Council (2005) has cited 6 unique features of SSA agriculture that represent unique challenges in terms of the performance by the agricultural sector: *"(i) dominance of weathered soils of poor inherent fertility; (ii) predominance of rain-fed agriculture, little irrigation and very limited mechanisation; (iii) heterogeneity and diversity of farming systems; (iv) key roles of women in agriculture and ensuring household food security; (v) poorly functioning markets for inputs and outputs; and (vi) a large and growing impact of human health on agriculture."* These challenges have to be observed against the backdrop of the opportunities that arise from unused and under-utilised arable land, which have already been exploited in other parts of the globe.

1.3 Research Objectives

The general objective of this study is to investigate the potential determinants and farm-level spill-over effects of tractor adoption and rising use in Tanzania and to interpret the findings in the context of changes in the economic, demographic, social, and policy landscape in SSA. The broader research problems relate to 1) the historically low use of mechanisation in SSA, which remains a longstanding puzzle, as identified by Pingali et al. (1988), and 2) the fact that the recent rise in mechanisation adoption and use in SSA remains poorly understood, especially regarding the adoption of tractors among small-scale producers. The objective of this study is thus to address these questions by investigating the causes and spill-over effects of tractor adoption by using Tanzania as a case study.

Chapter 1 of this study will investigate the likely determinants and spill-over effects of increased tractor use and adoption in SSA, arising as a result of structural changes currently being observed in the agro-climatic, demographic and economic environment, which have the potential to stimulate agricultural intensification, transformation and growth. The existing evidence of rapid changes in the agro-ecological, demographic and economic landscape in many SSA countries and the interaction between them provides an indication of the direction that the region is progressing towards. However, this evidence often does not provide insights on the country-specific and intra-regional details of the drivers that promote mechanisation at district and farm levels.

Hence, Chapter 1, in particular, is motivated by the observation that farm structures in SSA are changing at an accelerated pace. For instance, the densities of medium-scale farms in the region have grown in recent years, and there are divided opinions about their influence on national policy goals, such as the welfare of smallholder farmers, who still constitute a large proportion of rural households in Africa. Chapter 1 will report on existing, recent and past literature on the causes and consequences of increased tractor use in SSA.

The objective of this study is to contribute to the literature by analysing farm-level trends over the period from 2008/09 to 2014/15 by using National Panel Survey (NPS) data for Tanzania. The objective is, firstly, to generate a base that describes the status quo of tractor use in SSA, where initial evidence suggests that mechanisation is increasing at a relatively fast rate. Given this observation, the objective is to then develop a conceptual framework that will theorise the likely causes and consequences behind the increasing tractor use. Thirdly, the observance of certain agro-ecological, demographic and economic trends that are currently evident in the region will be discussed in the context of how these trends influence the adoption of capital-intensive forms of farming. Examples include the impact of rural-urban migration of the workforce in SSA, the rising trend that is observed in the number of medium-scale farmers who control an increasing proportion of the growing area under cultivation in the region, their respective impacts on neighbouring small-scale producers, and whether changes in factor prices could promote increased tractor use. The findings regarding the macro-level trends and their respective implications for rural transformation and technology adoption will be validated at farm-level by using household survey data for Tanzania.

In particular, land dynamics and trends will be investigated to determine whether a change has occurred in farm sizes and land size distribution, with a specific focus on the rise of medium-scale farming households. In conjunction with this analysis, the use of tractors by small- and medium-scale households will be determined. The objective is to analyse the distribution of owned landholding sizes, cultivated land distribution, tractor ownership, and households making use of tractor rental services by considering four agricultural land size distribution categories: 0-1.99 hectares, 2-4.99 hectares, 5-9.99 hectares, and exceeding 10 hectares. The specific objective is to test whether the area cultivated is increasing and, if so, for which land size categories. Furthermore, whether the land size distribution has changed will be tested by considering the numbers of households and hectares in each category over the survey years. Given the likely changes in land dynamics, it will be evaluated in the context of tractor use and whether an increasing trend can be observed. The analysis will also identify the factors driving the use of mechanisation by Tanzanian smallholders and ascertain whether there is evidence of the potential role of larger-scale farms in promoting a movement to more capital-intensive forms of farming.

Two tractor rental demand functions will be developed: 1) a pooled generalised linear Probit model, which provides a flexible generalisation of ordinary linear regression, and 2) a Mundlak-Chamberlain device, which provides an estimator that Wooldridge (2009) refers to as the Correlated Random Effects (CRE) model, which addresses the issue of unobserved heterogeneity at household level. The model specification is based on the binary response from households as to whether a tractor is used or not, which is based on a set of household and community characteristics, regional conditions and year dummy variables. The estimation approach will therefore explore the relationships between tractor demand at household level and the respective covariates, as is explained in the data and methods section. The analysis will also determine whether the framework for induced innovation is valid for Tanzania; hence, whether it upholds the importance of relative factor price changes and also points to the importance of spill-over effects from medium-scale farms.

To summarise the general objectives of this section, these are, firstly, to identify the factors driving the recent rise of mechanisation use by farmers in Tanzania, secondly, to explore the potential role of medium and large-scale farms in promoting a movement to more capital-intensive forms of farming, not only on larger farms but also on smallholder farms, and thirdly, to evaluate whether evolving trends in factor use between labour and capital on smallholder farms in Tanzania is consistent with the Hayami-Ruttan Induced Innovation theory.

The following subsequent specific objectives have been identified:

1) Identify the primary and secondary drivers of change behind the rapid increase in mechanisation over the period from 2005 to 2015.
    a. Identify and discuss the key drivers currently being observed in Africa in the context of mechanisation adoption, based on past literature on the conditions of agricultural mechanisation adoption in SSA.
    b. Determine the existing status quo of agricultural mechanisation, in particular, tractor use in SSA.

2) Based on the theory of agricultural transformation developed by Pingali et al. (1988), the literature review will investigate whether a link can be made between theory and recent developments in the agro-climate, demographic and economic structure in African countries in order to determine whether the drivers that enable increased use of mechanisation might perhaps have begun to take effect.

3) Explore the determinants of increased tractor use in Tanzania, using National Panel Survey data over the period from 2008/09 to 2014/15.
    a. Determine land dynamic trends among farming households in Tanzania by computing own and cultivated land according to four land size categories (0-1.99, 2-4.99, 5-9.99 and >10 hectares):
        i. For each group, compute the mean hectares per household for own and cultivated land to determine whether farm sizes have changed since 2008/09.
        ii. For each group, compute the number of households per land size category to determine whether land size distribution is changing.

iii. Compute the total area in hectares controlled by each land size group and determine whether a change has occurred since 2008.

b. Analyse land dynamics at district-level by using the information computed in a) above.

c. Determine tractor use among land size categories by analysing the household asset composition over the period from 2008/09 to 2014/15:

i. Determine the magnitude of own tractor use per land size category

ii. Determine the magnitude of rental tractor use per land size category

4) Determine whether an increase in tractor use can be observed at farm level by using the information computed in 3) above, according to:

a. Own tractor use

b. Rented tractor use

c. Analyse the variation of tractor use at district-level

5) By analysing the descriptive statistics, determine whether a relationship exists between changing land size and land size distribution and tractor use:

a. According to own tractor use

b. According to the development of tractor rental markets

6) Specify and estimate demand functions for tractor rental services.

a. Determine the likely covariates that will influence the household decision to rent a tractor.

b. Determine the statistical significance of the model specification.

c. Estimate these variables by using a Generalised Linear Model (GLM) and Correlated Random Effects (CRE) Probit models.

d. Compute the marginal effects to understand the relationship of covariates and the decision to rent a tractor.

e. Compute prediction analysis by constraining continuous and categorical variables according to specific scenarios.

f. Evaluate the relationship between farm sizes and tractor use. The reason why this is important is that, if the number of medium-scale producers in the region is increasing and if a positive spill-over-effect exists towards neighbouring small-scale producers, the agricultural mechanisation environment and the adoption of capital-intensive forms of farming have the potential to change in the future.

g. Evaluate the likely covariates that could influence the decision to rent a tractor.

h. Explore whether a positive relationship exists between the concentration of medium-scale producers per district and the use of tractor rental services by small-scale producers in the same district. The outcome of this investigation could determine whether a positive spill-over effect exists towards neighbouring small-scale producers in promoting capital-intensive forms of farming among small-scale producers.

7) Determine whether the induced innovation framework, which explores factor price changes and the impact that these changes have on technological adoption, is valid for the Tanzania case study.

a. Analyse the median changes in district-level factor prices (wage rate, tractor rental costs and tractor rental use over the period from 2008/09 to 2014/15).

b. Generate a scatter plot that explores the relative changes in factor prices and the impact on the number of households who are renting tractors at district-level, where the y-axis refers to the change in the factor price ratio and the x-axis refers to the percentage change in the number of farming households renting tractors. If the induced innovation hypothesis is valid, a positive relationship can be expected in the event that factor prices are changing in favour of tractor rental costs.

c. Design and estimate a model specification to statistically validate whether the induced innovation hypothesis is valid for the Tanzania case study. The dependent variable is identified as the percentage change in the number of households renting tractors, with a set of covariates that is defined as 1) the change in the factor price ratio (wage rate divided by tractor rental cost), 2) household asset wealth, market distance, yield, maize price, fertiliser costs and the concentration of medium-scale farmers per district. Hence, the objective is to determine the relationships between these covariates and the change in tractor rental use among farming households.

1.4 Statement of Hypotheses

1.4.1 Hypothesis 1 (H1): Changes in Farm Size and Land Size Distribution in Tanzania

H1: The number and median farm size of medium-scale agricultural households in Tanzania, defined as farms larger than 5 hectares, are increasing with this group increasingly controlling more agricultural land relative to small-scale agricultural households.

Recent studies have documented the changing landscape in farm size distribution that is observed in a number of African countries. The rapid rise of medium-scale farming operations in most cases reflects the increased interest of urban-based individuals in land acquisition – professionals who are politically connected or members of influential rural households (Jayne et al., 2016).

As a departure point of this study, it needs to be established whether similar trends on changing land dynamics can be observed in Tanzania. This can be achieved by assessing relative changes, if any, in farm size between small- and medium-scale agricultural households over the period from 2008/09 to 2014/15. Secondly, it needs to be established whether a relative change has occurred in the land size distribution between small- and medium-scale agricultural households over the stipulated time period with the hypothesis that the number of medium-scale producers are increasingly controlling more land relative to small-scale producers.

Although the hypothesis can be perceived as weak, it is closely linked with the development and order of subsequent hypotheses with the broader objective to determine whether a rise of larger-scale farmers, who own or use tractors, has promoted the development of tractor rental markets that are used by nearby smallholders. This study hypothesises that:

a) Land size distribution in Tanzania is changing, where medium-scale farmers (>5 hectares) are controlling the majority of cultivated land.

b) The mean farm sizes for agricultural households, particularly in the >5 hectares land size distribution categories, are changing.

c) District-level differences in mean farm sizes and land size distribution have occurred.

The descriptive statistics discussed in Chapter 3, which investigates changes in farm structures and farm sizes, formally test this hypothesis.

1.4.2 Hypothesis 2 (H2): Increase Tractor Utilisation in Tanzania

H2: Increased tractor use is observed at farm-level in Tanzania and is driven by the development of tractor rental markets instead of own tractors. The increased use is correlated with farm size.

The influential theory behind agricultural transformation, growth and intensification of farming systems, as developed by Boserup (1965) and Ruthenberg (1980), argued that many countries in Africa were not correctly positioned for mechanisation at large throughout the period from 1980 to 1990 (Diao et al., 2014). Binswanger-Mkhize and Savastano (2014) stated that the Boserup-Ruthenberg model for intensification is often conditional upon the occurrence of rapid population growth and increased market access. This could lead to higher utilisation of inputs and higher investment in mechanisation and irrigation infrastructure, which together have the potential to offset the negative impacts associated with rapid population growth and the concomitant higher food demand. This study hypothesises that:

a) Amid rapid changes in the demographic landscape and the corresponding economic structure and given the agro-climatic conditions in Tanzania, the transformation of agricultural and food systems have positively influenced the demand for tractors and thus increased tractor use in Tanzania.

b) Increased tractor use is not confined to large-scale producers.

c) Increased tractor use is dominated by the development of tractor rental markets and not through the acquisition of own tractors.

The landscape of agriculture in SSA is altered by structural changes in labour markets, by evidence of an emergent investor farmer, and by a rising rural population (ReNAPRI, 2020). Pingali et al. (1988) concluded that the private sector has led the generation of mechanical innovations and the development of a vibrant industry for agricultural machinery, which is sensitive to a number of agro-climatic and economic factors, including farm size. For instance, the economic costs of using tractors as an alternative to draught animals are determined by the relative costs of capital and labour, interest rates, the utilisation of capacity, farm size, and maintenance factors. The evolution of farming systems over the long term, an increasing land to labour ratio, and farm sizes have led farmers' demand for labour-saving technology (Diao et al., 2014). Farm size distributions in Africa are changing at an accelerated pace, and in most of the countries, for which national rural household surveys exist, it is no longer true that the most African farmland is controlled by small-scale producers (Jayne et al., 2019), with evidence of the increasing control by this group in Tanzania, Kenya, Zambia and Ghana (AGRA, 2016).

This study hypothesises that:

a) A larger farm size is coupled with increased tractor use, either through own tractor acquisition or through the development of tractor rental markets.

b) Similar to other African countries, it is expected that, as the number of medium-scale producers increases, and if this group controls larger shares of cultivated land, increased tractor use can be anticipated.

c) As the concentration of medium-scale investor farmers in any district increases, it is expected that positive spill-over-effects towards neighbouring small-scale producers would exist.

The descriptive statistics discussed in Chapter 3, which explores tractor utilisation in Tanzania, together with the econometric analysis in Chapter 4, will formally test this hypothesis.

1.4.3 Hypothesis 3 (H3): Changing Factor Prices in Tanzania

H3: The availability of tractor rental markets in specific areas may have altered relative factor prices in ways favourable to the introduction of mechanisation by smallholders.

The Boserup-Ruthenberg framework has allowed researchers to understand the causes of agricultural growth, the nature of intensification of farming systems, investments, and the adoption of technology (Binswanger-Mkhize & Savastano, 2014). The theory of institutional innovation, as developed by Ruttan and Hayami (1970), was utilised to evaluate the emerging demand for mechanisation that forms part of a technology adoption process. The resulting induced-technical innovation model emphasised agricultural technology innovation and adoption as a continuous sequence, often biased toward saving land and labour as the limiting factors (Diao et al., 2014). This study hypothesises that:

a) A higher concentration of medium-scale farms per district encourages intensification, where a supply push of mechanisation services follows. Hence, an increase in the availability of rental services encourages small-scale agricultural households to also make use of tractor rental services. This hypothesis is drawn on the concept that, where larger-scale farmers own or use tractors on their own farms, and downtimes in use exist, it can be anticipated that tractor owners could rent out tractor services to farms in nearby communities, if the rental costs per hectare are competitive with manual or animal traction-based land preparation. Under such conditions, we might anticipate mutual synergies between large farms and small farms through the development of tractor rental markets, whereby larger farms more fully utilise the capacity of expensive capital investments, and whereby smallholder farmers gain access to cost-cutting land preparation technology that simultaneously frees up labour for reallocation to higher-return, off-farm activities.

b) Highly commercialised agricultural regions are more likely to make use of tractor rental services.

The econometric analysis discussed in Chapter 4, which investigates the covariates of the demand for tractor-rental services and the induced innovation hypothesis, will formally test this hypothesis.

1.4.4 Hypothesis 4 (H4): Household Tractor Demand Models in Tanzania

H4: Land size distribution, wage rate, tractor rental cost, asset wealth, market distance, household head type, household head age, the cost of fertiliser, maize price, the share of medium-scale producers in a district, and year and regional dummy variables can all be considered as covariates of the household decision to rent a tractor.

In the framework of induced technical innovation developed by Ruttan and Hayami (1970), land and labour endowment are considered as relatively scarce resources, and the scarce nature of these endowments is mirrored in the changes in their relative prices. In practical terms, alternative agricultural technologies are developed to facilitate the substitution of relatively abundant factors for scarce factors, where technology for mechanical power is regarded as labour saving, and which is created to substitute power and machinery for labour (AGRA, 2016; Diao et al., 2014).

According to Binswanger-Mkhize & Savastano (2014), since the independence of SSA countries in the 1960s, rapid population growth, urbanisation and, among other things, new market opportunities for producers and economic growth have arisen, which has caused the demand for agricultural and food products to increase. The Boserup and Ruthenberg theory behind agricultural intensification of farming systems states that population growth and access to markets can lead to increased investments in land, mechanisation, irrigation and input use as a result of higher per capita food demand. Pingali et al. (1988) found similar evidence that rising population and market access are the main determinants of agricultural intensification, which entails that the per capita land availability causes a reduction in fallow periods. Market access conditions, derived from improved roads and infrastructure in the region, are improving as a result of rapid urbanisation, with the consequence that food systems need to be developed to feed the growing demand. Better access to markets leads to intensification as a result of higher prices and elastic demand, implying higher rewards for effort (Pingali et al. 1988). The study hypothesises that:

a) Larger land size farms are coupled with increased tractor use, mainly through rental markets.

b) The time series variable “year” will be significant in the rental demand model, which stipulates that tractor use has increased over time.

c) Household head characteristics (sex and age) will impact upon the decision to rent a tractor.

d) Asset wealth is coupled with increased tractor use, mainly through own tractor acquisition.

e) Improved market access, as observed in the region, resulted in more elastic demand which is coupled with increased tractor use.

f) The wage rate in a district is positively associated with the decision to rent a tractor. Hence, as the wage rate increases, the demand for tractor rental will also increase.

g) Increasing fertiliser cost, as a key substitute based on the principle of buying power, will decrease the probability of renting a tractor.

h) Increasing maize price, as a proxy for income or profitability, is positively associated with tractor use.

i) The concentration of medium-scale farms per district will attract input supplies, such as tractors, and concurrently, these services will be made available to neighbouring farmers, including farming households who cultivate less than 5 hectares of arable land.

j) As tractor rental costs increase, the probability of renting a tractor will decrease.

The econometric analysis discussed in Chapter 4, which investigates the covariates of the demand for tractor-rental services and the induced innovation hypothesis, will formally test this hypothesis.

To summarise, the conceptual framework, design and the development of the study hypotheses and chronological order between them are closely interlinked. Several studies suggest that farm size and land size distribution are changing in various parts of the continent, however, this statement cannot be generalised for the entire region. It is therefore important to firstly validate whether a change in farm sizes and relative land size distribution can be observed in Tanzania (formulated in H1: Changes in farm size and land size distribution).

The next component to be investigated is whether tractor use is increasing and if so, whether it is driven by the acquisition of own tractors or through the development of tractor rental markets (formulated in H2: Increase tractor utilisation in Tanzania). In the event that H2 can be accepted, the analysis can proceed to investigate whether increasing tractor use is only observed among larger land size groups or whether there exists evidence of increasing use among small-scale producers (therefore, integrating elements from H1 into H2). If the latter is true, it is key to understand the potential determinants that drive increasing use among small-scale producers.

The study draws upon two broader concepts, firstly whether a change in relative factor prices has contributed to increasing tractor use (H3: Changing factor prices in Tanzania) and secondly, by identifying a number of household- and community characteristics that could influence the demand for rental tractors (H4: Household tractor demand models in Tanzania). Emphasis is placed on the role of medium-scale farms in promoting more capital intensive forms of farming with potential spill-over effects to neighbouring small-scale producers (part as H4: Concentration of medium-scale producers per district).

The outcomes of H1 and H2 are therefore strategically correlated to the outcomes from H3 and H4 which could inform the broader study objective to understand the determinants and spill-over effects of increasing tractor use in Tanzania. In order to adequately address the nature of correlation between the hypotheses, consistency in the source of data that will be used is detrimental to outcomes of the study.

1.5 Methodology and Data

1.5.1 Data

The definition of agricultural mechanisation is broadly defined as the process of applying tools, implements and powered machinery and equipment to achieve agricultural production, both crop and livestock (FAO, 2013; Kormawa et al., 2018 and Diao, Silver & Takeshima, 2016). In this study, the term "mechanisation" follows a similar interpretation as quoted in Diao et al. (2020) which defines "mechanisation" in broad sense or general use of mechanical power, including technologies and processes that involve their use.

The broader conceptual framework of this study draws upon the underlying foundations of mechanisation that could assist in setting the scene for tractorisation in Tanzania which refers to the activities associated with the use of any type of tractor. Tractorisation includes the use of single axle, two-wheel tractor, two-axle four-wheel tractor or track-type (Kormawa et al., 2018). Although the two-wheel tractor (power tiller or pedestrian tractor) forms part of the definition of tractorisation, this study attempts to focus on the use of traditional two-axle, four-wheel tractors, however, results may reflect the use of power tillers as well.

The use of tractors range across various activities in the production system. Many regions in SSA are considered to be in the initial phases of agricultural mechanisation, defined as the power substitution phase (Kormawa et al., 2018). In this phase, draft power and manual labour are substituted with mechanical power for power-intensive operations such as land preparation.

After the power substitution phase, mechanisation in control-intensive operations will follow which include activities such as mechanised weeding, either through tilling- and/or spraying operations, seeding and transplanting, fertiliser application, harvesting and threshing, transportation, post-harvest handling and processing.

A variety of data and methods were used to investigate the drivers of increased tractor use in Tanzania, which will be discussed in detail below. Data analysis of household surveys in Tanzania, as conducted by the World Bank, requires particular expertise and programming. Stata, which is a commercial, statistical software package, will be primarily used for data handling and processing to generate descriptive statistics for cross-sectional analysis, and to conduct econometric estimations as described below.

Details of annual data on tractor imports and supplier country for 40 sub-Saharan African countries, from 2001 to 2018, were sourced from the International Trade Centre (ITC) or Trademap Database. The Harmonized Commodity Description and Coding System (HS)[4] is an internationally standardised system of names and numbers used to classify traded products and is maintained by the World Customs Organization (WCO). It is important to note that the trade data refers to 4-wheel tractors and exclude the category of pedestrian tractors.

The Tanzanian National Panel Surveys (NPS) for 2008/09, 2010/11, 2012/13 and 2014/15, implemented by the National Bureau of Statistics with support from the World Bank, comprise a series of surveys that collect household and plot-level data on agriculture, non-farm income activities, expenditure for consumption, and other demographic-related characteristics for agricultural- and urban-based households (Tanzania National Bureau of Statistics, 2015). The purpose of the surveys is to provide high-quality, household-related data to stakeholders for monitoring dynamics in poverty, tracking progress of development strategies, and evaluating policy initiatives (Tanzania National Panel Survey, 2017). Agricultural information is collected at both crop and plot level, and includes data on agricultural inputs, production, and sales information. It is important to note that the 2014/15 national panel survey was refreshed by amending the sampling approach and add new households. This was done to ensure a proper

[4] The HS is organised logically by economic activity or component material. Chapter 87 of the Customs Tariff number refers to “vehicles other than railway or tramway rolling stock, and part and accessories thereof”. The code 8701 refers to “tractors other than heading 8709” where the latter stipulates, “work trucks, self-propelled, not fitted with lifting equipment”. Hence, 870190 represents “tractors excluding other than of heading number 8709, pedestrian controlled tractors and road tractors”

representation of estimates, while maintaining a sufficient primary sample to maintain cohesion within panel analyses. Longitudinal surveys tend to suffer from bias that is introduced by households leaving the survey, over time.

The sample design is a stratified, two-stage design and consists of 51 design strata, corresponding to a rural/urban designation for each of the 26 regions. The 2014/15 design consisted of 3 360 households, corresponding to 419 enumeration areas (EA). The survey results over the stipulated years were utilised to understand trends in land sizes, land size distribution, and regional tractor use among households by generating descriptive statistics. The objective of unpacking these statistics was to provide inferences on the determinants of increased tractor use.

Figure 1 represents a spatial illustration of agricultural households in Tanzania based on the sampled households, according to four land size categories, namely 0-1.99, 2-4.99, 5-9.99 and >10 hectares. Throughout the study, reference is made to these land size categories regarding the key variables of interest. It is acknowledge that living surveys in Africa (LSMS) often undercount larger farms (> 10 hectares) and has the potential to impact the outcomes of the study if improved statistics can be collected. It is likely that the robustness of the study results would improve significantly if a more accurate representation of medium-scale farms can be established.

Although the variables of interest will be discussed in more detail later in the study, the NPS basic information document and questionnaire do not provide more detail regarding their definition of “tractors” as a capital inventory item. It is possible that pedestrian tractors can fall into this category.

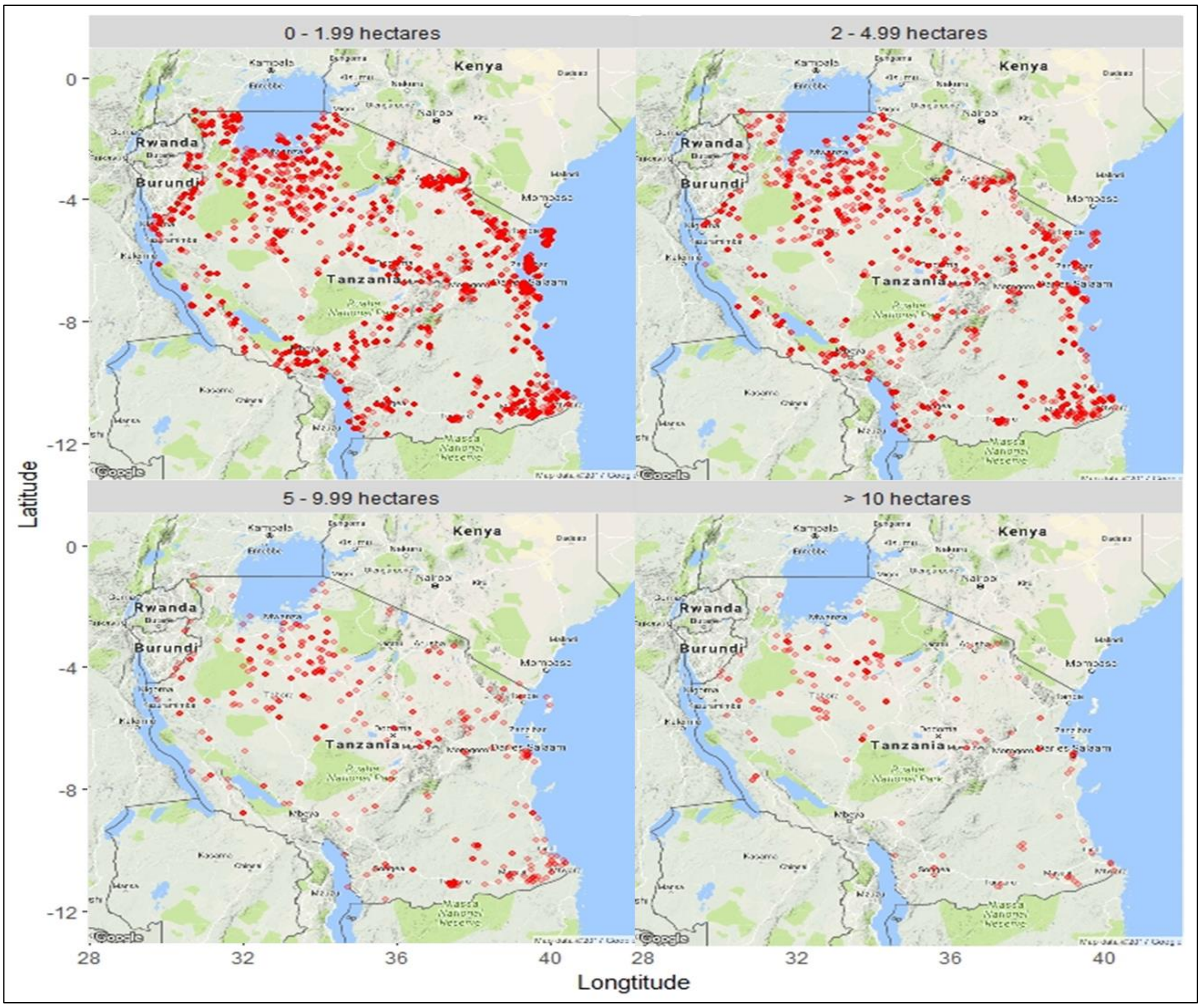

Figure 1: Agricultural households per land size category in Tanzania (Land owned/control from 2008/09 to 2014/15)

Source: Own calculations, using World Bank LSMS online data: Tanzania National Panel Survey, 2008/09, 2010/11, 2012/13 & 2014/15

1.5.2 Demand Models for Tractor Rental Services in Tanzania

To estimate a demand function for tractor rental services, the first approach made use of a generalised linear model (GLM), which provided a flexible generalisation of ordinary linear regression. GLMs can assume different error distributions and also account for heterogeneity of the error variance, contrary to ordinary linear models. The GLM relates the response variable to predictor variables through a link function g(.), as follows:

$$g\{E\ (y)\} = g(\mu) = X\beta + \varepsilon,$$

where X is the derived set of predictors, β is the set of regression coefficients, and ε is the set of random errors. The response variable can assume different distributions, depending on the phenomena being modelled. In this study, the Probit model, which assumes a normal cumulative distribution, was used to estimate the likelihood of renting a tractor, which is defined as:

$$\eta = \Phi^{-1}(\mu)$$

where $\Phi^{-1}()$ is the inverse of the cumulative Gaussian distribution function, that is the Gaussian quantile function. The final Probit model relates the predictors to the response through the respective link function (Albert & Chib, 1993 and Hahn & Soyer, not dated):

$$\hat{\mu} = \widehat{P(y = 1|X = x)} = \Phi(x\hat{\beta})$$

While the first approach can control for unobserved regional effects, there still remains the issue of unobserved heterogeneity at the household level. To address this issue, we leverage panel econometrics to incorporate the Mundlak-Chamberlain (MC) device (Mundlak, 1978; Chamberlain, 1984) into the models, which provides an estimator that Wooldridge (2009) refers to as the Correlated Random Effects (CRE) model. The MC device employs household-level averages of all time-varying components of the model in order to control for unobserved time-constant heterogeneity, under the assumption that such heterogeneity is correlated with the time-averages. For the binary response model, the unobserved effects Probit model can be specified, as follows:

$$P\{Y_{it} = 1 \mid X_{it}, c_i\} = \Phi(\mathrm{X}_{\mathrm{it}}\beta + c_i), t = 1, \ldots, T$$

We assume strict exogeneity and specify the MC device as follows:

$$c_i = \psi + \overline{X_i}\lambda + a_i, \qquad a_i|x_i \sim Normal(0, \sigma_a^2)$$

where ψ is a scalar and λ is a $K\ x$ 1 vector of coefficient parameters to estimate (Burke & Jayne, 2014). $\overline{X_i}$ is denoted as time-averages and is included as an additional set of regressors. Mundlak assumed that the error in a_i has a mean of zero, conditional on the entire history of the covariates X_{it} which assumes that a_i is uncorrelated with X_{it}, for all t and therefore $\overline{X_i}$. CRE bears potentially two interpretations of time-variant explanatory variables, which are the within and the between household effects. The within household effects refer to the time-varying explanatory variable's coefficients or β, where these estimates are identical to the fixed effects estimator. The CRE estimated coefficients on all time-averaged components of the model represent the between-household effects, or λ.

The household tractor rental Probit model contains a set of household and community characteristics, regional conditions and year dummy variables, and is specified as follows:

$$P\left(Y_{tractor_{rent}} = 1 \,\middle|\, X_k\right)$$

$$= P\,(Y = 1 \mid x0 + x1_{land_{cult}} + x2_{year} + x3_{head_{type}} + \mathrm{x}4_{\mathrm{head_{age}}}$$

$$+ \mathrm{x}5_{\mathrm{logasset_{wealth}}} + \mathrm{x}6_{\mathrm{logmarket_{dist}}} + \mathrm{x}7_{\mathrm{logwage_{rate}}} + \mathrm{x}8_{\mathrm{logfert_{cost}}}$$

$$+ \mathrm{x}9_{\mathrm{logmaize_{price}}} + \mathrm{x}10_{\mathrm{logtrac_{rent}}} + \mathrm{x}11_{hh\_5\_10ha} + \mathrm{x}12_{hh\_10\_20\_ha}$$

$$+ \mathrm{x}13_{hh\_20\_ha} + \mathrm{x}14_{\mathrm{region}} + \epsilon_{\mathrm{i}}$$

where the dependent variable is the dichotomous response of 'yes' or 'no', and refers to the outcome whether a household will rent a tractor or not, based on the relationship with X_k. X_k can be defined as the determinants that could influence tractor rental decisions, where $Land_{cult}$ refers to household cultivated land size categories, with sub-populations defined as 0-1.99 hectares, 2-4.99 hectares, 5-9.99 hectares and >10 hectares land size groups. $Wage_{rate}$ refers to the local wage rate for land preparation, which is key to understanding how changes in the relative factor price in agriculture, associated with rapid change in demographics and economic transformation, have affected the demand for mechanisation through tractor rental markets. $Trac_{rent}$ is the cost to rent a tractor, which is anticipated to have a negative correlation with the decision to rent a tractor. $Maize_{price}$ represents the price of maize per kilogram, which is a key food crop in the country. $Fert_{cost}$ represents the district-level fertiliser cost per kilogram, which could be interpreted as a substitute input. $Asset_{wealth}$ refers to the total value of all household assets. It could be expected that wealthier households are able to rent a tractor, as opposed to less-wealthy households. $Market_{dist}$ represents the distance from the farm to the closest market, which serves as a proxy for market access, with a lower probability of renting a tractor being assumed for households located farther away from markets. It is anticipated that farms which are located closer to towns could experience labour shortages, where tractor rental markets are likely being more developed. $Head_{type}$ refers to the household head type, whether male or female. $Head_{age}$ is a categorical variable stipulating the age group of the respective household head. The purpose is to test whether younger household heads are more likely to make use of technology, as opposed to older household heads. The $hh_{5\text{-}10ha}$, $hh_{10\text{-}20ha}$ and hh_{20ha} variables represent the concentration of medium- and large-scale farmers at district-level, where $hh_{5\text{-}10ha}$ indicates the percentage of households between 5 and 10 hectares, $hh_{10\text{-}20ha}$ the percentage between 10 and 20 hectares and hh_{20ha} the percentage of households exceeding 20 hectares. These variables test whether a positive spill-over effect on tractor rentals exists, given the concentration of medium-scale farmers located in a district. *Region* and *year* refer to regional and time dummy variables.

Since the National Bureau for Statistics in Tanzania had redesigned the sample design for the 2014/15 survey, panel econometrics analyses were not possible for all 4 waves of data, but only for the period from 2008/09 to 2012/13. The estimation strategy was twofold; 1) to leverage the additional wave of survey data (2014/15) and 2) to leverage panel data econometrics to address the problem of unobserved heterogeneity at the household level. The joint interpretation of these approaches could validate the coefficients of key variables of interest and provide useful insights into the interaction between them. By limiting the dataset to households located in the 0 to 5 hectare land size group, the outcomes can be compared to determine whether different factors are associated with rental tractor use between small- and larger-scale producers. A key element of this strategy is to determine the impact of medium- and large-scale producers on the decisions taken among smallholders to rent a tractor, and whether positive spill-over effects exist.

1.5.3 Model Estimation Approach – Pooled GLM Probit

As a departure point for understanding the dynamics surrounding the decision to rent a tractor at farm household level, a number of covariates were specified that could inform the determinants of tractor rental markets in Tanzania. Two Limited Dependent Variable (LDV) approaches were tested to determine the relationship between the dependent variable defined as the binary outcome for a household to rent a tractor or not, and a range of independent variables that are likely to influence tractor rental decisions. It is key to note that the final model selection from the econometric analysis was based on a sample of the full survey, where the sample denotes those regions where at least two percent of households rented tractors. The relationship was tested by utilising an ordinal binary response model estimation approach that employed the logistic regression (Logit) and probability regression (Probit) models. The descriptive statistics on the model variables are presented in Appendix A1.

The first step in the econometric analysis was to determine the appropriate estimation technique and the conclusion was made that the Probit link function reflected a better fit, as opposed to the Logit link function, due to the difference in the link function between the two model approaches. The Logit model is based on the assumption that $F(.)$ follows a logistic cumulative distribution, whereas the Probit model assumes that the function $F(.)$ follows a normal cumulative distribution (Wooldridge, 2009). The overall estimation results for the Probit link function reflected a better fit to the data type of the LSMS survey results than the Logit function did.

The second step was to compute an analysis of variance table (ANOVA) for generalised linear model fits for model specification 1. The objective of the computation of the ANOVA tables was to provide initial evidence of the covariates that have the potential to influence the decision to rent a tractor at farm household level. The analysis of the deviance table was computed using the Type 1 (Sequential Sum of Squares) and Type 2 (Adjusted Sum of Squares) tests. The Type 1 Sum of Squares (SS) are sequential, which entails that the factors are tested according to the order they are listed in the model specification. Hence, the reductions in the residual deviance as each term of the formula is added in turn are given as the rows of a table, plus the residual deviances themselves (R-documentation, 2017). The Type 2 test, which will be reported later in this study, refers to the adjusted SS and tests for each factor's main effect after the other factor's main effect has been computed. Hence, it is assumed that no significant interactions exist between variables. The purpose of computing the ANOVA tables by using the Type 1 and Type 2 tests was to determine the overall significance of the variables in the proposed model specification. The Type 2 deviance table is presented in Table 2.

Table 2: Analysis of Variance Table – Type 2 (Adjusted SS) Test: Output - Model specification 1

Response Indicator: Y = Tractor Rent = 1					
	Partial SS	**df**	**F**	**Pr(> t)**	**Significance**
Model	39.68	42	10.40	0.000	***
Land cult	3.88	3	17.59	0.000	***
Year	4.79	3	17.59	0.000	***
Head type	0.82	1	9.01	0.003	**
Head age	0.41	3	1.50	0.212	
Log asset wealth	0.00	1	0.05	0.828	
Log market distance	0.04	1	0.43	0.512	
Log wage rate	3.37	1	37.06	0.000	***
Log fertiliser cost	0.29	1	3.22	0.073	*
Log maize price	0.13	1	1.37	0.242	
Log tractor rental cost	2.55	1	28.08	0.000	***
Medium-scale farmer concentration: 5-10 ha	1.21	1	13.28	0.000	***
Medium-scale farmer concentration: 10-20 ha	0.00	1	0.00	0.954	
Medium-scale farmer concentration: >20 ha	0.09	1	0.96	0.327	
Region	20.84	23	9.98	0.000	***
	Significant. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1				

Although certain variables in the ANOVA table were reported as insignificant, the decision was made to remain with the identified covariates as stipulated in model specification 1, as these insignificant variables may deliver altered results in the MC CRE model estimation approach. Subsequently, a GLM and MC CRE estimation approach was utilised by estimating the model specification through using the Probit link function.

1.5.4 Estimation Approach to Test the Induced Innovation Hypothesis in Tanzania

The induced innovation hypothesis test to determine the correlation between changes in factor prices and households renting tractors will be estimated by denoting the dependent variable as Y = percentage change in the number of households renting tractors, X_1 as the change in the factor price ratio (wage rate divided by tractor rental cost), X_2 as the change in the cost of fertiliser, X_3 as the change in maize price, and X_4 as the change in the quantity of maize harvested (Δ2008-2010; Δ2010-2012 and Δ2012-2014). In order to test the induced innovation hypothesis, a pooled ordinary least squares (POLS) regression is utilised to statistically validate this aspect of the study.

1.6 Delimitations

Although the study will address the general topic of mechanisation in SSA, as an introduction, a case study from Tanzania will be used to determine the drivers that have influenced the mechanisation adoption process over the period from 2008/09 to 2014/15. The motivation to use Tanzania is due to data limitations and broad-based evidence on tractor use in SSA, and also because of Tanzania's historic policy environment that surrounds mechanisation use. Similar to countries such as Kenya and Nigeria, Tanzania has showed remarkable economic growth and this can be associated with the macro-level drivers of change, as discussed earlier.

The World Bank LSMS household surveys focus primarily on small-scale agricultural households, which represent the vast majority of rural households not only in Tanzania, but also in other parts of the region. Large-scale, commercial farmers are often not covered in these surveys, which restricts the understanding of mechanisation adoption among larger-scale producers.

Although mechanisation refers to in broad sense or general use of mechanical power, the aim of this study is to interpret the role of increasing tractor use (tractorisation) in Tanzania by relying on the broader principles and evidence that are available in SSA. The definition of tractorisation includes the use of pedestrian tractors or power tillers. Although the aim of this study is on the use of two-axle four-wheel tractors, power tillers cannot be disregarded and will feature in the descriptive- and econometric results.

In the methodology and data section of this thesis, reference was made that literature suggests that many parts of SSA are in the initial- or power-substitution phase of agricultural mechanisation. For the case study in Tanzania, it is assumed that the contextualisation of tractor use reflects similar findings that are representative of the power-substitution phase. However, due to the design- and limitations of the LSMS questionnaire, the analytics cannot be confined to only land preparation agricultural activities.

Although policy recommendations form a key part of this study, the focus will be placed on the producer or demand side, and not on the policy framework or private-sector supply side. The reason is to attempt to understand market-driven responses through investigating the behaviour of continuous users, non-users, adopters and dis-adopters of tractor use.

1.7 Study Outline

The study outline is presented in Figure 2, depicting the five chapters of this study. Chapter 1 has introduced the study with background information regarding the importance of the study, and has set out the problem statement, statements of the hypotheses, the research objectives and the methodology, and concludes with the study outline. Chapter 2 will cover an in-depth literature review with the focus on historic research regarding the conditions for agricultural intensification in the context of existing mega drivers, as is observed in SSA. The conceptual framework will be developed by analysing the interaction between drivers of change and past literature, with the objective to understand whether structural shifts can promote agricultural intensification, growth and transformation. The chapter will then zoom into mechanisation by gaining an understanding of the evolution of farming systems in SSA and agricultural mechanisation, followed by an in-depth stock-take of existing mechanisation trends in SSA. The chapter will conclude by summarising other demand- and supply-related drivers of mechanisation and the potential role that tractors adoption can play in the region. The transition from broader-based mechanisation principles to tractorisation is made in Chapter 3, that focuses on in-country analytics, using Tanzania, and focuses on the use of tractors. The Tanzania-specific case study will focus on descriptive statistics on land dynamics and tractor use over the period from 2009 to 2015. In Chapter 4, an econometric analysis will be conducted to generate household-level tractor demand models, followed by a formal induced innovation analysis to validate the theory in terms of changing factor prices. The estimation results will be applied to generate sensitivity and scenario analysis by utilising post-estimation techniques. The study will conclude in Chapter 5 by developing specific policy and private-sector implications and recommendations.

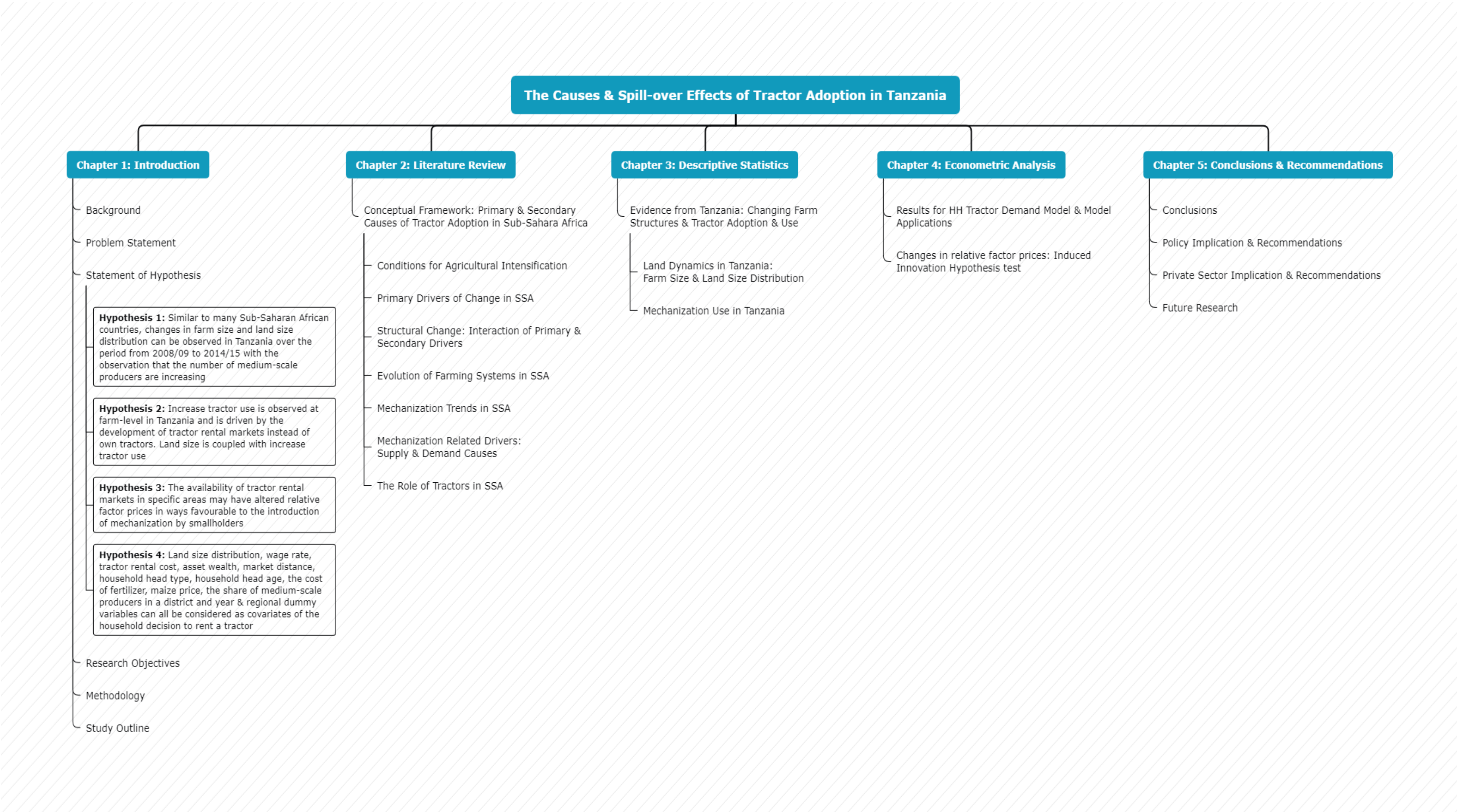

Figure 2: Outline of study: The Causes and Spill-over Effects of Tractor Adoption in Tanzania

Chapter 2:
Literature Review: A Conceptual Framework for the Determinants of Rising Tractor Use in sub-Saharan Africa

2.1 Introduction

Recent evidence suggests that the use of mechanisation in SSA is accelerating, which is possibly coupled with key developments in the agro-climatic, demographic and economic structure in many African countries, including Tanzania (Diao et al., 2020; Kormawa, Mrema, Mhlanga, Fynn, Kienzle, Mpagalile, 2018 and Malabo Montpellier Panel, 2018). Urbanisation, increasing demand for food products coupled with rising population, rising food prices, rising rural wages and seasonal bottlenecks in labour availability over past decades have created a resurgence in interest from policy makers and development stakeholders in promoting agricultural mechanisation in SSA (Diao et al., 2020; Diao et al., 2016 and Kormawa et al., 2018).

The influential theory behind agricultural transformation, growth and intensification of farming systems, developed by Boserup (1965) and Ruthenberg (1980), reasoned that African countries were not ready for widespread mechanisation in the 1980s and 1990s (Diao et al., 2014). Binswanger-Mkhize and Savastano (2014) stated that the Boserup-Ruthenberg model for intensification is often conditional upon the occurrence of rapid population growth and increased market access. These circumstances could lead to higher utilisation of inputs and higher investment in mechanisation, which have the potential to offset the negative impacts associated with rapid population growth and the concomitant higher demand for food. Diao et al. (2020), however, stated that the supply of mechanisation in SSA has largely failed to meet demand, unlike the predictions from the studies in the 80's. These failures are attributed to market failures, underpinned by unique characteristics to the continent (including complementary technologies, infrastructure and machine size) and improper interventions from governments.

Based on these initial statements, it is observed that there exists increasing mechanisation adoption in pockets of SSA, including Tanzania, but cannot be generalised for the entire region. Theoretical studies in the past have formulated potential conditions that are important to facilitate growth in mechanisation use. Decades later, there is mounting evidence of certain conditions emerging that are sufficient in promoting agricultural transformation and potentially, also mechanisation.

There exists a renewed interest in mechanisation in SSA, however, the underlying determinants that underpin demand growth for mechanisation remain complex, coupled with major restrictions in data availability. Although this study focusses on a case study from Tanzania, it is argued that evidence from other parts of SSA can inform the broader conceptual framework of mechanisation adoption, assist in identifying some of these complexities which in turn, can be tested at micro- or farm-level. The findings from the Tanzania farm-level analyses may be relevant to other parts of the continent and improve the understanding of some of these uncertainties. For instance, Mrema et al. quoted in Diao et al. (2020) stated that the number of operational tractors in Tanzania has increased over the period from 2005 to 2015 where the private sector often led the development of machinery markets and service providers to meet mechanisation demand, including emerging medium- to large-scale producers providing custom hiring services. Despite the increase in use, uncertainty exists regarding the roles of factors of mechanisation, including land tenure policy and roles of governments in promoting private sector engagement in machinery markets.

As a departure point, a literature review is necessary to 1. identify, analyse and contextualise the broader demographic- and economic trends (drivers of change that influences agricultural transformation) currently observed in the region. These trends will be discussed in the context of agricultural mechanisation by identifying potential relationships followed by 2. a thorough understanding of the theory of agricultural transformation and mechanisation in light of these modern developments; 3. develop a comprehensive stock-take of mechanisation trends and policy for the broader SSA region with a focus on Tanzania and finally 4. develop a framework for demand and supply for tractors, coupled with the outcomes from 1 to 3 above. It is envisaged that the literature review will form a sound departure point and conceptual framework for the upcoming chapters that focuses on the determinants of increasing tractor use and spill-over effects in Tanzania.

2.2 Drivers of Agricultural Transformation and Growth in SSA

It is argued that Africa's rate of urbanisation and urban population are higher than what is reflected in official data (AGRA, 2020, Diao et al., 2020, Malabo Montpellier Panel, 2018;

Ousmane & Makombe, 2014, Traub, Yeboah, Meyer & Jayne, 2014 and Tschirley, Bricas, Sauer & Reardon, 2020). Real per capita income growth over the past two decades was high which in combination with other factors contributed to rapid transformation in agri-food systems. Changes in food consumption, employment in post-farm segments and shifts in farm production towards higher value crops are some of the drivers of change that are observed on the continent and will require more capital intensity, knowledge and skills to meet food demand (AGRA, 2020 and Tschirley et al., 2020).

These examples of changes in macro-level trends in SSA suggest that the dynamics shaping the African landscape are changing at an accelerated pace, which has the potential to create a structural change in the demand for technological innovation, and increased input use and investment in agriculture. It is therefore important to identify, understand and interpret these trends in the context of the broader transformational process in agricultural food systems.

The drivers of agricultural transformation are interrelated, they change over time and are often multidimensional. Thus, an approach was made to segregate the drivers into 1. those that are the main- or primary drivers of change in agricultural transformation and 2. those that originate as a result of the primary driver or "consequence" (in this study referred to as secondary drivers). As will be addressed later in this chapter, the transformation of agricultural food systems is key in the interpretation of adoption of mechanisation.

A list of important primary- and secondary drivers of change that have the potential to impact agricultural transformation and mechanisation in SSA are presented in Table 3. The drivers include rapid population growth in Africa, increased demand for food and feed products, urban population growth and urbanisation, a shift in the labour force to off-farm employment, positive productivity in agricultural growth and poverty alleviation, land degradation, increasing land prices, volatility in climate patterns, increasing dependence on staple food imports, improved market access, and changing farmland ownership and land size distribution (Traub et al., 2014 and Badiane & Makobme, 2014).

Table 3: Primary and secondary drivers of change in SSA that influence agricultural transformation and growth

Macro trends in sub-Saharan Africa	Evidence and Implications	Potential implications for mechanisation
Primary Drivers		
Rapid population growth	• Currently at 1.1 billion and projected to increase to 2.1 billion by 2050 (UN, 2019) • Unlike other parts of the world that shows a declining trend in rural population, it is expected that rural population in SSA will grow by 60% towards 2050 • Pressure on food systems • Potentially increase land prices and growth in land markets • Fuelling migration that influences demographic and labour markets	+: Rising demand for food will require productivity growth (land and labour) and expansion, potentially stimulating the demand for tractors
Urbanisation and urban population growth	• Rapid population growth is projected for several African mega-cities although Tschirley et al. (2020) added 5 patterns of change in urbanisation: 1. Even higher rapid urban growth and higher populations; 2. Decentralised growth and new urban agglomerations; 3. Accelerating emergence of megacities; 4. Continuing importance of medium and smaller cities; and 5. Rural densification • Growing population puts increasing pressure on agri-food systems, especially supply chains • As income distribution possibly changes, dietary requirements and patterns are changing • Due to rising imports from outside SSA, the region is becoming more dependent on global markets, which entails that several products are priced at import parity • High prices further lead to opportunities and investment in farming	+: Changing consumption patterns may entail a shift from staple foods to higher-value crops and products, stimulating the demand for investment into agro-processing sector and mechanisation
Improved market access conditions for smallholder farmers	• Urbanisation and development of food systems to feed growing demand is reshaping market access conditions Further stimulated by rising secondary cities	+: Elastic demand could encourage productivity gains and thus investment into yield- and expansion-increasing technologies
Increasing climate variability	• Need exists to identify and implement strategies that render food systems more resilient to climate variability • Climate Smart Agriculture (CSA) has emerged as an approach that enhances the resilience to climate	+: Further motivation to change tillage approach to conservation

	variability and includes 1) sustainably increasing agricultural productivity growth and incomes, 2) adaption of resilience techniques, and 3) reducing or removing greenhouse gas emissions	
Land degradation	• Roughly 28% of rural Africa's farmers cultivate land that is considered to be degrading over time (Barbier & Hochard, 2016 quoted in AGRA, 2016) • Increased cropping intensity as a result of land pressure through increasing population, land degradation is accelerating • Nitrogen is considered a major nutrient, mined from African soils annually	+ and − : Primary tillage and use of conservation approaches
Secondary Drivers		
Generally positive agricultural productivity growth rates and poverty reduction	• Several African countries have indicated noteworthy growth in agricultural value added and total farm productivity since 2012 • The countries that registered the highest growths in agricultural productivity per worker in farming also experienced rapid shifts in the labour force out of farming, as well as faster labour productivity growth in non-farm sectors • Countries such as Nigeria, Angola, Mozambique and Ethiopia reflected both growth in annual agricultural productivity and poverty reduction (2000-2013) • However, in Benin, Kenya and Madagascar, poverty reduction did not materialised, despite evidence of growth in annual agricultural value added (2000-2013)	+: Persistent low yields entail continual occurrence of the poverty trap, which prevents farmers investing in technology. Increased yields, as a result of growing productivity, may stimulate investment in technology and machinery
Region's increasing dependence on imported staple foods	• Agricultural food supply in sub-Saharan Africa has the ability to meet increasing demand as a result of rising population growth, urbanisation and changing dietary requirements, for example increased maize supply over the past decade • However, for several other food and feed products, existing supply is not sufficient and supplies need to be imported • Employment prospects arising from agricultural trading and value-adding have not been fully realised	+: Higher food prices could attract investment into agriculture and technology. From a food perspective, it supports the need for increase in productivity and expansion and hence, local food production.

Labour force shifting to off-farm employment	• Sharp increase in the rate at which workers exiting farming in favour of off-farm activities • Uncertainty exists whether this rate will be maintained or decline in coming years • Farming will remain a key employment source	+: Less labour availability in rural areas could stimulate labour-savings intensification
Changing farmland ownership and farm size distribution	• Rising rural population, evidence of an emergent investor farmer, and structural changes in labour markets are simultaneously shifting the landscape of agriculture in sub-Saharan Africa • One such change is the concerted effort to transfer land out of customary tenure to private individuals (Jayne et al., 2015). • Furthermore, recent studies have found evidence of an emergent investor farmer operating on farm sizes ranging from 5 to 100 ha • The rapid rise of medium-scale holdings in most cases reflects increased interest in land by urban-based, politically connected professionals or influential rural households (Jayne et al. 2016) • New titles imply tenure changes (conversion of customary/state land to privatised land) that are linked with changes in land markets, as land sales and rental markets rapidly develop	+: Tenure security will benefit mechanisation, since equipment can be funded through foreign capital. As farm size increases, the economic feasibility of machine use increases.
Rising land prices	• It appears that land prices have increased in areas associated with high agro-ecological potential within reasonable proximity of urban areas (Jayne et al., quoted in AGRA, 2016) • Rising land prices are caused by increased demand (both domestically and internationally) • Governments have realised the revenue potential from the lease or sale of agricultural land, hence putting pressure on customary land administration • Potentially shift in land from less to more productive users and support agricultural productivity growth (Chamberlin & Ricker-Gilbert 2016; Jin & Jayne, 2013 quoted in AGRA, 2016)	+: Attracts investments into agricultural land, both from urban elites and agricultural investment firms, which is often coupled with the ability to invest into technology

Source: (AGRA, 2016 and Traub et al., 2014)

The conceptual framework anchors are based on the theory on the determinants that drive agricultural intensification formed by Boserup (1965) and Ruthenberg (1980). The theory was further investigated by Pingali, Bigot and Binswanger (1988) who explored the evolution of farming systems in SSA and agricultural mechanisation. The theoretical findings of these researchers are argued in the context of the theory of institutional innovation, in which changes in demand for institutional innovation are induced by changes in relative resource endowments (land, labour and capital) and by technical change (Hayami & Ruttan, 1970). Induced innovation and the relationship between factor prices and technical change imply that the development and application of new technology is endogenous to the economic systems (Hayami & Ruttan, 1970).

In recent studies, the framework as developed by Hayami and Ruttan was utilised to assess emerging demands for mechanisation as part of a technology adoption process, where the induced technical model emphasised agricultural technology innovation and adoption as a continuous sequence, often biased toward saving land and labour as the limiting factor in certain regions in SSA (Diao et al., 2014, Diao et al., 2020 and Jayne, 2016 quoted in AGRA, 2016).

In this framework, land, labour and capital endowments are considered as relatively scarce resources, and the scarce nature of these endowments is reflected in the changes in their relative factor prices. In practical terms, alternative agricultural technologies are developed to facilitate the substitution of relatively abundant factors for scarce factors, where mechanical technology is regarded as labour-saving technology that is designed to substitute power and machinery for labour (AGRA, 2016 and Diao et al., 2020).

To underpin this concept, Binswanger-Mkhize, McCalla and Patel (2010) have described an important linkage between the economic transformation process and its respective role in agriculture. Before achieving economic transformation, agriculture will account for the bulk of the economic output and the labour force. The share of agriculture in total value-added will normally fall short of its share in the labour force, which is indicative of the lower productivity of labour in agriculture, as compared with what is observed in industry and services. Industrial growth then leads to an increasing share of industry and manufacturing sectors, which pulls labour out of agriculture at a rapid pace. Services will eventually start to increase their share in the total economy and absorb additional labour. The movement of workers from lower to higher productivity causes a structural change, which accelerates economic growth. Amid rising productivity in agriculture, the gap in labour productivity between sectors is narrowing, with the share of agriculture in total output and employment approximating other sectors, and incomes across sectors begin to reach parity. Thus, agriculture becomes more like any other sector of the economy.

The drivers of change as presented in Table 3 have the potential to influence traditional forms of farming in SSA and have the ability to promote agricultural intensification, growth and the adoption of agricultural technologies such as tractors. Binswanger-Mkhize et al. (2010) have suggested that high commodity output prices accelerate the pace of agricultural intensification and mechanisation, given that they are transmitted to the farm gate price. What is evident from these trends is that the agricultural and food systems landscape is changing at an accelerated pace, which causes a structural change.

With respect to the growing domestic and regional demands for food and the corresponding impacts on agricultural commodity markets, there has been a significant demand pull and supply push effect on global and regional commodity markets over the past decade. This effect needs to be considered in the context of mechanisation, since it has resulted in changes in food systems and value chains in the region and boosted crop profitability significantly. From the supply side, a commodity super cycle has been experienced globally over the past decade, which resulted in increasing real prices of major grains and oilseeds (Badiane & Makobme, 2014 and Traub et al.,2014).

The two main drivers for this rapid increase in commodity prices were the introduction of corn-based ethanol production in the United States and oilseed-based biodiesel production in Europe, on top of a sharp increase in demand for maize and oilseeds from China. For a few years, global consumption of grains and oilseeds outstripped production and consequently, stock levels declined, prices increased in real terms, and field crops[5] became highly profitable. This stimulated numerous investments in land and agriculture and food systems, and had a remarkable impact on policy shifts and supply responses.

As a result of rapid investments (including agriculture, agro-processing and markets) in the region, value chains were and will most likely continue to be transformed (Badiane and Makombe (2014), which particularly improves market access and creates more elastic demand.

[5] Field crops represent cereals, oilseeds, pulses, hay and pasture and others that are cultivated on large areas for consumption purposes. Examples include maize, rice, cotton, sorghum, soybeans, sunflower, tobacco, wheat, barley, oats, rye, triticale, teff, peanuts, canola, flax, safflower, beans and pasture crops.

This transformation process is further stimulated by increased participation from the finance sector (Ströh de Martinez, Feddersen, and Speicher, 2016), the transfer of technology into the region, and increased off-take agreements being taken up by the private sector. For instance, the World Bank stated that on average, access to finance in SSA has increased from 24 to 34 percent over the period from 2011 to 2015 (World Bank quoted in Ströh de Martinez et al., 2016).

Directly and indirectly, these factors have influenced land ownership, land size distribution, and land sizes in SSA, not only by foreign investors, but also by local entrepreneurs. The aforementioned commodity super cycle period is of importance for the case study in Tanzania since it corresponds with the survey waves.

From the demand side, the regional pull effect came from a rapid increase in the demand for food that arose as a result of population growth, both urban and rural, and also through rapid economic growth in the region. The demand-pull has a substantial impact on the development of food systems and value chains. To elaborate on the importance of value chain transformation, it will be seen that, as a result of a sharp increase in demand for processed food items, imports will increase for those products that cannot be sourced locally. Typically in this scenario, a retailer will import these food items and put a margin on top of the import parity price. If critical volumes are reached, a processor will likely show interest in the particular value chain. A feasibility study could follow, where the local sourcing of raw materials is evaluated, together with the alternative to decide whether raw materials can be imported. Sourcing local production will be strategic in nature, and will consider using local, established informal or formal traders, approaching farmers directly, or a combination of both.

Traub et al. (2014) quoted in Badiane and Makombe (2014) stated that factors that are likely to keep prices relatively high in the future include continued high population growth rates (Malabo Montpellier Panel, 2018), rising income growth and demand for food (Tschirley et al., 2020), rising global demand for livestock products, slowing productivity growth in major grain producing regions, higher cost to bring new land under cultivation and growing connection between global food- and energy prices. Many of these factors are still prevalent in the SSA region which suggests that more capital intensity, knowledge, skill and organisation will be required going forward (Tschirley et al., 2020 quoted in AGRA, 2020).

Other key elements that enable a shift to improved commercial farming include the availability of finance (Ströh de Martinez et al., 2016), improved inputs such as seeds, fertilisers and plant protection chemicals (Ariga, Mabaya, Waithaka, & Wanzala-Mlobela, 2019 and Haggblade, Minten, Pray, Reardon, & Zilberman, 2017 quoted in Tschirley et al., 2020), extension services (Diao et al., 2020 and Ojijo, Franzel, Simtowe, Madakadze, Nkwake and Moleko in AGRA, 2016), and the availability of off-take agreements (Chapoto, Demeke, Onumah and Ainembabazi quoted in AGRA, 2016). All of these factors have led to the intensification of agricultural systems (Jayne, 2016).

In the context of mechanisation, and depending on the relative prices of land, labour and capital, multiple forms of intensification should be considered. If land is scarce and labour abundant, such as in examples from Asian countries (Jayne et al., 2019 and Diao et al., 2020), the norm is to experience labour-intensive forms of intensification. If labour is scarce and land is abundant, labour-saving forms of intensification tend to be experienced. Within the African continent, an increase in the rise of labour-saving and capital-using technologies and increasing use of land-savings technologies are likely in regions such as Rwanda, Nigeria, Ethiopia, Highland Tanzania and Southern Ghana that have experienced high levels of economic dynamism, in conjunction with high population densities and rising participation in agricultural factor markets (Jayne et al., 2019). In Northern Ghana and most of rural Tanzania, which exhibit high levels of economic dynamism but low population densities, it is possible to observe labour scarcity and a consequential rise in labour-savings technologies and a rise in larger-scale investment farms featuring capital-using, labour-saving technologies.

In areas with a high population density, but with evidence of economic stagnation, such as in southern Malawi and Madagascar, it is possible to observe slow wage increases and abundant labour availability for agriculture, with land scarcity, youth outmigration and some potential for labour-using and land saving investments being experienced. On the contrary, in countries that experience low population density and economic stagnation, such as the DRC and Zimbabwe, there could be limited incentives for extensification or intensification, with potential for capital-intensive land investments.

The implication and likelihood of tractor use and adoption will largely differ between the scenarios. If, for instance, the ratio between factor prices (land, labour, capital and skills including research and development) within regions is changing as a result of rapid population growth, and/or labour shifting to off-farm employment, urbanisation, changes in property rights or tenancy (Diao et al. 2020) and increasing land prices will have implications for the decision to use a tractor or not.

It is important to note that research in mechanisation in Africa is scarce and remain limited. Tschirley et al. (2020) stated that in order to serve Africa's urban food demand, an increase in capital intensity and greater knowledge, skill and organisation will be required.

The next step is to interpret these emerging trends and drivers of change in the context of the broader conditions for agricultural intensification, which is underpinned by four conceptual framework anchors, being:

- The framework of agricultural intensification, or the BR-framework developed by Boserup (1965) and Ruthenberg (1980), which considered population growth and market access as important drivers to facilitate agricultural intensification, growth and capital investment into farming operations.
- The evolution of farming systems in SSA, developed by Pingali, Bigot and Binswanger in 1988.
- The changing farm structures and the evolution of medium-scale investment farmers in many SSA regions.
- The method of exploring the fundamental factors affected by the induced innovation hypothesis, as was developed by Hayami and Ruttan in 1970, which states that farming practices are influenced by the economic system that determines the relative costs of agricultural land, labour and capital inputs. An important element to consider is the application of the induced innovation hypothesis in recent developments. Examples include studies conducted by Agyei-Holmes (2014 and 2016) who has investigated the potential benefits of emerging economy tractors in Tanzania. The study argued that these benefits can be enhanced if calculated attempts are made to modify the existing technology transfer and diffusion process. By considering three strands of literature, namely, Technical Choice and Appropriate Technology, Below the Radar Innovations and International Technology Transfer, the study argued that once technology is of low cost and small scale in an environment where effective demand exists, diffusion will occur naturally. Below the Radar Innovations refer to imports of cheaper tractors and

power tillers from China and India opposed to traditional sourcing regions (European region and Japan).

These anchors are interpreted in the context of the broader conditions for agricultural intensification, followed by the drivers of change that are currently observed in the SSA region. The interactions between these drivers, and the corresponding impacts on decision making at farm level, together with the potential linkage to the causes of increased mechanisation use, are then formulated. The next section elaborates on selective trends as stipulated by Table 3, within the context of the theory of agricultural intensification. For the purpose of this study, only certain of these drivers of change which are defined as the potential causes of increased tractor use, will be discussed in the context of increasing mechanisation use in SSA. These trends have an important link to those enabling drivers of transformation of farming systems in SSA, as theory suggests, and could potentially explain why the increases in the use of tractors are currently being observed.

2.3 The Theory of Agricultural Transformation in Modern Developments

According to Binswanger-Mkhize & Savastano (2014), since the independence of sub-Saharan African countries in the 1960s, rapid population growth, urbanisation and, among other things, new market opportunities for producers and economic growth have arisen, which has caused the demand for agricultural and food products to increase. The theory behind agricultural intensification of farming systems, developed by Boserup (1965) and Ruthenberg (1980), states that both market access and population growth can lead to increased investments in land, mechanisation, irrigation and input use as a result of higher per capita food demand. Pingali et al. (1988) found similar evidence that access to markets and rising population are the main causes of agricultural intensification, which entails that the per capita land availability causes a reduction in fallow periods.

As presented in Table 3 and in Figure 3, population growth in SSA, both urban and rural, has undergone a significant increase over past decades, and is currently estimated at 1.1 billion, with 678 million people residing in rural areas (World Bank, 2021). The population is expected to increase to 2.2 billion by 2050 (World Bank, 2021). The rural population as a percentage of total population is projected to decrease from 58% in 2021, to 42% in 2050. Rapid growth in rural population has transformed established areas from land-abundance to areas of land scarcity, with the value of land increasing significantly in recent years (Abay, Chamberlin & Berhane, 2021 and Jayne et al., 2019). Market access conditions, through improved roads and infrastructure in the region, are improving as a result of rapid urbanisation and hence the development of food systems to feed growing demand. Better access to markets leads to intensification as a result of higher prices and elastic demand, implying higher rewards for effort (Pingali et al., 1988).

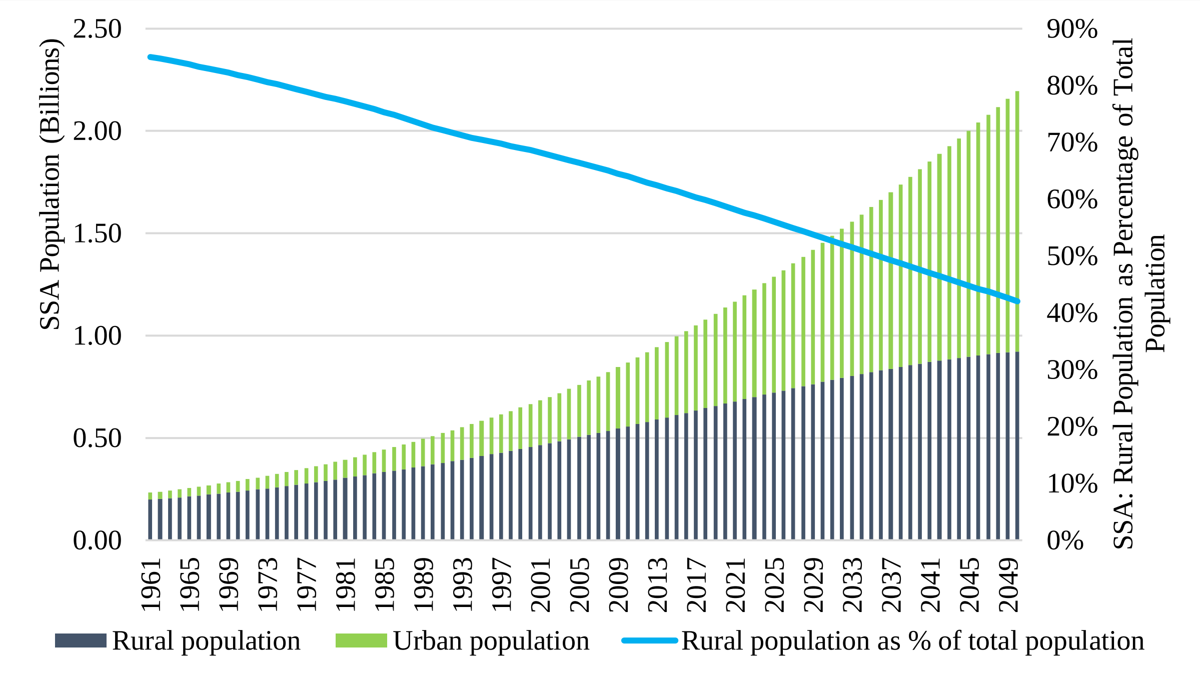

Figure 3: Rural and urban population in sub-Saharan Africa
Source: World Bank, 2021

In research concerning the conditions of agricultural growth, Boserup (1965) investigated the problem of the interrelationship between population growth and food production, and identified two fundamental approaches to understanding the relationship. Firstly, it is important to understand how changes in agricultural conditions affect the demographic situation of a country, and secondly, how population change will affect agricultural output, classically defined by expansion through creating more fields or by more intensive cultivation of existing fields. The Boserup-Ruthenberg framework has aided scholars to understand the landscape of agricultural growth, intensification, the technology adoption process, and investments (Binswanger-Mkhize & Savastano, 2014). Similar to the suggestions of Binswanger-Mkhize and Savastano (2014) to investigate whether rapid population growth, increased urbanisation, and economic growth have resulted in rapid farming system intensifications and growth in agriculture, it is important to link these drivers to the role and perception of mechanisation on the African content.

Table 3 further indicates that farm structures in the region are changing, with the emphasis on land ownership, land size distribution, and farm sizes. Large portions of African land exist where rural Africans face land scarcity, coupled with rapidly rising land prices and potential land insecurity (Abay et al., 2021; Knapman et al., 2017; Lawry et al., 2014; Wineman & Jayne, 2018). The landscape of agriculture in SSA is shifted by the simultaneous occurrence of rising rural population, evidence of emergent investor farmers, and structural changes in labour markets. Historically, the rise, particularly in the rural population, resulted in farm sizes decreasing (Masters et al., 2013; Jayne et al., 2015; Binswanger-Mkhize & Savastano, 2014). There also exists evidence of transfer of land out of customary tenure to private individuals (Jayne et al., 2015). For example, the percentage of households with land titles in Ethiopia and Uganda has risen, across all farm-size categories, with medium-scale farmers experiencing the fastest rate of growth. New titles imply tenure changes (conversion of customary/state land to privatised land) that are linked with changes in land markets, as land sales and rental markets develop rapidly. Furthermore, the fastest-growing segment of the family farm sector in sub-Saharan Africa comprises medium-scale farms, between 10 and 100 hectares (Jayne et al., 2015).

Pingali et al. (1988) concluded that the private sector has been the dominant force in the generation of mechanical innovations and the development of an agricultural machinery industry, which industry is sensitive to a number of agro-climatic and economic factors, including farm size. For instance, the economic costs of using tractors instead of animals are determined by the relative costs of capital and labour, the interest rate, the capacity utilisation, farm size, and other related maintenance factors. The long-term trends in the evolution of farming systems, the rising land–labour ratio, and the size of farms have led farmers' demand towards labour-saving technology (Diao et al., 2014).

Figure 4 illustrates the area owned/controlled in four African countries, according to farm size distribution. According to Jayne et al. (2019), medium-scale farmers control increasingly larger shares of the total farmland in Kenya (20% of total farmland), Ghana (32%), Tanzania (39%) and Zambia (50%). Their study listed four major causes of changing farm size distributions in

Africa, namely the rise of land markets, the recent global commodity super cycle associated with high prices, reforms in agricultural policy, and the increased impact of farm lobby groups. There are several unique pathways to enter the medium-scale farmer framework, including the successful expansion from small- to medium-scale farming, which is generally in the 5- to 25-hectare spectrum. This process is enabled by increasingly active land markets that promote new land acquisitions. Secondly, there is an increasing number of non-farm business people and wage earners who diversify into farming activities. There is also evidence of land acquisitions by urban-based professionals, rural elites and retired individuals (Jayne et al, 2019).

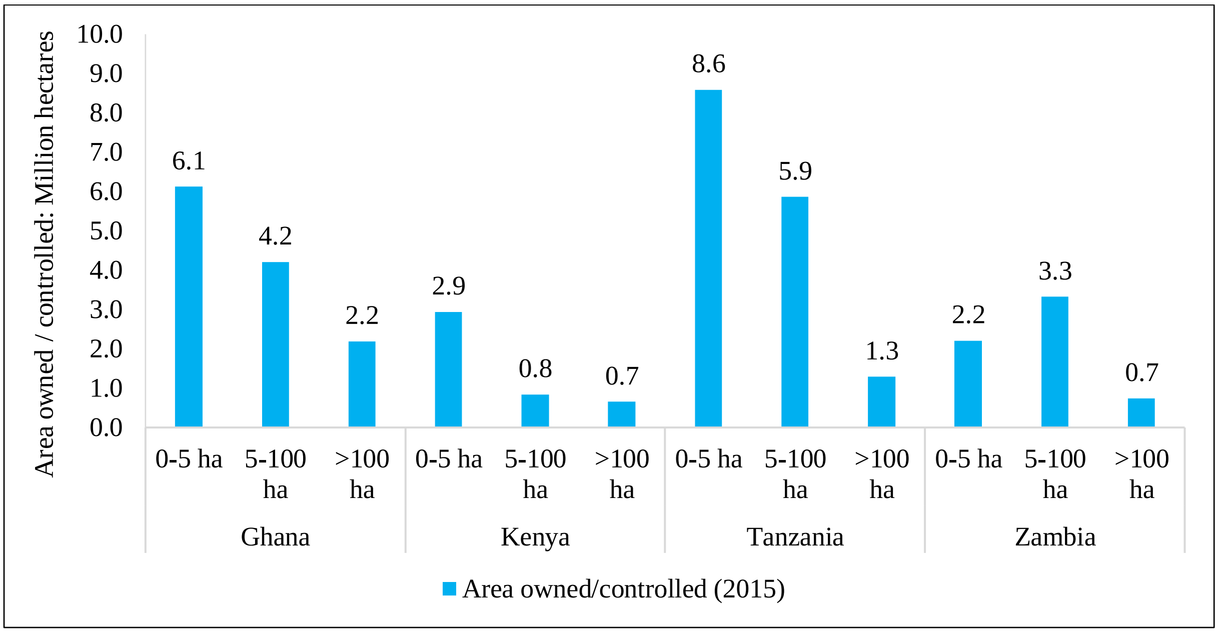

Figure 4: Area owned or controlled according to land size distribution (2015)
Source: (AGRA 2016)

According to AGRA (2016), the share of land in small-scale land holdings below 5 hectares has declined in Ghana, Tanzania and Zambia. Medium-scale farms, defined as farms between 5 and 100 hectares, account for an increasing share of total farmland. In some countries, contrary to the notion of large-scale foreign land grabs, the medium-scale group have acquired more land than foreign investors. According to Jayne et al. (2019), the national shares of area under cultivation, production values and marketed crop outputs on farms cultivating less than 5 hectares have been generally declining over time, with corresponding increases for medium-scale farmers. For instance, the share of the national cropped area under medium-scale farms in Ghana is close to 50%, with this group accounting for over 50% of all nationally marketed oilseeds and horticultural crops. However, this occurrence is not observable everywhere, as the pace of medium-scale farm acquisitions is slower in densely populated countries such as Malawi, Rwanda, Kenya and Uganda, which are associated with land scarcity and high land values.

The rapid rise of medium-scale farm holdings in most cases reflects increased interest in land by politically connected, urban-based professionals or influential rural households (Jayne et al., 2016). Furthermore, it has been well documented that medium-scale farmers tend to dominate farm lobby groups and influence agricultural policies and public expenditures on agriculture in their favour.

Medium-scale farmers are considered to be a diverse group that reflects unique entry pathways into agriculture that are encouraged by rapid development of land rental, land purchase, and long-term lease markets (Jayne et al., 2019). The rise of this group is affecting the region, in ways which are often complex to generalise, although findings from recent studies suggest that medium-scale farmers are considered to constitute a dynamic driver of agricultural transformation and that they generate mostly positive spill-over effects on smallholder farms.

The characteristics of the Asian Green Revolution that started in the 1980s were widely accepted as a potential model where a smallholder-led growth strategy would facilitate a pathway for achieving economic transformation and mass poverty reduction in Africa. Policy frameworks and strategies on the African continent regard these new trends in farm-size distribution as important, and the question is often asked whether there are beneficial elements to be had for the vast majority small-scale farming households in the region.

According to Jayne et al. (2019), the majority of studies in Africa that attempt to analyse farm structure use Living Standard Measurement Surveys (LSMS)[6]. It is increasingly recognized that these datasets generally provide imprecise and likely under-reported estimates of the number of farms operating on areas of above 10 hectares. Amid the notable rate of agricultural production growth achieved in SSA since 2000, it is key to understand the contribution received from medium-scale farms.

[6] The Living Standard Measurement Survey (LSMS) is the World Bank's household survey program focused on strengthening household survey systems in client countries and on improving the quality of microdata to better inform development policies.

An understanding of the potential role that medium-scale farmers can play in SSA could serve to reform the thinking of public-sector policy frameworks and private-sector market engagements. It would furthermore promote the idea of redesigning academic research and information/data sources. However, it is important to also understand the positive and negative consequences that arise from the evolution of this group of farmers. Jayne et al. (2019) found that medium-scale farms are attracting new private investment in value chains, which also improves the market access conditions for nearby smallholders.

For instance, in Tanzania, Kenya and Zambia, it was found that, in areas where there is a larger concentration of medium-scale producers, there is also evidence of greater investment by large-scale grain buyers, which in turn enables increased participation from nearby small-scale producers in these grain markets (Sitko, Burke & Jayne, 2018 and Jayne et al., 2019). Wineman et al. (2020) showed that spill-over benefits with increased access to inputs occurs in districts where medium-scale farmers are more concentrated. Chamberlin and Jayne (2018) reported that districts with a higher concentration of medium-scale farms are associated with significantly higher farm and non-farm incomes of small-scale and non-farm households. Hence, there is anecdotal evidence that suggests the existence of many social and mutually beneficial economic ties with small-scale households. Large-scale investments could, therefore, transform rural areas in Africa and serve as catalyst of growth (Wineman et al., 2020). This process is dependent on large-scale farms playing a role in attracting innovative investors, and in demonstrating the use of modern input technologies and agricultural techniques, which would uncover the agro-ecological suitability of the region (Deininger & Xia, 2016 & 2018 and Wineman et al., 2020).

The objective of this study is to investigate similar evolving trends that develop as a result of the increasing visibility of medium-scale farmers in Tanzania and the respective impact on technology use, such as mechanisation adoption. Bishop-Sambrook, quoted in Sims & Kienzle (2016), has investigated the relationship between farm power and land size, and found that households typically cultivate 1-2 hectares per annum, and further that draft animal power service providers typically cultivate 2 hectares per annum, households owning draught animal power cultivate between 3 and 4 hectares per annum, tractor service providers cultivate about 8 hectares, and households owning a tractor cultivate more than 20 hectares.

The drivers of change independently have the ability to transform agricultural value chains in the region. However, the interaction between them perhaps exhibits an even larger potential to cause a structural shift in urban and rural economies, the demographic profile of a country, agricultural and food value chains, the policy framework, and perceptions. For instance, an important element to be considered, jointly with the changing environment, is the existing evidence of policy reforms that have the intention to remove major barriers, such as private trading in land, reduction in trade barriers, and lower involvement in the control of agricultural markets. This process has facilitated and accelerated an improved alignment between domestic and global food prices. In response, agricultural households, regardless of size, have invested in agricultural value chains, which provides sufficient evidence of the transformation of agri-food systems in the region. The interrelationship between these drivers must be interpreted in the context of historic perceptions of agriculture in SSA and the ability to transform value chains. The historic, theoretical findings from the 1960s and 1980s, which previously suggested that SSA was not ready for mechanisation, must be revisited in the context of structural changes in the region. Hence, these drivers of change will influence the process of tractor adoption, either directly (for instance, an increase in farm size) or indirectly (for instance, through changes in the relative factor price ratio).

2.4 Mechanisation Trends and Policy in SSA

2.4.1 Reversal of Low Levels of Mechanisation Adoption in SSA?

Historically, mechanisation use in SSA has been very low, and substantially lower than in other developing regions (Table 4 and Figure 5). In 2002, there were 1.3 tractors per 1 000 hectares of cultivated land in SSA, compared with 9.1 per 1 000 hectares in South Asia and 10.4 in Latin America (Pingali, 2007). The number of agricultural tractors in use per 100 square kilometres of arable land in Tanzania declined by more than 50% over the period from the 1960s to the 1980s, before a marginal recovery was observed towards the early 2000s (World Bank, 2016). Mrema (2016), has suggested that the number of tractors in use in Tanzania had peaked in 1985, at 18 533 units, and that this was followed by a period of a significant decline, to 7 210 units in 2005, which may support the argument that government-led approaches in mechanisation supply often failed as a result of a failure to recognise a market-led approach.

Table 4: Sources of farm power in 2005 (percentages)

Region	Hand (manual)	Animal	Engine
Developing regions: Near East, Asia and North Africa, Latin America and Caribbean	25	25	50
SSA	65	25	10
Central Africa	85	11	4
Western Africa	70	22	11
Southern Africa	54	21	25
Eastern Africa	50	32	17

Source: Adopted using FAO, 2008a and FAO, 2008 quoted in Kormawa et al., 2018

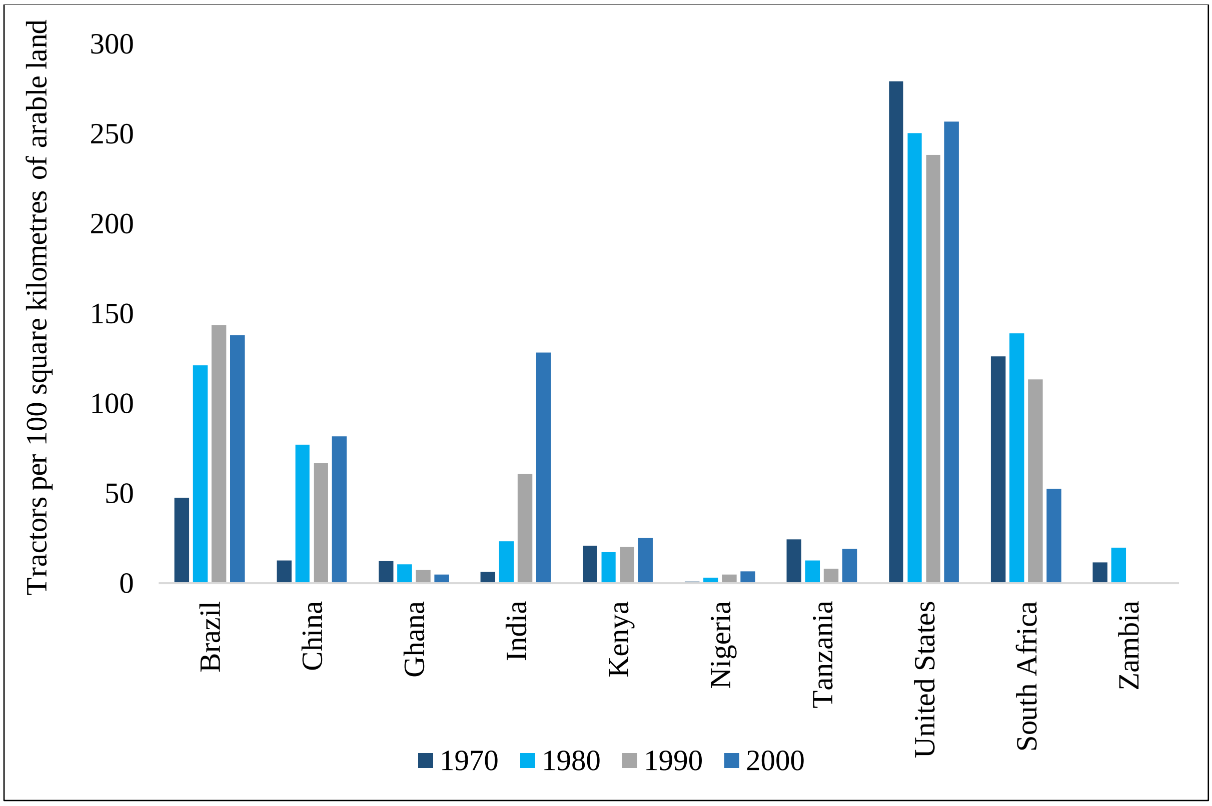

Figure 5: Tractors per 100 square kilometres of arable land
Source: World Bank, 2016

Over the past decades, most of the developing regions of the world have seen the introduction of labour-saving technologies (Diao et al., 2016). The demand for labour-saving technologies in SSA was much lower with large spatial variations (Mrema et al., 2008). The intensification of production systems has created bottlenecks in operations such as land preparation, threshing and harvesting activities, which has led to widespread mechanisation adoption in regions like

Asia and Latin America and in countries such as South Africa. Interesting to note that in South Africa, the area and production of maize have increased significantly over the period from 1904 to 2015 which were enabled by the adoption of tractors and other agricultural machinery (Greyling, 2019). In 1937, farmers were using 6 019 tractors which continued to increase to reach a peak in 1976 with a total of 173 570 units (Liebenberg, 2012). The replacement of draft oxen with tractors has enabled a shift in area expansion since it freed up land for marketable cropping purposes which was previous used to feed traction animals while at the same time, increasing the amount of land that is manageable by the family farm (Brand, 1969; Van Zyl, Vink & Fenyes, 1987 quoted in Greyling, 2019). The evidence in South Africa suggested that employment on farms has continued to increase with the adoption of tractors for land preparation after the Second World War until combine harvesters were introduced from the late 1960s. This was due to more land that was ploughed and more labour that was required to harvest the crop.

The persistent, low levels of mechanisation usage in the land-abundant parts of SSA is considered a longstanding puzzle (Pingali et al., 1988) and remain complex to understand (Diao et al., 2020; FAO, 2013 and Diao et al., 2016). The question raised by Pingali et al. (1988), given that the rapid spread of mechanical equipment is historically associated with an abundance of land, is why the spread of mechanisation in SSA has been slower than in countries such as China and India where labour is abundant and wage rates are low. Agyei-Holmes (2014 and 2016) stated that these two countries have developed innovations which fit their localised operation conditions. These innovations were relatively low-cost technologies which were affordable to poor farmers. In SSA during that period, farmers who were poor continued to either rely on animal power, hand hoes or expensive machinery from Western Europe and Japan. The expensive nature of these machinery that originated from Europe and Japan meant that poor farmers could not afford them. Large-scale farmers who could afford them, did not have enough excess capacity during the season to provide sufficient rental services.

The FAO (2013) has referred to SSA as a region that did not follow in the footsteps of China and Latin America during the Green Revolution's period of rapid intensification, which is often characterised as a shift into profitable farming. In Asia, the Near East, North Africa and Latin America, 50% of farm power is provided by engines. Critical success factors for mechanisation include effective demand, economic machine utilisation rates, and an effective machinery supply chain (also underpinned by the Below the Radar Innovations from China and India) and support services (FAO, 2009). The effective demand creates both the need and opportunity for mechanisation, which has to be linked to market-led enterprises. Instead of engaging in a national mechanisation strategy, the regional characteristics of farmers would inform the nature of the effective demand.

Figure 5 reflects the fact that levels of mechanisation in African countries are substantially lower than in developed regions such as China, Brazil, and the United States of America. Figure 6 focuses specifically on Tanzania and indicates that the numbers of agricultural tractors in use had declined by more than 50% over the period from the 1960s to the 1980s. The mechanisation unit of the Ministry of Agriculture in Tanzania has estimated that the total number of tractors in use in 2010 was 8 466. This amounts to roughly 7 tractors per 100 square kilometres (World Bank, 2012).

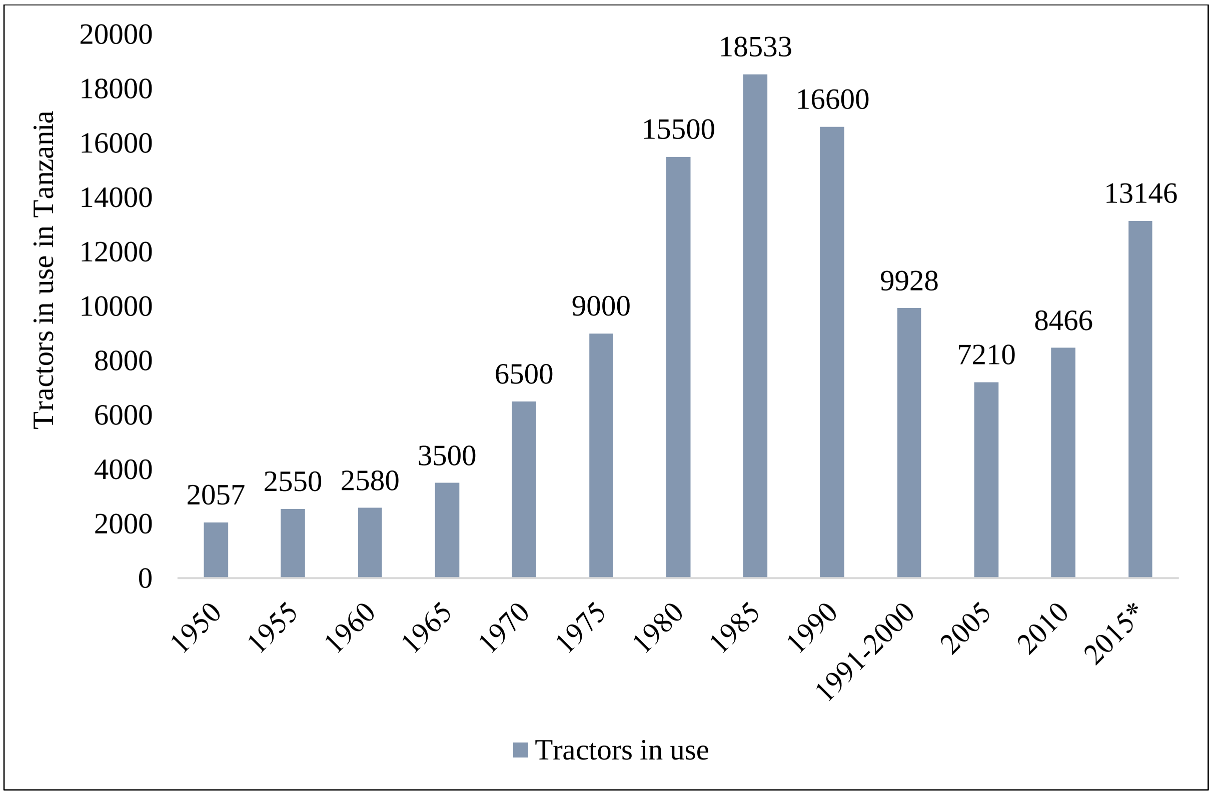

Figure 6: Agricultural tractors in use in Tanzania: 1961-2002
Source: FAOStat, 2017; FAO Production Yearbooks: Vol 13, 24, 29, 36, 42; TSAE, 1981; MAFC-TAMS, quoted in Mrema, 2016

Mrema (2016) has stated that, after independence, the Structural Adjustment Programs (SAP) that were introduced over the period from 1985 to 2005 had boosted the social and economic policy of Tanzania and had significantly affected the pace and type of mechanisation. The objective of these programmes was to reduce the role of the public sector in production and to stimulate the role of the private sector in service provision to smallholders.

Mrema (2016) further conducted research on tractor users in Tanzania through field visits and found that the national tractor fleet was mainly concentrated in six regions, namely Morogoro, Arusha, Kilimanjaro, Manyara, Dodoma and Shinyanga. This concentration would seem to point to the emergence of service providers who had invested in their own machinery for their own cultivation needs and for the provision of tractor rental services. Through interviews, it was found that tractor-hire businesses operated at a national level, in pursuit of business by following the rainfall isohyets and land-preparation seasons. Mrema (2016) suggested that an in-depth impact study should be carried out to determine the extent to which this pan-territorial use of tractors occurs. The existence of the persistent low use of mechanisation was identified in the driving forces for agricultural intensification and the incentives for increased productivity.

The period since the mid-2000's was characterised as a reversal period with operational four-wheel tractors (including imports of second-hand tractors from Europe and Japan) increasing from 2005 to 2015 (Mrema et al., quoted in Diao et al., 2020). Although land preparation was still dominated by the use of manual labour (62%), in some regions (Arusha, Manyara, Mbeya and Kilimanjaro), land preparation conducted tractors has exceeded 45% (Tanzania MALF, 2016 quoted in Diao et al. 2020).

However, after decades of persistently low levels of mechanisation in African agriculture, Trademap data published by the International Trade Centre, which mainly uses national revenue statistics, reflects an increase in the amount of imports into various African countries of tractors. Figure 7 illustrates the nominal values of tractor imports (referred to as tractors, parts thereof and accessories) into SSA in US$ over the period from 2001 to 2018. It is evident from the graph that imports of tractors into SSA increased substantially over the period, especially in 2008, which was mainly driven by a spike in imports into Zimbabwe and Angola. Over the period from 2006 to 2010, which is often referred to as the global commodity cycle period associated with high oil and other commodity prices, Western Africa reported a noteworthy increase in the value of imports, driven mainly by Nigeria. The hike in 2013 came as a result of an increase in Kenya and Ethiopia. Except for North Eastern Africa, all other regions reported a decline in imports from 2014 to 2015.

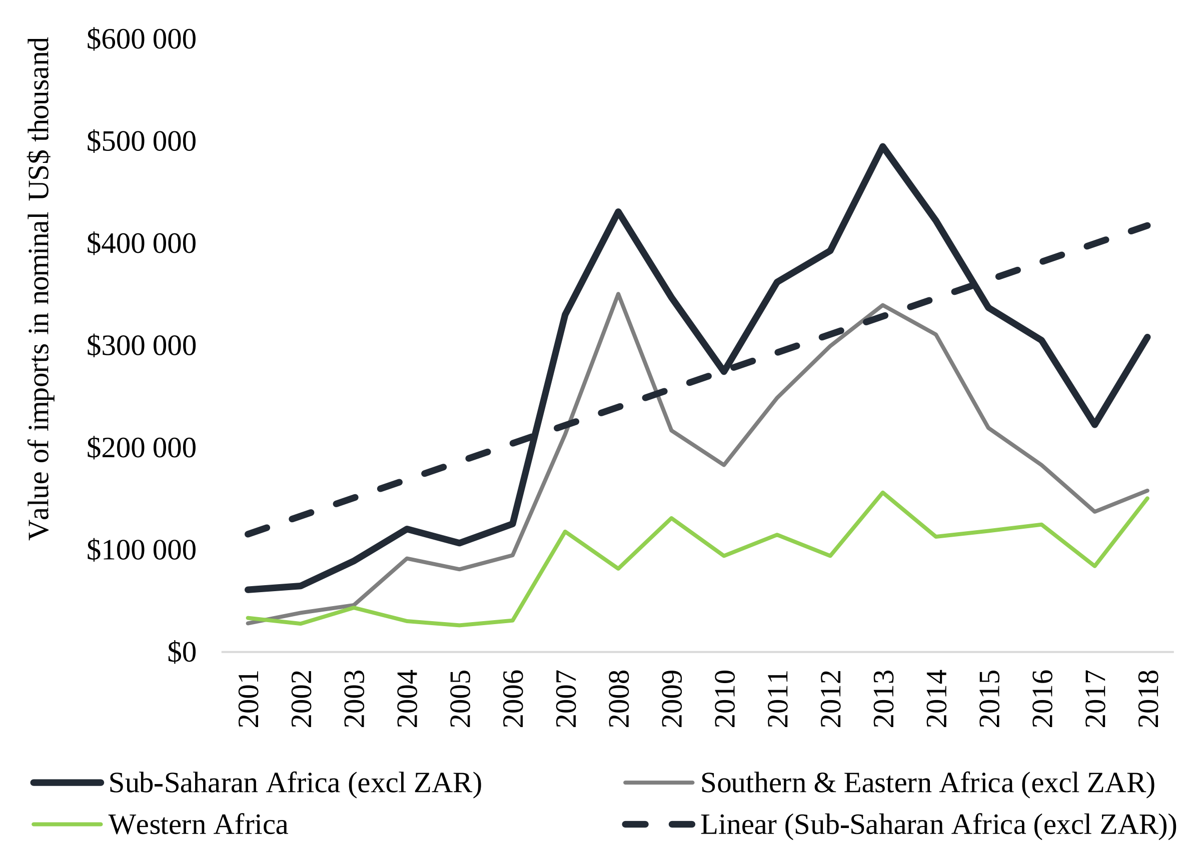

Figure 7: Value of tractor imports into sub-Saharan Africa, excluding South Africa, (HS870790-5) in nominal US$ (2001-2018)[7]

Source: Own calculations using data from International Trade Center's Trademap database, 2020 & van der Westhuizen et al., 2017

Figure 8 provides an indication of tractor imports into selected African countries and represents the import values and linear trend lines for Ghana, Nigeria, Kenya, Tanzania and Zambia. The value of tractor imports into Kenya reflected a firm trend, as opposed to other focus countries, especially over the period from 2012 to 2015. In addition, Kenya indicated an increase from 2014 to 2015, whereas the remaining countries reported decreases in import values. Tractor imports into Tanzania reflected a noteworthy increase from 2009 to 2011. Over the period under review, Nigeria reflected robust imports, although showing a substantial decrease since

[7] The Harmonized Commodity Description and Coding System (HS) is an internationally standardised system of names and numbers used to classify traded products and is maintained by the World Customs Organization (WCO). The HS is organised logically by economic activity or component material. Chapter 87 refers to vehicles other than railway or tramway rolling stock, and part and accessories thereof. Tractors were measured in this study as code 870190-5, hence excluding pedestrian, road & track-laying tractors.

2013 (the price for Brent Crude oil underwent a drastic decrease in 2015, from roughly US$100 to just above US$50).

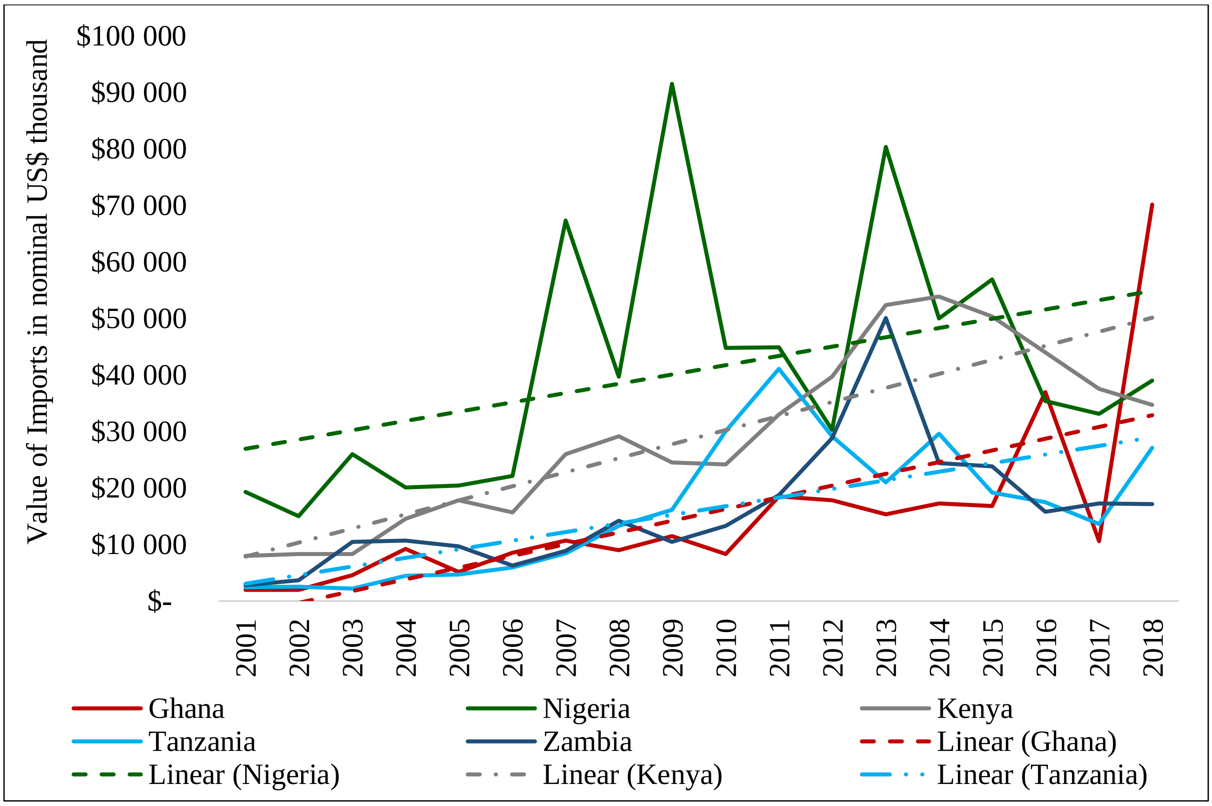

Figure 8: Value of tractor imports in selected sub-Saharan African countries (HS870790-5) in nominal US$ (2001-2018)

Source: Own calculations using data from International Trade Center's Trademap database, 2020 & van der Westhuizen et al., 2017

The period averages and percentage annual changes for the stipulated periods are illustrated in Figure 9 for selected African countries. Ethiopia indicated a substantial increase and annual growth in imports over the period from 2001 to 2015. Albeit from a low base, the import value over 2011–2015 exceeded the values in countries like Kenya and Nigeria. The period (average) annual growth for Ethiopia was 133% per annum. Other examples of noteworthy annual growth were reported by Tanzania (54%), DRC (67%), Namibia (76%) and Angola (59%). South Africa remained the largest mechanisation market in Africa, with an annual growth of 12% over the period.

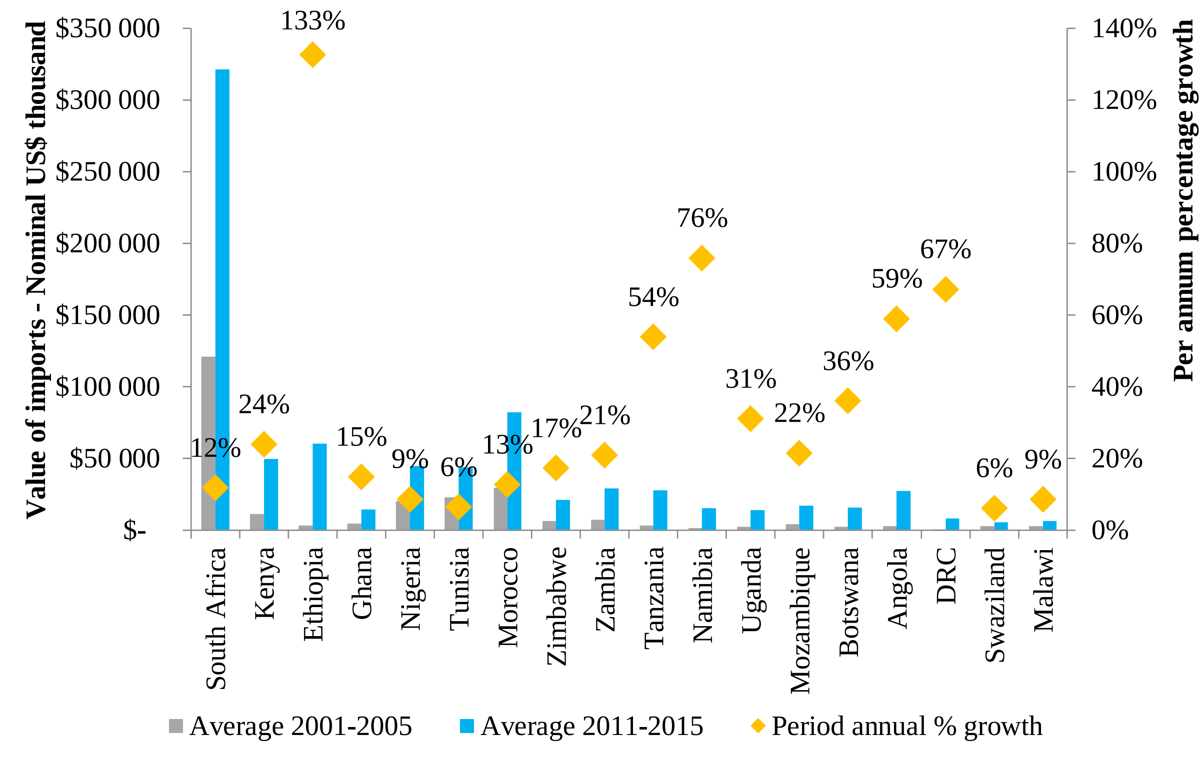

Figure 9: Period averages & percentage changes in the value of tractor imports into sub-Saharan Africa, excluding South Africa, (HS870790) in nominal US$ (2001-2015)

Source: Own calculations using data from International Trade Center's Trademap database, 2016

Mrema (2016) made use of data obtained from the Tanzanian Revenue Authority that reports the numbers of tractor and power tiller units imported into Tanzania, which is presented in Figure 10. The annual imports of tractors over the period from 2005 to 2014 averaged at 713 units, while power tillers averaged at 753 units. The import of tractors indicated an increasing trend over the period, and increased faster than power tiller imports. Imports peaked in 2014, amounting to 1212 tractors.

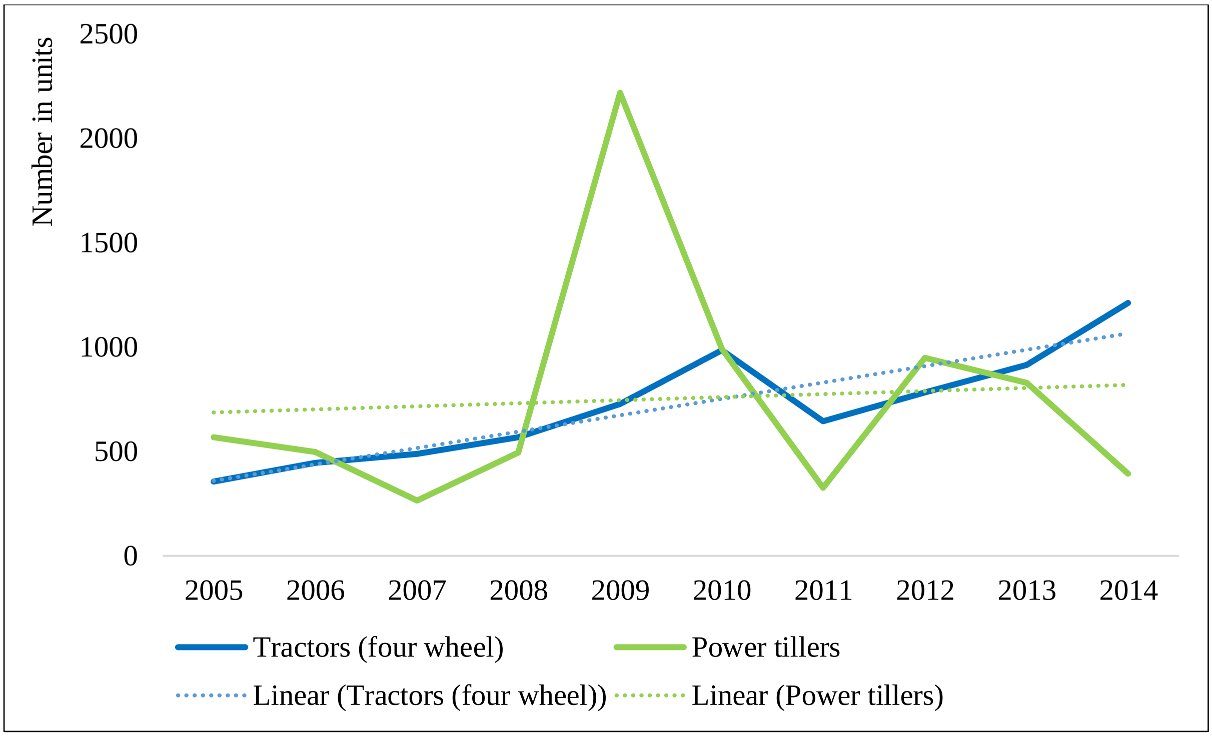

Figure 10: Agricultural tractors & power tiller imports into Tanzania: 2005-2014
Source: Mrema, 2016, using data from Tanzania Revenue Authority

The adoption of mechanisation by producers is an evolutionary process, influenced by country-specific demographic, socio-economic and economic factors, which are impacted upon by government policy choices (Diao et al., 2014). Diao et al. (2020) argued that farming systems in many regions in Africa have intensified, associated with shorter fallow periods and increasing share of annual cropping areas. The adoption of mechanisation, although still at the initial phase of power substitution (Kormawa et al., 2018), can be expected when the appropriate conditions are in place and would not be profitable in the absence thereof (Diao et al., 2016).

Cluster and descriptive analyses conducted in Ghana and Nigeria of the adoption of mechanisation both suggested an increased demand for mechanisation (Diao et al., 2014; Takeshima, Pratt, & Diao, 2013). Findings in Nigeria indicate that tractor use was correlated with input-intensive production systems and highly concentrated among medium-scale farms, and that small-scale producers in southern Nigeria were willing to pay for land-preparation services if the services were available (Takeshima et al., 2013 and Diao et al., 2020). Government and development agencies in Ghana have begun to design agricultural development programmes that are centred on large-scale farmers and other commercial entities as nucleus change agents to assist in creating a vibrant and more commercialised smallholder sector. Examples include block farming, similar to Zambia's farming blocks, and procurement and sales of machinery at subsidised prices to medium- and large-scale producers (Chapoto et al., 2014). Other initiatives use a value chain approach to link small-scale producers to markets, finance, inputs and equipment services through large-scale commercial farmers.

The evidence presented in this section suggests that the use of mechanisation in many SSA countries is accelerating (although at varying speeds and different patterns), which is possibly coupled with key developments in the agro-climatic, demographic, and economic structure in many African countries. These observations regarding SSA suggest that the dynamics shaping the African landscape are changing at an accelerated pace, which has the potential to create a structural change in the demand for technological innovation, increased input use, and investment in agriculture.

Gaining an understanding of these drivers of tractor use and the implications thereof may help in redefining the role of mechanisation not only in Tanzania, but in the region. It could further guide policy decision-making to promote tractor use and the designing of sustainable policies to such an extent that it would underpin the enabling drivers of increased use. It is crucial to consider the role of mechanisation, which is often referred to as conferring the ability to expand areas under production, and to perform operations on time. Furthermore, the benefits derived from the multi-functional use of tractors, such as transportation, potentially address the shortfall of seasonal labourers and the reduction in drudgery associated with manual labour activities.

2.4.2 Policy Surrounding Mechanisation in SSA

During the 1980s, literature often focused on evaluating interventions by governments in mechanisation services, reaching the consensus that the early push by governments in Africa failed due to lack of economic demand from farmers and the fiscal burden of state-sponsored programmes (Diao et al., 2014 and Diao et al., 2020). Pingali et al. (1988) stated that the planning of project interventions to promote mechanisation is most effectively executed at regional or sub-regional level, rather than at national level.

The most appropriate goal of government interventions is in the identification and alleviation of short-term constraints in the transition from animal power. The transition from animal-draught power to tractorisation occurs rapidly and does not depend on government interventions. The study also found that government-led tractor-hire schemes for primary operations have not been economically viable. Evidence in SSA suggests that the successful development of farm mechanisation has not been dependent on governments' direct involvement in machinery supply and on offering mechanisation hire services (FAO, 2009). Government-managed and operated tractor-rental programmes, which were common throughout the period from 1960 to 1980, were not successful. Efforts directed at developing suitable machinery and implements had little impact on the pace of mechanisation (FAO, 2009). The promoters of structural adjustment in the 1980s predicted that the private sector would get involved in mechanisation, if the correct policies were to be promulgated, and would lead to a success in mechanisation, where the public sector had failed. However, these predictions did not materialise, which may be an indication that appropriate policies surrounding mechanisation that would ensure an enabling and environment conducive to business are not yet in place.

The FAO (2009) has stated that the approach to take towards a successful mechanisation strategy should be perceived within a longer time frame, where emphasis should be placed upon increasing the profitability of investments at primary level. The role of the public sector in providing access to mechanisation should be restricted to promulgating enabling policies, building technical and business management skills, and stimulating demand (Sims & Kienzle, 2016).

According to the World Bank (2012), the Government of Tanzania, prior to the 1980s, was actively involved in importing tractors, managing state farms, implementing tractor-hire schemes, and in the provision of credit to farmer groups to purchase tractors. Due to inadequate management, weak infrastructure, poor equipment maintenance, and difficulty in accessing spare parts, the government's participation in the mechanisation sector was not successful (MAFC, 2011 quoted in FAO, 2013). With the introduction of the structural adjustment programme in the 1980s, government decided to exit direct engagement in mechanisation and instead to provide a conducive environment for private sector actors to operate and distribute tractors. A few public programmes remained, with some focusing on financing tractors. For instance, the Agriculture Inputs Trust Fund (AGITF) has provided loans worth TZS23.3 billion (roughly US$10 million) for the acquisition of 671 tractors. The Tanzanian Investment Bank also focuses on subsidised loans to farmers' cooperatives for the purchase of tractors and power tillers.

In recent years, the government has developed an Agricultural Sector Development Strategy (ASDS) with the aim of achieving sustained growth in agriculture by transforming the sector from subsistence farming to commercial agriculture (World Bank, 2012). The strategy is designed to support private-sector, demand-driven services to small-scale producers. Agricultural mechanisation forms one of the key priorities, with the focus on promoting private-sector investments to erect centres for mechanisation that provide tractors and equipment to smallholder farmers through rental schemes. The strategy also provides financial incentives to the Institute of Rural Technology to design and develop farm tools and machinery that is adopted to Tanzanian farms, and to provide training and demonstrations on the use of new agricultural technologies at district level (World Bank, 2012). More recently, the government directed that a more focused agricultural mechanisation plan should be prepared. Around 2010/11, the Government of Tanzania has waived a portion of the import duty on tractor and power tiller imports plus a duty-free import on spare parts. This was coupled with the provision of credit at competitive interest rates (between 4 to 8%) to farmers and businessman who wanted to buy tractors (Agyei-Holmes, 2014 and 2016).

Other examples of recent government support initiatives include concessional loans and grants that is secured by government (Mrema et al. quoted in Diao et al., 2020). Machinery was made more affordable under the Agricultural Sector Development Strategy through loans. Between 2010 and 2011, a US$40 million concessionary credit obtained from the Indian government was used to import and distribute 1,800 units of four-wheel tractors. In 2015, the Private Agricultural Sector Support Trust was established and the AGITF was revamped. This has facilitated farmers to acquire loans for machinery.

The public sector should prioritise the establishment of enabling environments in order to guide effective mechanisation in sub-Saharan Africa. These environments should focus on providing technical assistance and business advisory services for the private sector that is involved in machinery supply and hiring services. Lessons to be learned from the Chinese experience in supplying mechanisation to smallholder farms include subsidies, extension services, the development of infrastructure, and a solid manufacturing sector that prioritises the smallholder sector (Sims & Kienzle, 2016). For instance, the Chinese government offered a 30% subsidy for the acquisition of agricultural machinery. Other subsidies for inputs further support the smallholder farmer. Extension services are key and include advice on production systems. Consolidation of plots is also encouraged to facilitate mechanisation (Sims & Kienzle, 2016). Excessive transaction and information costs for the provision of mechanisation services need to be absorbed or mitigated. Furthermore, the promotion and facilitation of cross-border collaboration for the movement and provision of mechanisation is essential. Hence, enabling policies and other legal frameworks, such as favourable import duties, which facilitate the ease of doing business and improving logistical factors remain critical for establishing a conducive mechanisation environment. Other factors include training and human resource development, provided through effective extension services, and research and development that promotes solutions at sub-regional level (FAO, 2009). Emphasis is also placed upon the desirability for the banking industry to extend credit lines to farmers.

The promotion of technologies, such as tractors for primary land preparation, should accommodate flexible strategies for promoting a diversity of mechanical technologies that are compatible with local economic, social and development conditions. The foundation of any mechanisation strategy or programme is a sound comprehension of the field situation, which requires close contact with farmers, input and service suppliers, and other stakeholders, such as those in agro-processing.

The role that governments can play in promoting mechanisation services, through improving the policy, legal and regulatory environment, is critical. However, the emphasis in this study is rather placed upon the farm-level enabling drivers that shape the adoption and continuous use of mechanisation services. The results could inform governments on appropriate and sustainable mechanisation strategies, achieved through a broad-based agricultural development approach, by understanding what drives agricultural mechanisation at primary level. Hence, this study’s primary focus is not on policy surrounding mechanisation, but rather on the natural characteristics that could explain the increasing demand for tractors. The findings will be applied in the context of policy recommendations for agricultural mechanisation in sub-Saharan Africa.

2.5 Framework for Demand and Supply of Mechanisation

The theory behind agricultural transformation and the intensification of farming systems, developed by Boserup (1965) and Ruthenberg (1980), suggests that labour-abundant and capital-scarce African countries were not ready for widespread mechanisation during the 1980s and 1990s (Diao et al., 2014). Pingali et al. (1988) investigated the causes of slow adoption, where emphasis was placed on the slow evolution of African farming systems. Their study outlined important evolutionary stages that explain the transition from hand-hoe to animal traction to the use of tractors, where labour-savings technologies and area expansion are key underpinning drivers.

Rising populations and access to markets are the most important determinants of agricultural intensification, defined as the movement from forest- and bush-fallow systems of cultivation to annual and multiple-cropping systems (an increase in the number of cultivation cycles per annum). Rising population density or the amount of land that is available per capita initiates a reduction in fallow periods. Improved market access, achieved through better roads and infrastructure, has a similar positive effect on the intensity of land use, since higher commodity prices and elastic demand for tradeable goods entail a greater marginal reward for effort.

Furthermore, higher reward to labour encourages migration into the area from neighbouring regions where transport costs are higher. The evolution of agricultural intensification, through an increase in population density and improved market conditions, leads to the cultivation of heavier clay soils since these soils offer higher marginal returns through higher and more consistent yields. The absence of investment in water control and drainage means that the cultivation of these types of soils is often more difficult to cultivate. Hence, in the event of population pressure, the preference for one type of land (e.g. lighter soils) over another (e.g. heavier soils) is reversed, which offers higher marginal returns on investments in labour, fertiliser and land.

The next evolutionary stage is that where agricultural intensification leads to an increase in yields. However, in the absence of animal or motorised power, the additional labour requirement typically leads to a decline in yield per man-hour. Hence, in the absence of the plough, the intensification of agricultural systems leads to an increase in employment in agriculture.

When farming intensity rises beyond the forest-fallow stage, both the number and the intensity of farm operations increases. The labour required per unit of output and per unit of land increases at a pace higher than the pace of the increase in the availability of labour. Animal traction is considered a labour-saving resource due to the high requirement of labour per unit of output of hand-hoe cultivation in intensive farming systems. However, under forest- or bush-fallow farming systems associated with low labour requirements, the introduction of animal traction does not improve the welfare of the farmer, which means that the transition from the hand-hoe to animal-drawn plough is only profitable at higher intensities of farming.

The study by Pingali et al. (1988) concluded that the transition from the hand-hoe to animal-draught power is closely linked to the evolution of farming systems. The transition from animal-draught power to tractor power falls within the framework of choice-of-technique analysis. For instance, within a well-developed farming community that utilises animal traction, the advent or introduction of a tractor in the region leads to a choice that the farmer has between animal traction and motorised techniques. That choice will depend on the relative cost of labour and capital, interest rates, utilisation of capacity, size of the farm, availability of fodder, relative maintenance costs of animals and tractors, and availability of spare parts, fuel and repairs services.

In light of the choice-of-technique analysis theoretical framework and the driving forces that underpin agricultural intensification and, consequently, the adoption of technologies to facilitate more intensified farming systems, recent macro-level trends suggest that farming systems are evolving rapidly in many parts of SSA, which may be altering the trends in factor price ratios (labour, capital and land) and increasing the potential for technological innovation (e.g. AGRA, 2016; Richards et al., 2016; United Nations, 2017; Jayne et al., 2016; Jayne et al., 2019). Investments in food production and supply chains have been stimulated due to the region's increasing dependence on imported foods, higher international commodity prices, and the consequent higher regional food prices. Pingali et al. (1988) found that high commodity prices accelerate the pace of intensification and mechanisation, given that they are transmitted to the farm gate. Prices, however, are not a sufficient motivation for technical change, which is influenced by other factors such as the availability of adequate market infrastructure.

The incentives to expand areas under cultivation have stimulated the demand for technologies that facilitate the increase in production (AGRA, 2016; Jayne et al., 2016). Between 2000 and

2006, SSA attained 4.6% inflation-adjusted, annual mean increases in agricultural growth – the highest of any region in the world (World Bank, 2017, quoted in Jayne et al., 2019). The region has also reported an increase of 35% in per capita GDP growth in real terms (Barrett, Christiaensens, Sheahan & Shiferaw, 2017 and Jayne et al., 2019). The transformation of food systems and supply chains has further stimulated off-farm employment opportunities (Tschirley et al., 2015; Yeboah & Jayne, 2016), which has in turn raised the opportunity cost of labour in farming, especially in areas experiencing economic dynamism and growth (Yeboah & Jayne, 2016). Meanwhile, capital costs over the past decade have been at historic lows in Africa, due both to relatively low international borrowing rates over the past 15 years and to significant financial market development in SSA (Andrianaivo & Yartey, 2009; Odongo & Ojah, 2015). Agyei-Holmes (2014) founded that the purchase price of tractors in Tanzania has decreased due to new sourcing areas such as China and India. Previously, more expensive tractors were sourced from the European region or Japan, which limited the off-take from small- and medium-scale farmers due to affordability.

For these reasons, and consistent with the induced innovation hypothesis, mounting evidence is pointing to increased capital-intensive and labour-saving forms of agricultural production being undertaken in at least parts of Africa, including the rising use of herbicides and pesticides (Haggblade et al., 2017); the lower use of labour per hectare cultivated (Jayne et al., 2016); an increasing share of nation-wide cultivated land and agricultural output on medium-scale farms (Jayne et al., 2016; Jayne et al., 2019), and, most relevant for this study, the rising use of mechanisation in agricultural production (Diao et al., 2014 & Mrema, 2016).

Pingali et al. (1988) argued that the development of an agricultural machinery industry, and the economic costs of using tractors instead of human or animal labour, are sensitive to a number of agro-climatic and economic factors, including farm size, the utilisation of land capacity, interest rates, and the relative costs of labour and capital. Their study stated that, within any given area, animal traction is typically being used by large households when tractors are first introduced on larger landholdings. AGRA (2016) and Jayne et al. (2016; 2019) report changes in the distribution of farm sizes, featuring a rapid rise of farmland under medium-scale farms, while Deininger et al. (2011) report a rise in large-scale, often foreign-owned, farms in Africa. The relationship between land size and mechanisation is particularly important in the context that Bishop-Sambrook (quoted in Sims & Kienzle, 2016) explained how farm size is closely correlated with the mode of land preparation.

Because of substantial spatial variations in factor market conditions across the region and even within countries, multiple forms of agricultural intensification in SSA should be anticipated, based on the Hayami-Ruttan induced innovation framework. In the event that larger-scale farmers own and use tractors on their own farms, we might anticipate that tractor owners could rent out tractor services to farms in nearby communities, if the rental costs per hectare are competitive with manual or animal traction-based land preparation. It is also possible that medium-scale farms are attracting investment by input suppliers, including mechanisation rental services, which improve market access conditions for the surrounding smallholder farms. Under such conditions, we might anticipate that smallholder farmers would gain access to cost-cutting land preparation technology, which would simultaneously free up labour for reallocation to higher-return, off-farm activities.

2.6 Conclusions

To summarise, this chapter presented compelling arguments that although the rate of mechanisation adoption remains low in many parts of SSA, there exists evidence that the preconditions for demand growth are slowly emerging which is coupled with increase tractor use. This observation (growth in mechanisation demand) was argued in the context of existing trends or drivers of change that underpin and promote agricultural intensification, as was developed by Boserup, Ruthenburg, Pingali et al. and Hayami and Ruttan. Although there are clear linkages to the aforementioned theories (such as increasing population growth and densities), there still remains several uncertainties on the demand- and supply side of mechanisation. This warrants further investigation that requires much more in-depth- and farm-level analytics to understand the complex mechanisms that underpin the connection between agricultural transformation and mechanisation.

Chapter 3:
Descriptive Statistics: Changing Farm Structures and Tractor Use in Tanzania

3.1 Introduction

The conceptual framework described above has highlighted the likely causes of increased tractor use in SSA due to changes currently observed in the demographic, agro-climatic and economic landscape, which have the potential to promote agricultural intensification and stimulate growth. The macro-level trends represent an aggregated view and are often insufficient to provide evidence of country-specific and intra-regional realities at farm-level. Due to the limited availability of information on tractor utilisation, Chapter 3 analyses farm-level trends over the period from 2008/09 to 2014/15 by using National Panel Survey (NPS) data for Tanzania.

The objective is, firstly, to investigate whether the macro-level trends, such as changing farm structures and increasing utilisation of tractors, can be observed at farm-level. Secondly, to understand the possible dynamics surrounding mechanisation adoption in Tanzania. In particular, land dynamics and trends are investigated to ascertain whether a change has occurred in land sizes and land size distribution, and to determine the associated impact on tractor adoption. The objective was to analyse owned landholding size distribution, cultivated land distribution, tractor ownership, and tractor rental markets at farming household level by considering four land size distribution categories: 0-1.99 hectares, 2-4.99 hectares, 5-9.99 hectares, and agricultural households exceeding 10 hectares. The specific objective was to test whether cultivated farm sizes are increasing, and if so, for which land size categories. Furthermore, an investigation was undertaken as to whether a change has occurred in land size distribution by considering the number of households and hectares in each category over the survey years. Lastly, an attempt was made to understand the co-evolution between land dynamics and tractor use by considering tractor ownership and tractor rental markets at district level (households owning and renting tractors and the cultivated area where tractors were used).

Hypothesis 1 in Chapter 1 stated that, The number and median farm size of medium-scale agricultural households in Tanzania, defined as farms larger than 5 hectares, are increasing with this group increasingly controlling more agricultural land relative to small-scale agricultural households. Hypothesis 2 stated that increased tractor use is observed at farm-level in Tanzania and that it is driven by the development of tractor rental markets, as an alternative to having to own tractors. The increased use is exceedingly correlated with farm size. Hypothesis 1 and Hypothesis 2 (partially) will be formally tested in this chapter.

3.2 Land Dynamics in Tanzania

3.2.1 Total Owned Landholdings Size Distribution in Tanzania (2008/09 to 2014/15)

Table 5 indicates owned landholdings size distribution for the short and long rainy seasons in Tanzania. Table 5 also presents the mean farm size per land size category, total owned hectares, and the number of households owning land for each category for 2008/09, 2010/11, 2012/13 and 2014/15.

The results indicate that, on average, across all categories, the mean owned landholding size increased over the period from 2008/09 to 2012/13 (1.99 to 2.23 hectares), followed by a decrease in the 2014/15 survey year[8], although still higher than for 2008/09. The 0-1.99 hectare land size category accounted for 69.4% of total households, although the owned category only accounted for 26.9% of the total farming area in 2008/09. Towards 2012/13, the share of total households and hectares owned in the 0-1.99-hectare category reported a decrease. The 5-99 and >10 hectare land size categories accounted for only 6.7% of total households, while the controlled category accounted for more than 35% of the total farming area in 2008/09, and indicated an increase to 42.6% in 2014/15.

The total of the owned landholding area category reported an increase from 12.40 million in 2008/09 to 15.04 million hectares in 2012/13. The refreshed survey in 2014/15 indicated that owned landholding hectares had decreased to 11.80 million hectares. A noteworthy trend that

[8] It is important to note that the National Bureau for Statistics in Tanzania had redesigned the sample design for the 2014/15 survey to ensure continuous proper representation of estimates and maintain a sufficient primary sample. It is therefore expected that variation could occur in the 2014/15 survey results, and this does not necessarily entail that trends have shifted. Secondly, the questionnaire in 2014/15 for land ownership details had changed from the 2008/09 to 2012/13 questionnaires, where the 2014/15 description of ownership allowed for more categories, which may cause drastic variations from previous survey years. For instance, for the first 3 waves of survey, land ownership details were limited to 5 categories, whereas in 2014/15, a total of 10 categories described ownership status of farming households.

was observed is the continuous increase in total households owning farm land over the survey period. The number of households owning agricultural land has increased by 1.20 million, which provides confirmation that land ownership is increasing in the region and/or that rural population is increasing, as is indicated by Figure 3. This is particularly true for the 0-1.99 hectare land size category.

The change in mean owned land sizes differed for the respective land size categories. The 5-9.99 hectare category was the only group that reported consecutive increases in average owned land size over the survey years. The mean landholding size for this group increased from 6.76 to 6.95 hectares from 2008/09 to 2014/15, and total landholding area increased by 325 182 hectares over the same period (18% increase).

Table 5: Owned landholdings size distribution in Tanzania: 2008/09, 2010/11, 2012/13 & 2014/15

Total land holdings size distribution		Year				2008-09 Share of		2010-11 Share of		2012-13 Share of		2014-15 Share of	
		2008-09	2010-11	2012-13	2014-15	Hectares	% HHS	Hectares	% HHS	Hectares	% HHS	Hectares	% HHS
0 - 1.99 hectares	Mean size in ha	0.77	0.80	0.73	0.77	26.9%	69.4%	24.7%	66.7%	21.9%	66.7%	26.0%	75.6%
	Total ha	3 128 855	3 522 464	3 289 531	3 062 535								
	Number of HH	4 054 714	4 428 411	4 490 078	5 323 399								
2 - 4.99 hectares	Mean size in ha	3.05	2.99	3.11	2.91	36.8%	23.9%	35.1%	25.2%	34.7%	25.0%	31.4%	18.1%
	Total ha	4 267 312	5 001 946	5 225 611	3 709 356								
	Number of HH	1 397 246	1 673 974	1 681 410	1 273 101								
5 - 9.99 hectares	Mean size in ha	6.76	6.82	6.84	6.95	15.8%	4.7%	18.2%	5.7%	17.9%	5.8%	18.4%	4.4%
	Total ha	1 839 465	2 602 575	2 688 213	2 164 647								
	Number of HH	272 247	381 503	392 734	311 637								
> 10 hectares	Mean size in ha	20.72	19.89	22.55	20.91	20.5%	2.0%	22.0%	2.4%	25.5%	2.5%	24.2%	1.9%
	Total ha	2 375 751	3 137 608	3 842 365	2 859 791								
	Number of HH	114 642	157 749	170 397	136 757								
Total	Mean size in ha	1.99	2.15	2.23	2.07	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
	Total ha	11 611 383	14 264 593	15 045 720	11 796 309								
	Number of HH	5 838 850	6 641 638	6 734 620	7 044 894								

Source: Own calculations using World Bank LSMS online data: Tanzania National Panel Survey, 2008/09, 2010/11, 2012/13 & 2014/15

3.2.2 Cultivated Land Size Distribution in Tanzania (2008/09 to 2014/15)

The results discussed in owned landholding size distribution suggested large variations in land sizes and distribution, from both a mean hectare perspective and a possible shift into larger farm size categories. When a similar analysis was conducted for the amount of cultivated land controlled by the respective groups, the results indicate a dissimilar picture. This suggests that the amount of cultivated land or, differently stated, the amount of hectares in arable production did not follow a similar trend as owned landholdings did. The subsequent analysis will determine whether the amount of medium-scale farmers is in fact increasing, as was suggested in the conceptual framework.

Figure 11 illustrates the cultivated land size distribution per category by reporting the percentage of households located in each group and their respective cultivated areas. In 2008/09, the 5-9.99 and >10 hectare land size categories cultivated 32.1% of total land, but only accounted for 5.5% of total households. By 2014/15, these groups controlled more than 40% of the total cultivated land and comprised 7.2% of total households. Farms in the 0-1.99 and 2-4.99 hectare categories experienced a decline in the share of national cultivated hectares over the period. The largest increase in area cultivated since 2008/09 occurred in the >10 hectare group (+76%) and the 5-9.99 hectare category (+54%). In absolute terms, the two groups cultivated over 2.3 million hectares more in 2014/15 than in 2008/09. The mean farm size for the 5-9.99 hectare group increased from 6.60 hectares in 2008/09 to 6.91 hectares in 2014/15, being the only group to have experienced consecutive increases over the period. Farm sizes in the 0-1.99 hectare category remained relatively constant.

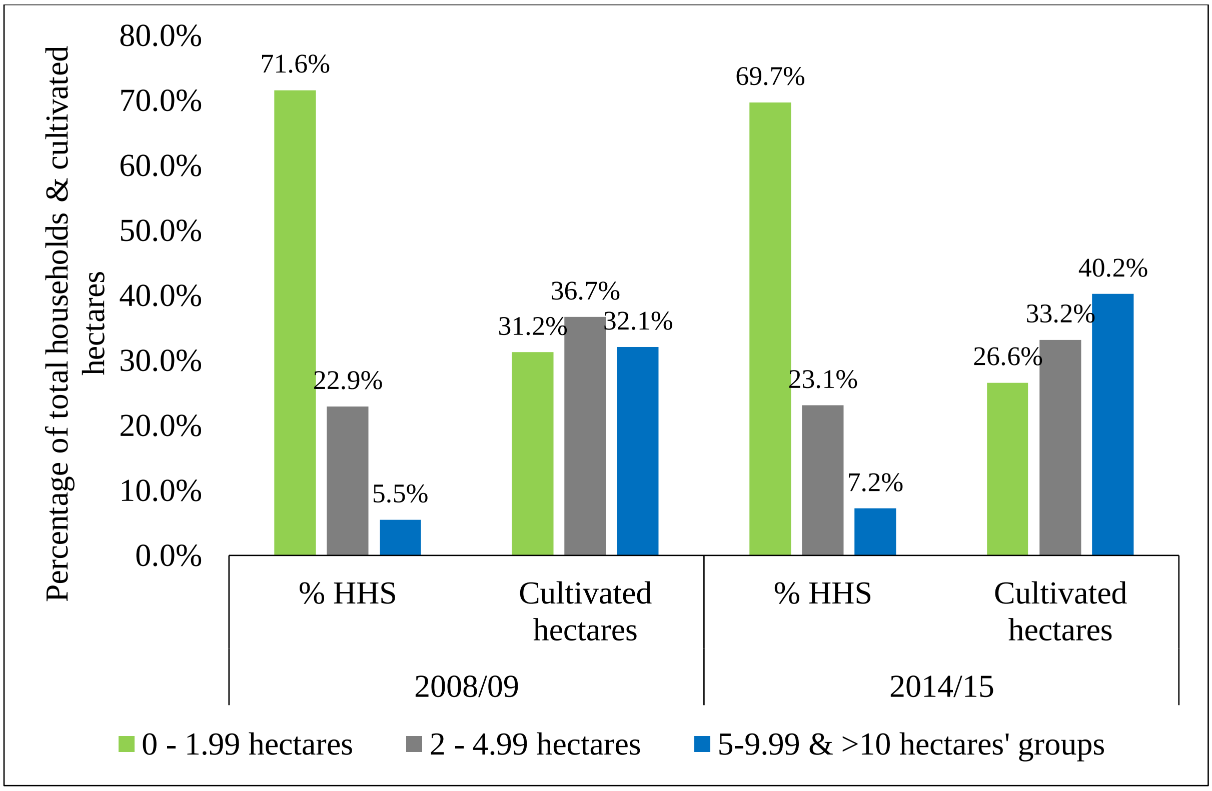

Figure 11: Cultivated land in Tanzania: % of households and cultivated hectares per land size category
Source: Own calculations using World Bank LSMS online data: Tanzania National Panel Survey, 2008/09 & 2014/15

Table 6 provides a more detailed overview of the cultivated land dynamics in Tanzania. According to the results, the amount of cultivated hectares consistently increased over the survey period, with a substantial increase in the refreshed panel in 2014/15, likely because of a change in the survey design. In 2008/09, a total of 10.89 million hectares were cultivated. Regarding the 2012/13 survey, an increase of 1.68 million hectares in cultivated area was reported. In 2014/15, the cultivated area increased by 1.88 million hectares from the 2012/13 survey wave. The difference between owned and cultivated areas suggests that a large amount of agricultural households had borrowed land, rented in land, made use of land that was allocated from village councils, or used other land acquisition methods.

Table 6: Cultivated land size distribution in Tanzania: 2008/09, 2010/11, 2012/13 & 2014/15

Total cultivated land size distribution		Year				2008-09 Share of		2010-11 Share of		2012-13 Share of		2014-15 Share of	
		2008-09	2010-11	2012-13	2014-15	Hectares	% HHS	Hectares	% HHS	Hectares	% HHS	Hectares	% HHS
0 - 1.99 hectares	Mean size in ha	0.81	0.76	0.75	0.81	31.2%	71.6%	31.6%	72.4%	28.1%	70.4%	26.6%	69.7%
	Total ha	3 402 114	3 665 811	3 534 554	3 843 276								
	Number of HH	4 180 617	4 811 493	4 740 090	4 910 405								
2 - 4.99 hectares	Mean size in ha	2.99	2.90	3.03	2.95	36.7%	22.9%	35.8%	21.5%	38.6%	23.8%	33.2%	23.1%
	Total ha	3 994 263	4 154 975	4 855 812	4 792 787								
	Number of HH	1 337 783	1 431 048	1 601 701	1 626 474								
5 - 9.99 hectares	Mean size in ha	6.60	6.50	6.75	6.91	14.3%	4.0%	16.4%	4.4%	15.0%	4.1%	16.6%	4.9%
	Total ha	1 559 598	1 900 669	1 884 667	2 402 153								
	Number of HH	236 252	292 415	279 037	347 822								
> 10 hectares	Mean size in ha	22.94	17.84	20.16	21.28	17.7%	1.5%	16.3%	1.6%	18.3%	1.7%	23.6%	2.3%
	Total ha	1 931 528	1 894 113	2 294 254	3 408 366								
	Number of HH	84 197	106 168	113 792	160 193								
Total	Mean size in ha	1.86	1.75	1.87	2.10	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
	Total ha	10 887 503	11 615 569	12 569 288	14 446 583								
	Number of HH	5 838 850	6 641 124	6 734 620	7 044 894								

Source: Own calculations using World Bank LSMS online data: Tanzania National Panel Survey, 2008/09, 2010/11, 2012/13 & 2014/15

A noteworthy trend to mention is the continuous increase in the number of households engaging in arable production. Over the period since 2008/09, the total household participation increased by 1.2 million households, or an increase of 20.6%. The uncertainty prevails, however, whether the increase was attributable to agricultural intensification and growth, or to rising rural populations (Figure 3). Furthermore, the differences between the amount of households owning land and the amount of households who cultivated land (Table 5 and Table 6) for 2008/09, 2010/11 and 2012/13 suggest that the three larger land size groups owned more land than what they had cultivated. The opposite is true for the 0-1.99 hectare group, which cultivated more land than what they owned.

The 2-4.99 hectare group reported an increase in both the number of households located in this category and the amount of hectares cultivated. The total number of households increased by 288 691 over the period, with the households cultivating nearly 800 000 hectares more than recorded for the 2008/09 survey. The share of this group to total households indicated a sideways movement over the period; however, the total area controlled decreased from 36.7% in 2008/09 to 33.2% in 2014/15. Over the period, the mean size cultivated remained constant, at 2.97 hectares.

Interesting to note is that the >10 hectare land size category reported a decrease in the mean size, from 30.90 hectares in 2008/09 to 17.84 hectares in 2010/11, which might suggest that larger-scale farmers responded quicker to market developments, in this case, a period where lower prices were observed. According to own calculations using ReNAPRI (2017) commodity balance sheet data, the average domestic maize price reported an increase of 70% from 2007 to 2008, a consecutive increase of 23% to 2009, and a decline of 19% towards 2010.

Figure 12 illustrates the regional changes in area and households over the period from 2008/09 to 2014/15. The red triangles show the absolute change in area for the 5-9.99 and >10 hectare land size categories. The largest changes in area were observed in Singida, Mbeya, Tabora, Arusha and Mtwara. According to the results, Singida cultivated nearly 550 000 hectares more than in the 2008/09 survey period. This change was mainly driven by an increase in the >5 hectare producers. Over the same period, the total amount of households who cultivated land increased by 63 628 since 2008/09. The Kagera and Dar es Salaam regions reported the largest increases in households who cultivated agricultural land. There was also a firm increase for households located in the 5-9.99 hectare group in the urban region of Dar es Salaam. In the

2008/09 survey, no households were reported in the 5-9.99 hectare group, whereas an increase of 4 469 households was indicated towards 2014/15, with them cultivating 37 106 hectares or an average of 8.30 hectares. This trend is likely attributable to urban elites from urban areas who engage in agricultural activities in neighbouring agricultural land.

The largest decreases in area were observed in Shinyanga, Pwani and Mwanza, which cultivated roughly 1.9 million hectares less than in 2008/09. Interesting to note is that the decrease was largely because of the >5 hectare producers cultivating fewer hectares of land. Furthermore, the total number of households who positively responded in cultivating land decreased by 180 765 and 63 756 in Shinyanga and Mwanza, respectively, whereas in Pwani, the number of households increased by 33 774 from 2008/09. The results further indicate that in regions like Iringa, Rukwa and Mara, fewer households cultivated land than in 2008/09. Lastly, in Arusha, a significant increase occurred in the number of households located in the >10 hectare category. By 2014/15, total households increased by 8 568, who cultivated 239 426 hectares, at an average of 27.95 hectares per household.

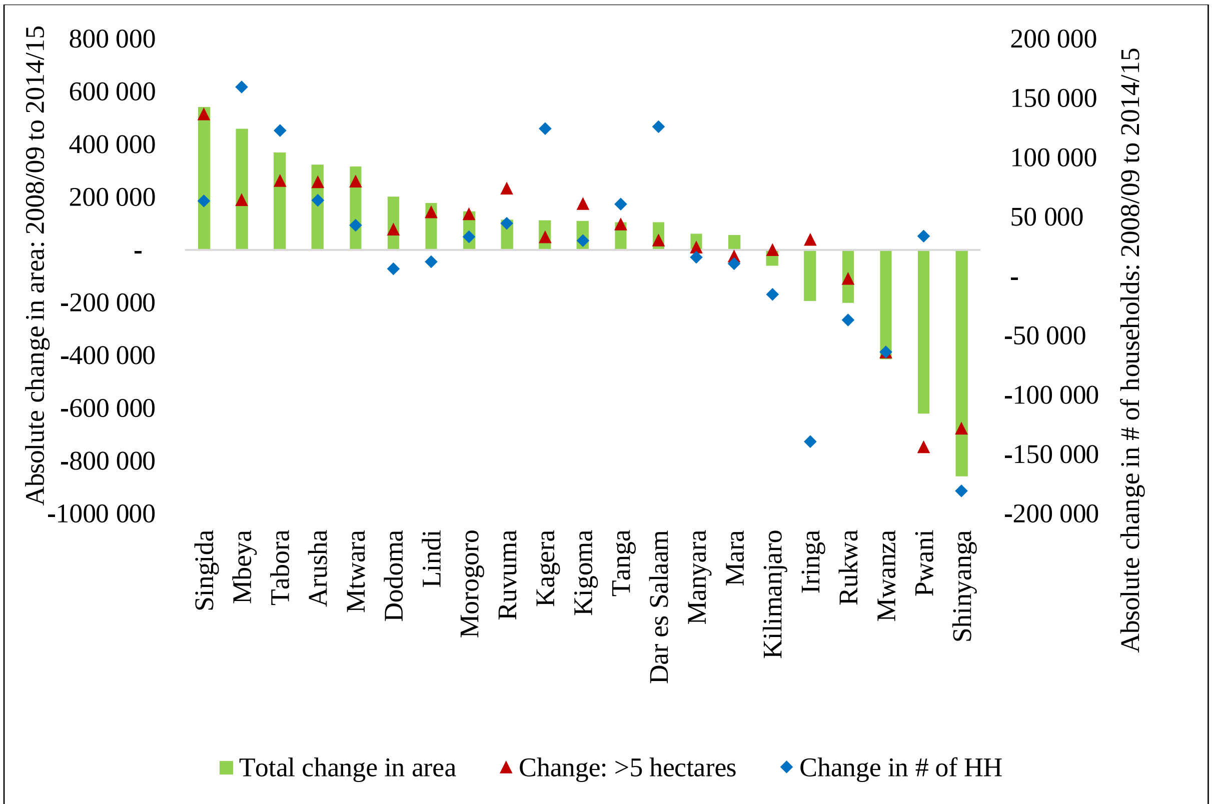

Figure 12: Regional cultivated land trends in Tanzania: Change in hectares & households: 2008/09 to 2014/15
Source: Own calculations using World Bank LSMS online data: Tanzania National Panel Survey, 2008/09, 2010/11, 2012/13 & 2014/15

Hypothesis 1 as defined in Chapter 1 states that, The number and median farm size of medium-scale agricultural households in Tanzania, defined as farms larger than 5 hectares, are increasing with this group increasingly controlling more agricultural land relative to small-scale agricultural households. The descriptive statistics on land dynamics in Tanzania provided evidence that mean farm sizes in the 5-9.99 and larger than 10 hectares land size groups had increased over the period from 2008/09 to 2014/14. There is also evidence that the number of households located in these land size groups and the areas under cultivation by them indicated an increase over the same period. Hypothesis 1 can therefore be accepted. The reason why this evolution is important is the potential link between larger farm sizes and tractor use, which will be formally investigated in the subsequent section and Chapter 4.

3.3 Mechanisation Use in Tanzania

Figure 7 and Figure 8 in Chapter 2, which report the importation value of tractors in the SSA region, suggest that SSA countries are increasingly making use of mechanisation, either through own tractor acquisition or through tractor rental markets. To date, there is limited evidence available on the determinants that drive increased tractor use at primary level. In particular, uncertainty exists whether tractor use at farm-level corresponds with the observation that tractor use at the country level is increasing. If a positive correlation exists between what is observed at national- and farm-levels, the questions then arise as who the tractor adopters and continuous users are and what the driving forces are that define the increased uptake of mechanisation. Further question arise whether it is possible that medium-scale farms have a positive spill-over effect on the adoption of tractors by neighbouring small-scale producers, and whether increased tractor utilisation is visible through the use of own tractors or through the development of tractor rental markets.

Mrema (2016) conducted research on tractor users in Tanzania through field visits and found that the national tractor fleet is mainly concentrated in six regions, namely Morogoro, Arusha, Kilimanjaro, Manyara, Dodoma and Shinyanga. This concentration would seem to point to service providers who invest in their own machinery for their own cultivation needs and for the provision of tractor rental services. These regions are also the main food baskets in Tanzania and centres for the cultivation of other cash crops such as tobacco and sugar. Through interviews, it was found that tractor-hire businesses operated at a national level in pursuit of business by following rainfall isohyets and land preparation seasons, often dominated in crops like rice, maize, tobacco and sugarcane. Mrema (2016) suggested that an in-depth impact study should be undertaken to determine the extent to which this pan-territorial use of tractors occurs.

This section builds on Mrema (2016) and attempts to address and validate some of the uncertainties by using survey data on agricultural household assets in Tanzania to determine whether increasing tractor use is observable among agricultural households. Secondly, if tractor use is in fact increasing, the objective is to understand the degree to which the use reflects use by owners only, or whether the development of tractor rental markets is occurring. A key objective is to understand the co-evolution between larger farm sizes, with changing land size distributions, and tractor adoption and use. Hence, it was investigated whether a rise in larger-scale farms in a region has promoted the development of tractor rental markets that are utilised by neighbouring farmers and/or smallholder farmers. The results will provide clarity on the potential role that larger-scale farms can play in promoting a movement towards increased capital-intensive forms of farming, not only on large farms but also on smallholder farms as well. The substitution of capital for family labour on smallholder farms may release labour from farming to other non-farm activities that provide higher returns to labour. It is also possible that large-scale farms may contribute to the diversification of income sources off the farm and stimulate sources of labour productivity growth for rural households. More broadly, the importance of mechanisation and its ability to accelerate the transformation process in agriculture cannot be emphasised enough. It remains a key production input, not only limited to crop production, but also along the value chain (Sims & Kienzle, 2016). The potential for mechanisation along the value chain includes transforming the production side through efficiency in crop establishment, fertilisation, weeding and crop protection, irrigation, and harvesting. It also has the potential to transform post-harvest treatment, storage, processing (chopping, milling, grinding and pressing operations) and marketing through transportation.

Figure 13 illustrates tractor use in Tanzania over the period from 2008/09 to 2014/15, and represents the number of farming households utilising tractors and the hectares of cultivated area where tractors were likely utilised. The secondary axis reports the percentage of small-scale households using tractor rental services. The graph indicates that the number of households who made use of tractors increased by 201% over the period from 2008/09 to 2014/15 (an increase of 327 320 farm households). Over the period, the tractor use to non-tractor use ratio for the number of households increased from 2.9% in 2008/09 to 7.5% in 2014/15. The hectares of cultivated area where a tractor was used (on the entire field or only a fraction of it[9]) reflected an increase of 546,578 (+74%) hectares. The decrease from 2008/09 to 2010/11 was mainly limited to the >10 hectare group, where three regions, namely Pwani, Shinyanga and Mwanza, reported a total decrease of 1 271 398 hectares in cultivated area (Figure 12). The increase in tractor use was driven mainly by the development of tractor rental markets and not through the use of the farm's own tractor. The results also indicate that tractor use was not confined to larger-scale producers, and included use on small-scale farms as well. The percentage of small-scale agricultural households who made use of tractor rental services increased from 2.7% in 2008/09 to 6.9% in 2014/15.

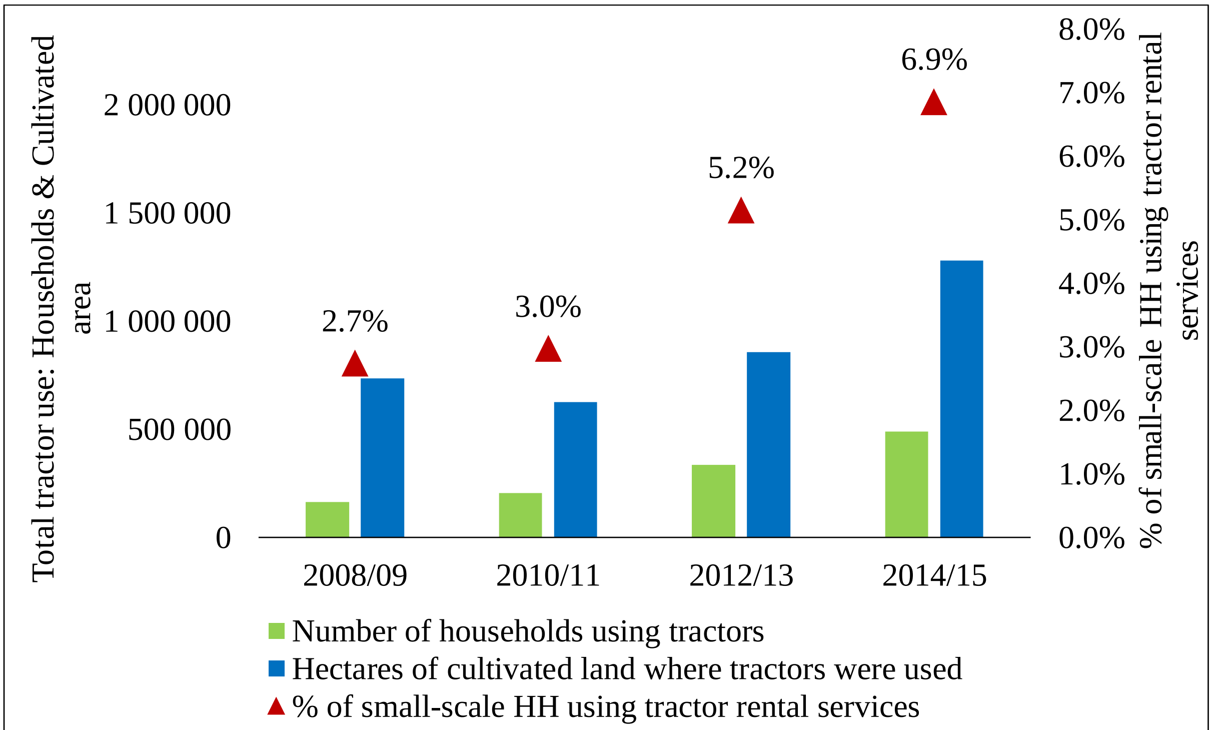

Figure 13: Total own & rented tractor use in Tanzania: # of households & cultivated hectares: 2008/09, 2010/11, 2012/13 & 2014/15

Source: Own calculations using World Bank LSMS online data: Tanzania National Panel Survey, 2008/09, 2010/11, 2012/13 & 2014/15

Figure 14 and Figure 15 illustrate rented tractor use in Tanzania among land size categories over the period from 2008/09 to 2014/15. Figure 14 indicates the percentages of households in a particular land size category who rented tractor services, while Figure 15 illustrates the percentage of cultivated area where a tractor was likely used. According to Mrema (2016), the total area cultivated where a tractor was used amounted to 14% in the period then under study.

[9] The survey questionnaire only requested the respondent to provide a binary response whether a tractor was used or not, and did not specify the amount of hectares where a tractor was used. Hence, it is uncertain whether the total area was cultivated using a tractor, either own or rented.

If one relates this back to the cultivated area analysis presented in Table 6, the average hectare area cultivated by using a tractor over the survey periods amounts to 1.73 million hectares. The first conclusion from the household tractor use share is that for all land size categories, although at a slow pace, a rising trend existed in the number of households positively responding regarding using a rented tractor over the period from 2008/09 to 2014/15. Hence, increasing tractor use among land size groups is not limited to larger-scale producers. The substantial spike in the 2014/15 period is likely due to the outcome of the refreshed survey that included a different sample to the previous three waves of surveys. Hence, it is likely that the latest results accounted for a correction in the number of tractor users.

It is evident from the graph that the number of households using tractors increased for all land size groups. Hence, increasing tractor use among land size groups is not limited to relatively large farms only, although use rates are indeed positively correlated with farm size category. This is mainly true when the 0-1.99 hectare group is compared with the larger groups that show a larger percentage of rented tractor use, in both household frequency and cultivated area in larger farm size categories.

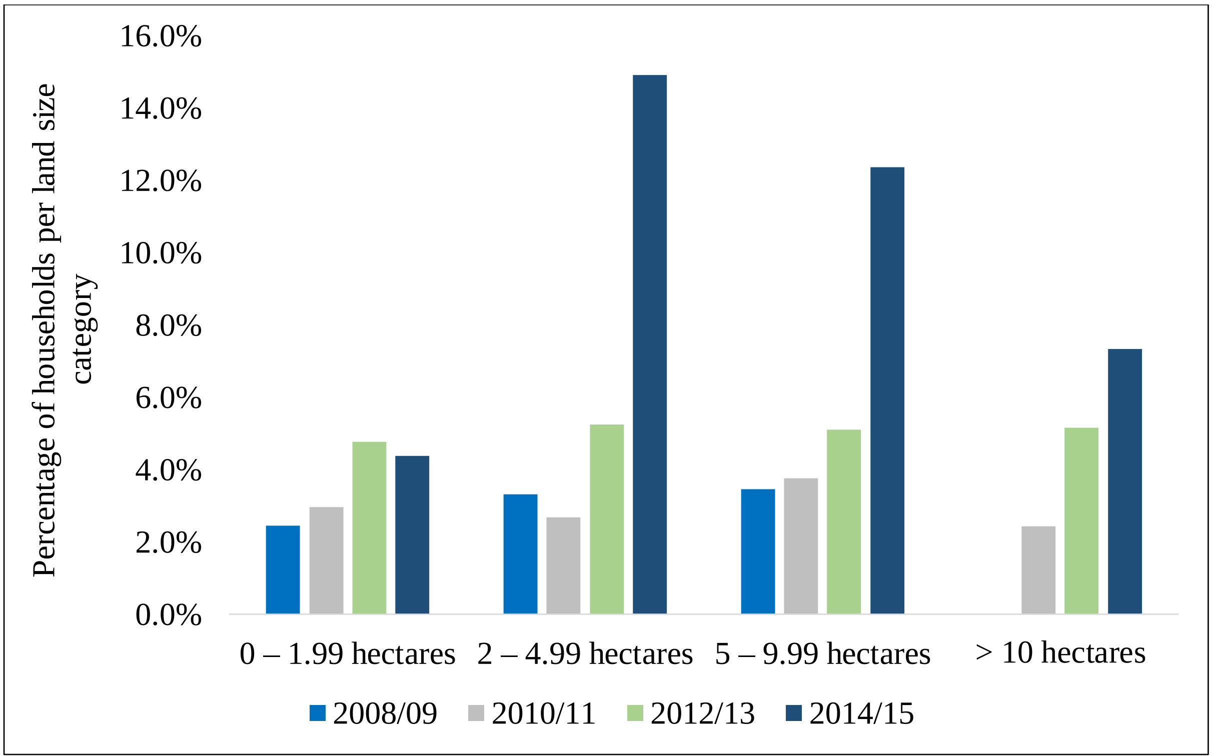

Figure 14: Percentage of households renting tractor services by operated farm size category – 2008/09, 2010/11, 2012/13 & 2014/15

Source: Own calculations using World Bank LSMS online data: Tanzania National Panel Survey, 2008/09, 2010/11, 2012/13 & 2014/15

Interesting to note, when observing the 2014/15 results, is that the 0-1.99 hectare group remained relatively constant, whereas for larger land size groups, a substantial correction was made. For instance, the 2-4.99 hectare group reflected a change from 5.3% of total households in 2012/13 to 14.9% in 2014/15 who positively responded to using a rented tractor. The same is true for the 5-9.99 and >10 hectare groups, although to a smaller extent. Figure 15 further illustrates the co-evolution of land sizes and tractor use. When excluding the 2014/15 results, the percentage of cultivated area where a tractor was used marginally increases as land size increases. This is particularly true for the 2-4.99 and 5-9.99 hectare groups. Through applying Mrema's (2016) findings regarding average tractor use equalling 14% of cultivated land in Tanzania, the results obtained in this study may undervalue the total area where a tractor was used among household categories.

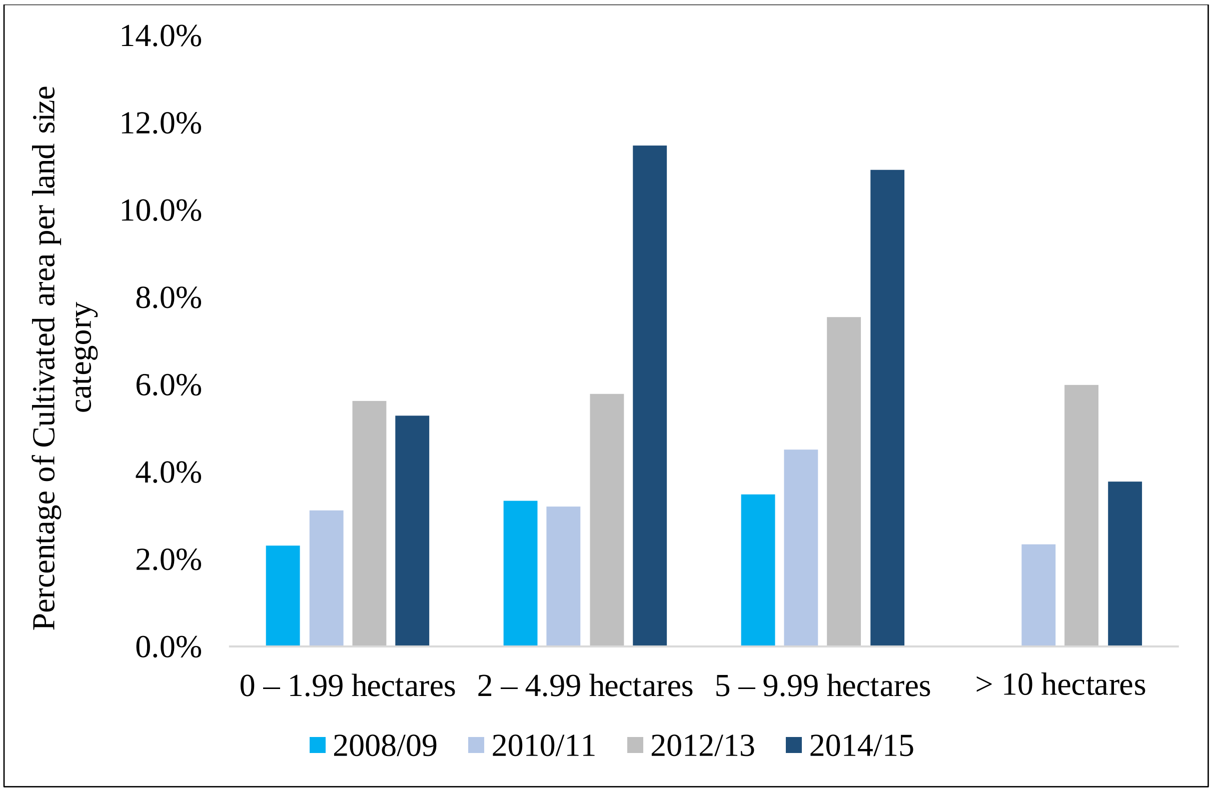

Figure 15: Percentage of cultivated area using rented tractor services by operated farm size category – 2008/09, 2010/11, 2012/13 & 2014/15

Source: Own calculations using World Bank LSMS online data: Tanzania National Panel Survey, 2008/09, 2010/11, 2012/13 & 2014/15

Table 7: Household rented tractor use and change over time (%): 2008/09 – 2014/15

Cultivated Land Size Category	% Change in number of households using tractors			
	2008/09 - 2010/11	**2010/11 - 2012/13**	**2012/13 - 2014/15**	**2008/09 - 2014/15**
0 – 1.99 hectares	32%	64%	9%	135%
2 – 4.99 hectares	-3%	97%	115%	309%
5 – 9.99 hectares	52%	40%	92%	309%
> 10 hectares	No rentals in 2008/09	128%	14%	161% change from 2010/11 to 2014/15

Source: Own calculations using World Bank LSMS online data: Tanzania National Panel Survey, 2008/09 & 2014/15

Table 7 summarises the percentage changes in the number of households renting tractors over the period from 2008/09 to 2014/15. The largest percentage change occurred in the 2-4.99 and 5-9.99 hectare land size categories, with a percentage change exceeding 300% since 2008/09. However, the 0-1.99 and >10 hectare groups also reported remarkable growth in rented tractor use. Hence, the adoption of rented tractor use over the period was the highest for larger land size categories, further supporting the argument that tractor use is coupled with land sizes.

Table 8 summarises tractor use trends (separating own use vs. rented) for the farm size categories over the period from 2008/09 to 2014/15. Farms smaller than two hectares had the lowest tractor use over the period. However, an increasing trend was still observed from 2008/09 to 2014/15, both in the percentage of farmers using tractors and in the proportion of cultivated area using a tractor. A substantial increase in tractor use is shown for the 2-4.99 hectare group. By 2014/15, an additional 150 000 households reported using a tractor. The proportion of cultivated hectares worked by a tractor among this group increased by 422 397 hectares (11.7% of total cultivated area). By 2014/15, 15.3% of households located in this group positively responded to making use of a tractor, an increase of nearly 12% from 2008/09. The land dynamics analysis has reported an increase of 840 000 hectares being cultivated by the 5-9.99 hectare land size group since 2008/09. Tractor use among households located in this group reflected a similar increasing trend. By 2014/15, 38 541 households responded positively to using a tractor, being 6.17% of total households located in this group. The 5-9.99 hectare group was also the only category reflecting consecutive growth over the survey periods, for both households using tractors and area cultivated. As can be expected, the >10 hectare land size group reflected the highest tractor use among all land size categories. By 2014/15, 13.8% of households responded positively to using a tractor.

Table 8: Tractor use in Tanzania: Percentage of households and cultivated area per land size category using rented or owned tractors (2008/09 – 2014/15)

Total area cultivated (all crops)	Contribution type	2008/09			2010/11			2012/13			2014/15		
		Renting tractors	Using own tractors	Total tractor users	Renting tractors	Using own tractors	Total tractor users	Renting tractors	Using own tractors	Total tractor users	Renting tractors	Using own tractors	Total tractor users
0 – 1.99 hectares	% of HH	2.4%	0.1%	2.5%	3.0%	0.2%	3.1%	4.8%	0.0%	4.8%	4.4%	0.1%	4.5%
	% of cultivated area	2.3%	0.1%	2.4%	3.1%	0.2%	3.3%	5.6%	0.0%	5.7%	5.3%	0.0%	5.3%
2 – 4.99 hectares	% of HH	3.3%	0.1%	3.5%	2.7%	0.1%	2.8%	5.3%	0.1%	5.3%	14.9%	0.4%	15.3%
	% of cultivated area	3.3%	0.2%	3.5%	3.2%	0.1%	3.3%	5.8%	0.1%	5.9%	11.5%	0.3%	11.7%
5 – 9.99 hectares	% of HH	3.5%	0.0%	3.5%	3.8%	0.0%	3.8%	5.1%	0.0%	5.1%	12.4%	0.0%	12.4%
	% of cultivated area	3.5%	0.0%	3.5%	4.5%	0.0%	4.5%	7.5%	0.0%	7.5%	10.9%	0.0%	10.9%
> 10 hectares	% of HH	0.0%	3.3%	3.3	2.4%	1.8%	4.2%	5.2%	1.2%	6.4%	7.3%	6.4%	13.8%
	% of cultivated area	0.0%	23.8%	23.8%	2.3%	12.5%	14.9%	6.0%	3.9%	9.9%	3.8%	3.6%	7.4%
Total	% of HH	2.7%	0.1%	2.8%	2.9%	0.2%	3.1%	4.9%	0.1%	5.0%	6.7%	0.3%	7.0%
	% of cultivated area	2.4%	4.3%	6.7%	3.3%	2.1%	5.4%	6.0%	0.8%	6.8%	7.9%	0.9%	8.9%

Source: Own calculations using World Bank LSMS online data: Tanzania National Panel Survey, 2008/09, 2010/11, 2012/13 & 2014/15

The key conclusions from the results can be summarised as follows:

1) Land size category: 0-1.99 hectares

The 0-1.99 hectare land size category represented the lowest tractor use (in comparison with the larger land size groups) over the period, with an average of 3.72% of households located in this group positively responding to using a tractor. However, an increasing trend did occur from 2008/09 to 2012/13 in both the number of households using tractors and cultivated area where a tractor was used, mainly driven by the use of rental tractors. In 2014/15, the number of households using tractors averaged at 4.5%, marginally lower than in the 2012/13 survey year. For the same period, the category's total cultivated area where a tractor was used averaged at 5.3%, also marginally lower than in 2012/13. As stated above, the 0-1.99 hectare group did not follow a similar correction in tractor use as was observed in the larger than 2 hectare groups. These results and, more importantly, the trend in tractor use could suggest that manual labour is still predominantly utilised for agricultural operations such as land preparation.

2) Land size category: 2-4.99 hectares

A substantial increase in tractor use for the 2-4.99 hectare group was reported both in the number of households and in total cultivated area. By 2014/15, an additional 150 000 households positively responded to using a tractor, totalling 195 255 households. The amount of cultivated hectares where a tractor was used had increased by 422 397 hectares (11.7% of total cultivated area). By 2014/15, 15.3% of households located in this group positively responded to making use of a tractor, an increase of nearly 12% from 2008/09.

3) Land size category: 5-9.99 hectares

From the cultivated land distribution analysis, it is seen that a rapid increase occurred for hectares cultivated by the 5-9.99 hectare land size category. By 2014/15, cultivated area had increased by more than 840 000 hectares from 2008/09. Tractor use among households located in this group reflected a similar trend. Although from a small base, tractor use reported an increase exceeding 300% over the period. In 2014/15, 38 541 households responded positively to using a tractor, comprising 6.17% of total households within this group. The 5-9.99 hectare group was also the only category that reflected consecutive growth over the survey periods, both for households using tractors and for area cultivated. In 2008/09, 3.8% of households located in this group made use of tractors and, towards 2014/15, the share had increased to 12.4%. The share in cultivated area increased from 3.5% in 2008/09 to 10.9% in 2014/15.

4) Land size category: >10 hectares

Over the period, the >10 hectare land size group indicated the highest tractor use among all land size categories, averaging at 7.56% of households located in this group. By 2014/15, 13.8% of households responded positively to using a tractor, an increase of 7.9% from 2008/09. The refreshed panel in 2014/15 reported an increase in tractor use of nearly 12 000 households from 2008/09 (nearly 8 000 households more from 2012/13).

The land size analysis flagged a substantial decrease in cultivated area over the period from 2008/09 to 2010/11. Over this period, cultivated area decreased by 804 023 hectares, with decreases being mainly observed in Pwani, Shinyanga and Mwanza. The percentage share of cultivated area where a tractor was used, for the >10 hectare group, reflects a similar variation, with a decrease from 45.4% in 2008/09 to 14.9% in 2010/11. The decreasing trend continued towards the 2014/15 survey period, with less area being cultivated in each survey period (percentage share). By 2014/15, only 7.4% of total area within this group was cultivated using a tractor, being 7.5% lower than in the 2010/11 survey. It is key to note that the total area cultivated, regardless of whether a tractor was used or not, had increased by more than 700 000 hectares over the survey periods. Given this increase, it was expected that tractor use would reflect a positive trend.

Figure 16 and Figure 17 illustrate regional tractor use. The blue dots in Figure 16 represent the positive response of households in the sample who had rented a tractor over the years. It is clearly visible from the map that rentals are concentrated mainly along the northern and eastern parts of mainland Tanzania. The map further suggests a regional spill-over, when considering rental over the years with high rental regions, which likely influenced neighbouring regions positively.

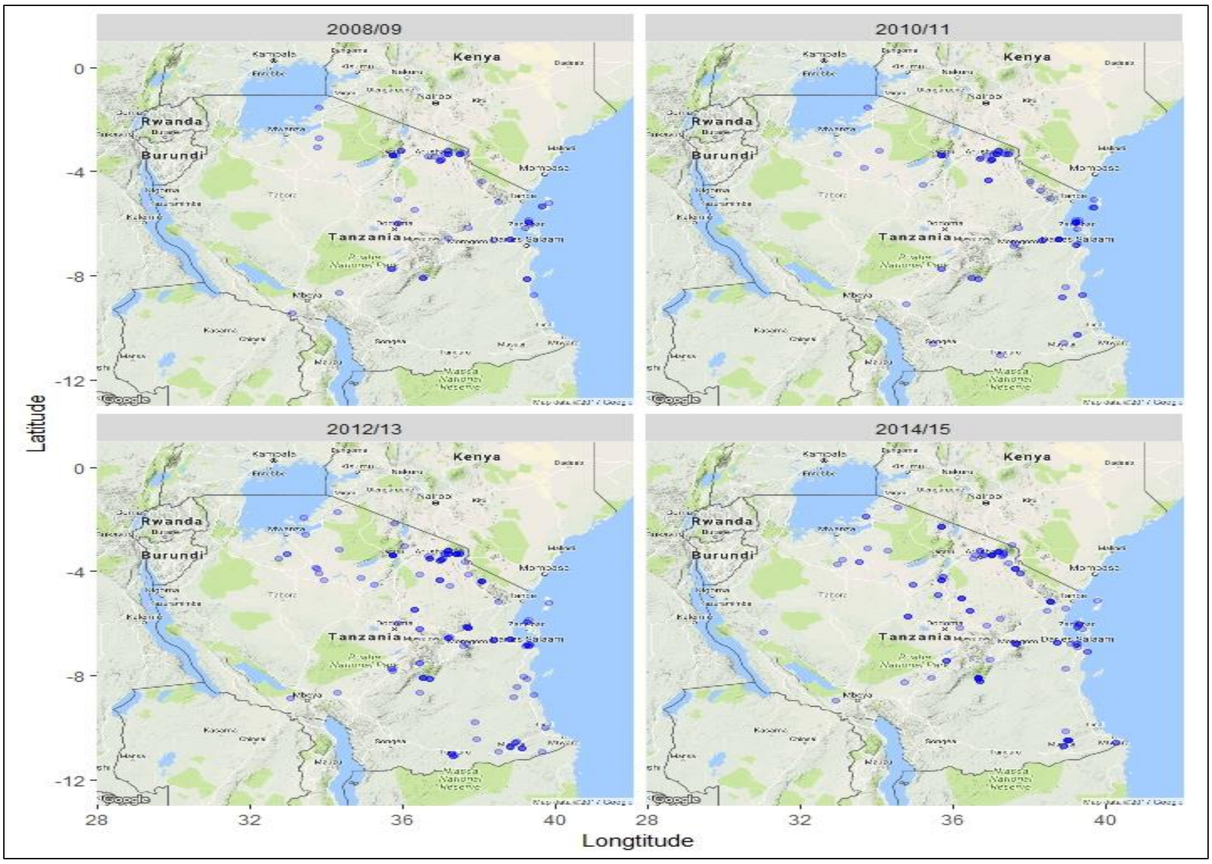

Figure 16: Regional tractor rental use in Tanzania: Sample results over years
Source: Own calculations using World Bank LSMS online data: Tanzania National Panel Survey, 2008/09, 2010/11, 2012/13 & 2014/15

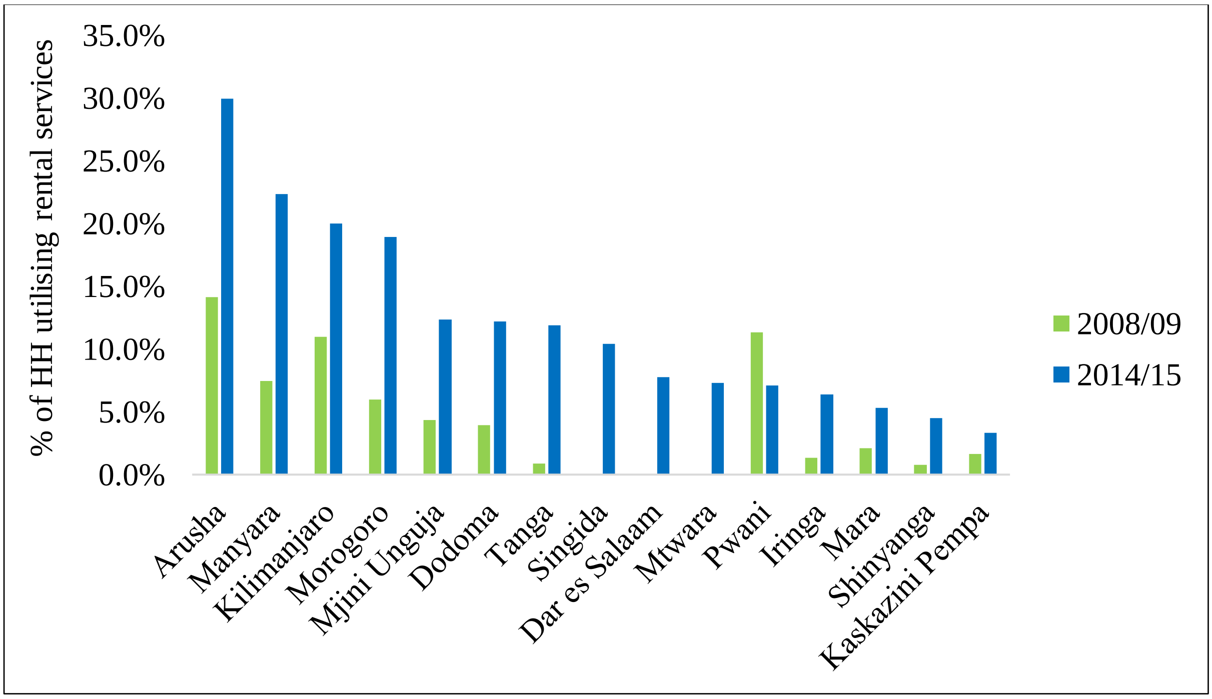

Figure 17: Regional tractor rental use in Tanzania: Percentage of households per region: 2008/09 & 2014/15
Source: Own calculations using World Bank LSMS online data: Tanzania National Panel Survey, 2008/09 & 2014/15

Figure 17 represents the percentage share of households in a region who had made use of tractor rental services[10]. Arusha and Manyara regions had the highest household participation in tractor rental markets. In 2014/15, approximately 30% of households cultivating agricultural land in Arusha, and 22.4% in Manyara, reported rented a tractor, being a 15% increase in Arusha alone since 2008/09. Kilimanjaro and Morogoro also reported shares of 20% and 19%, respectively. Arusha reported a substantial increase in the amount of farmers located in the >10 hectare group since 2008/09. By 2014/15, an additional 8 568 households had entered this group, which has cultivated nearly 240 000 hectares of agricultural land. The same trend was observed for Manyara, which reported an increase of 2 364 households in the >10 hectare group that had cultivated 67 642 hectares in 2014/15. Interesting to note is that, despite the high share of households making use of rented tractors in Kilimanjaro, the sample suggested that there were no households located in the 5-9.99 and >10 hectare groups in 2014/15. When observing the weighted results of rentals per region, it can be concluded that Morogoro (15.47%), Arusha (15.46%), Kilimanjaro (12.02%) and Dodoma (10.23%) are the regions with the highest participations in tractor rental markets.

In an approach to validate the regional participation in tractor rental markets, Figure 18 and Figure 19 provide the fieldwork results obtained from existing literature that illustrate the number of tractors, power tillers, and implements by region (Mrema, 2016). These findings are in line with the results presented in Figure 17, which shows that Arusha, Morogoro, Kilimanjaro and Manyara are highly mechanised regions. The mix of implements further suggests that these regions are highly commercialised, using a combination of ploughs, harrows, trailers, planters and weeders.

The results firstly validate the point that increasing tractor use in Tanzania is observed among farming households in Tanzania. The increase in the number of households making use of tractors is not limited to larger-scale producers, and is also observed among small-scale agricultural households. While observing the respective tractor usages among land size categories, evidence is seen that land size is coupled with tractor use.

[10] The rental share per region represents the unweighted sample results for households who positively responded to renting a tractor.

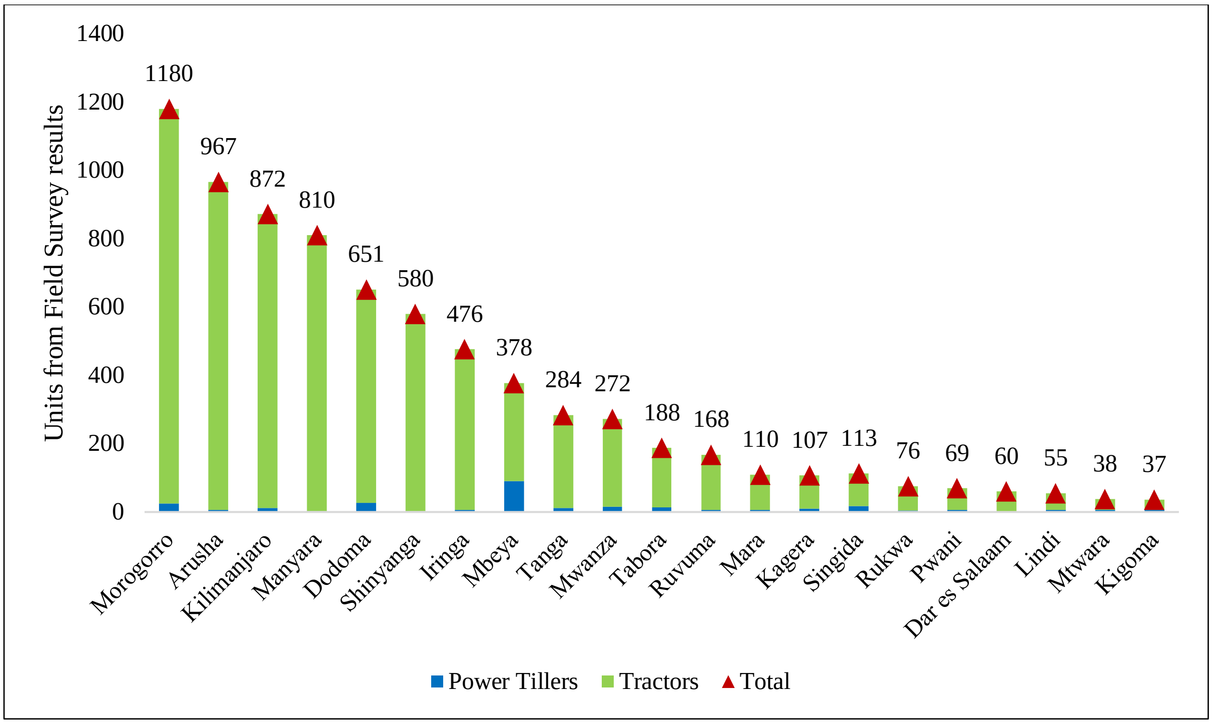

Figure 18: Tanzania - Number of tractors & power tillers by region: 2005

Source: Field survey results & DALDOs reports of TAMS quoted in Mrema, 2016

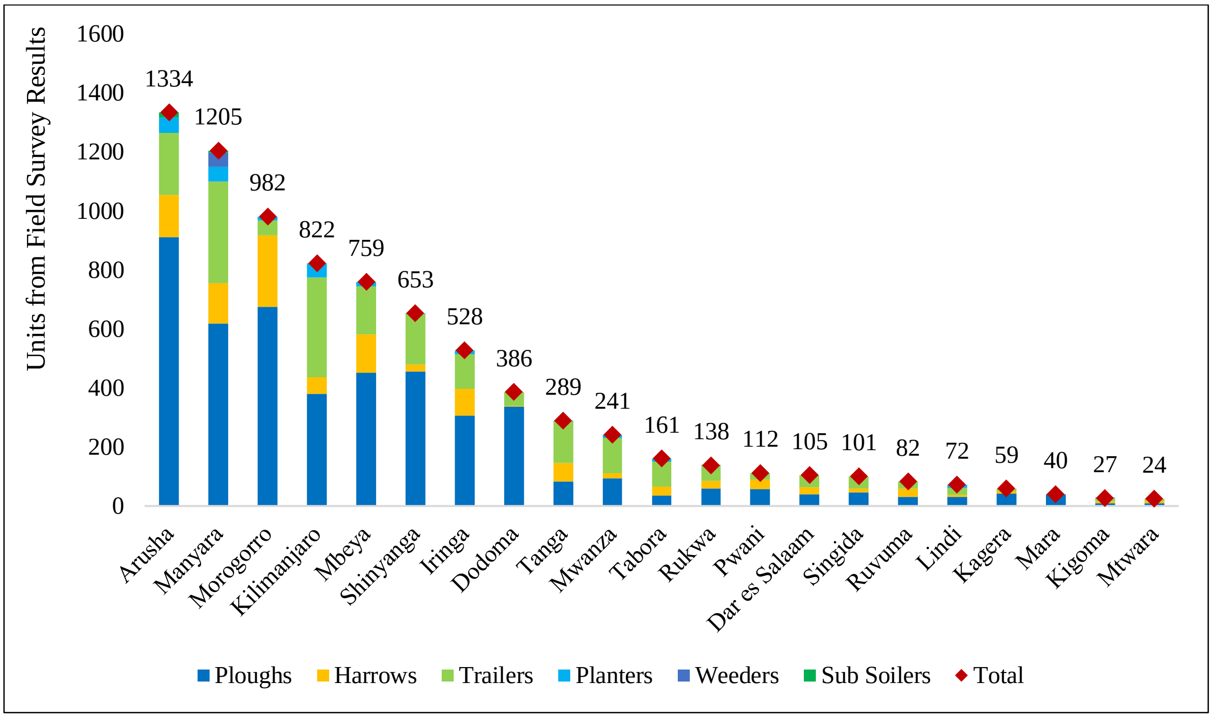

Figure 19: Tanzania - Number of implements by region: 2005

Source: Field survey results & DALDOs reports of TAMS quoted in Mrema, 2016

Although a substantial decrease was observed regarding cultivated area where a tractor was used from 2008/09 to 2010/11, recent data suggests an increasing trend from 2010/11 to 2014/15. The results further indicated that increasing tractor use is driven by the development of rental markets, and not through the acquisition of own tractors. The largest increase in the adoption of tractor rental markets was observed in the 2-4.99 and 5-9.99 hectare land size categories. The spatial illustration and regional analysis indicated the existence of variations in regional tractor adoption, with only a few regions indicating remarkable growth in rental services over the period. For some regions, evidence suggests that the increase in tractor use was due to an increase in the numbers of larger-scale producers, such as in Arusha and Manyara. For regions such as Kilimanjaro, this was not the case, which suggests that other drivers may influence the adoption of tractor use, likely as a result of high-value crop production and/or other forms of commercially driven agriculture.

Hypothesis 2 of this study states that increased tractor use is observed at farm-level in Tanzania, and that it is driven by the development of tractor rental markets and is highly correlated with farm-size. Although some of these relationships need to be formally tested through econometric analysis, Hypothesis 2 can be partially accepted, based on the findings from Chapter 3.

3.4 Conclusions

The objective of Chapter 3 was to develop descriptive statistics for changing farm structures (farm size and land size distribution) followed by an assessment of tractor use among these land size groups over the period from 2008/09 to 2014/15. The reason why this approach was important in the context of this study is to validate whether farm structures are changing and if so, whether there exists changing patterns in the use of tractors among these households. This step was important since it will feed into the econometric analysis in the next chapter (Chapter 4) where demand models for tractor rental services was developed.

The analysis found that medium-scale farms are increasingly cultivating more land relative to small-scale farms. The results also suggest that the total cultivated area and the number of households who engage in arable production have increased since 2008/09. The statistics provided evidence that mean farm sizes in the 5-9.99 and larger than 10 hectares land size groups had increased over the period from 2008/09 to 2014/14.

The use of tractors has indicated a significant increase over the period from 2008/09 to 2014/15 and was dominated by the development of tractor rental market and not through own acquisition of tractors. A key finding from the analysis is that the increase in the use of tractors is not limited to medium-scale producers with rising use among small-scale agricultural households as well. The spatial illustration and regional analysis indicated the existence of variations in regional tractor adoption, with only a few regions indicating remarkable growth in rental services over the period.

Chapter 4 will build on the foundations from Chapter 3 with the objective to integrate the land dynamics- and tractor use data into tractor demand models to investigate the determinants of increased tractor use and spill-over effects in Tanzania.

Chapter 4:
Econometric Analysis: Household Tractor Demand Models and Induced Innovation Hypothesis in Tanzania

4.1 Introduction

The descriptive statistics discussed in Chapter 3 have identified important emerging trends in land dynamics and the environment for tractor rentals in Tanzania. The results indicated that, apart from changes in average land and cultivated land sizes, medium-scale farmers are increasingly controlling more areas of land (Table 6). The findings also provided evidence that there is an increase in the number of tractors being rented in the country. Figure 13 also indicated that increased use in tractor rentals is not only observed on farms larger than 5 hectares, but also on smaller farms, whereas Figure 17 showed large variations in regional tractor rental use. This chapter interprets the findings from Chapter 3 using econometric analysis, with the specific objective to identify the factors associated with the rise of mechanisation rental markets in Tanzania. This is achieved by designing and estimating models of tractor demand at the farm household level. The findings from Chapter 3 should, therefore, be carefully assessed in context with the econometric analysis, since they provide the potential to explain key inter-relationships and sequences that underpin the adoption of tractor use in Tanzania.

Three specific hypotheses are explored in this chapter,: firstly, that increased participation in tractor rental markets by Tanzanian farming households is coupled with cultivated land size. Secondly, that medium-scale farms are promoting a movement to more capital-intensive forms of land preparation, not only on these farms but also on smallholder farms as well. It is hypothesised that the rise in demand for mechanisation services on smallholder farms reflects evolving trends in labour–capital factor price ratios, consistent with the Hayami-Ruttan induced innovation theory. Thirdly, that it is necessary to identify the covariates that inform the demand for tractor rental markets in Tanzania.

These hypotheses are tested by using tractor rental demand models that interrogate the four waves of data given in the National Panel Survey from 2009, 2011, 2013 and 2015, which are nationally representative.

For this study, probability regression (Probit) models, based on standard input demand models, were specified and estimated to identify the factors associated with tractor rental use among Tanzanian farmers. The dependent variable is defined as the binary outcome for a household to rent a tractor or not. Regions where less than two percent of households rented tractors were removed from the dataset, since there is almost no within-region variation to be explained. The dataset was further limited to include only households who cultivated between 0 and 5 hectares as an additional subset in order to explore the factors associated with tractor rental use among small-scale producers. Table 11 reports the summary of the estimation results for pooled GLM Probits and MC CRE, while the detailed results are presented throughout Chapter 4.

4.2 Household Demand Models for Tractor Rental Markets in Tanzania

4.2.1 Recap on the Model Specification and Interpretation of Variables

The Methodology and Data section in 1.5 in Chapter 1 has described the data sources, estimation techniques and approaches in detail. The objective of this section is to briefly highlight the model specification and variables followed by the in-dept interpretation of the estimation results. The model specification was defined as follows (the descriptive statistics on these model variables are presented in Appendix A1):

Model specification 1:

$$P(Y_{tractor_{rent}} = 1 \mid X_k) = P\,(Y = 1 \mid x0 + x1_{land_{cult}} + x2_{year} + x3_{head_{type}} + \mathrm{x4}_{\mathrm{head_{age}}} + \mathrm{x5}_{\mathrm{logasset_{wealth}}} + \mathrm{x6}_{\mathrm{logmarket_{dist}}} + \mathrm{x7}_{\mathrm{logwage_{rate}}} + \mathrm{x8}_{\mathrm{logfert_{cost}}} + \mathrm{x9}_{\mathrm{logmaize_{price}}} + \mathrm{x10}_{\mathrm{logtrac_{rent}}} + \mathrm{x11}_{\mathrm{share_{medium}}} + \mathrm{x12}_{\mathrm{region}} + \epsilon_{\mathrm{i}}$$

where the dependent variable is the dichotomous response of 'yes' or 'no' and refers to the outcome whether a household will rent a tractor or not, based on the relationship with X_k. The X_k is defined as the household and community covariates with year and regional dummy variables that could influence tractor rental decisions, where $x1_{land_{cult}}$ refers to household cultivated land size categories, with sub-populations defined as 0-1.99 hectares, 2-4.99 hectares, 5-9.99 hectares, and >10 hectares land size groups. Hypothesis 2 stated that increased tractor use is observed at farm-level in Tanzania and is driven by the development of tractor rental markets, instead of by own tractor acquisition. It also states that land size is coupled with increased tractor use. The descriptive statistics in Chapter 3 have already provided evidence that this hypothesis can be accepted, with the objective to formally validate this through applying the econometric techniques described in this chapter. Thus, the purpose is to determine whether it is more likely for a larger land size group to rent a tractor, which could provide evidence that, as the rise of the medium-scale farmer continues, the adoption of tractor rental markets may continue to increase in the future.

The component $x3_{head_{type}}$ refers to the household head type, whether male or female, and $\mathrm{x4}_{\mathrm{head}_{\mathrm{age}}}$ is a categorical variable stipulating the age group of the respective household head. The four categories include younger than 30 years, between 30 and 45 years, 46 to 60 years, and older than 60 years of age. The purpose is to test whether younger household heads are more likely to make use of technology than older household heads are. The descriptive statistics indicate that the median age group was between 30-45 years of age in 2008/09 and towards 2010/11, the median was between 46-60 years of age.

The component $\mathrm{x5}_{\mathrm{logasset}_{\mathrm{wealth}}}$ refers to the log of the total value of all household assets, while $\mathrm{x6}_{\mathrm{logmarket}_{\mathrm{dist}}}$ is considered as a key variable in the model specification since it relates back to theory on the relationship between market access and agricultural intensification. It represents the total distance to markets, which serves as a proxy for market access, indicating a lower probability of renting a tractor for households situated farther away from markets. According to Table A.1, the average distance to market over the survey years equals 6.44 kilometres; however, when considering the respective percentile statistics, households can be situated as far as 29 kilometres away from the market.

The component $x7_{\mathrm{logwage}_{\mathrm{rate}}}$ refers to the natural logarithm (log) for wage rate for land preparation, which is key to understanding how changes in relative factor prices, which are associated with rapid change in the demographic landscape and economic transformation, have affected mechanisation demand through tractor rental markets. In Chapter 1, Hypothesis 3 stated that the availability of tractor rental markets in specific geographic areas may have altered relative factor prices in ways favourable to the introduction of mechanisation by smallholders. The objective of the estimation approach is to validate a part of this hypothesis by investigating the relationship between factor prices and the decision by a household to rent a tractor, according to all land size distribution groups. Table A.1 in Appendix A1 and Figure 20 provide evidence that nominal wage rates had increased over the period from 2008/09 to 2014/15 (median wage rate reported an increase of 116% over the stipulated period).

The component $\mathrm{x8}_{\mathrm{logfert}_{\mathrm{cost}}}$ represents the log for fertiliser cost per kilogram in a specific region, while $\mathrm{x9}_{\mathrm{logmaize}_{\mathrm{price}}}$ represents the log transformation for maize price, which is seen as a proxy for profitability. For the purpose of this analysis, perfect market information for farmers is assumed, such that might potentially influence the decision to cultivated more or less land in any given year, with a further implication for tractor rental markets. In the event that a negative correlation between maize price and the decision to rent a tractor occurs, it can be explained that areas of greatest agricultural commercialisation and productivity (and accordingly tractor rental markets) tend to have the lowest regional maize prices due to surpluses being produced in these regions.

The component $\mathrm{x10}_{\mathrm{logtrac}_{\mathrm{rent}}}$ is the natural log for the cost to rent a tractor, which could entail a negative impact on whether a household would rent a tractor or not, while $\mathrm{x11}_{\mathrm{share}_{\mathrm{medium}}}$ indicates the percentage share of households larger than 5 hectares in a region. It is tested whether a positive spill-over effect on tractor rentals exists, given the number of medium-scale farmers in a region.

The components $\mathrm{x12}_{\mathrm{region}}$ and $x2_{year}$ refer to regional and time dummy variables. The regional dummy variable could provide inferences on regional variations in rental tractor use, where high adoption rental regions could typically include an influx of new medium-scale farmers. The time dummy variable refers to the four waves of survey, 2008/09, 2010/11, 2012/13 and 2014/15, which, if all else is held constant, might indicate whether or not there has been an increase in utilising tractor rental services. It is important to note that, in the initial model specification, a variable was included for own tractor use in the region to test whether a spill-over effect exists between households owning tractors and the development of rental markets for smaller land size categories. However, only a few cases were reported of households owning tractors in the sample, and accordingly it was decided to exclude this variable from the model specification.

The level of measurements refer to household- and community characteristics where household characteristics include land cultivated, gender and age of household head, asset wealth and market access conditions where the community characteristics include local wage rates, fertiliser prices, tractor rental rates and the share of medium-scale farms as a percentage of total number of farms in a district.

4.2.2 Interpretation of Estimation Results – Pooled GLM

Table 9 reports the estimation results and average marginal effects for the pooled GLM Probit demand models for rented tractors in Tanzania. The table represents the outcome for four estimation approaches:

1) **Model 1:** Full dataset where model specification 1 was estimated on the full survey dataset, which thus includes all regions and all land size distribution groups.
2) **Model 2:** Full dataset, but land size distribution group is limited to those households cultivating between 0 and 5 hectares of arable land. The reason for estimating this approach is to investigate whether rental tractor use is only limited to larger-scale producers or whether the adoption of mechanised technologies can also be observed for small-scale producers.
3) **Model 3:** Dataset is restricted to regions where at least 2% of households have reported utilising rented tractors. The reason for this estimation approach is to determine whether the overall model fit can be improved through focusing on regions where tractor rentals are more prominent.
4) **Model 4:** Dataset is restricted to 2% rental regions and further limited to include only households that cultivate between 0 and 5 hectares of arable land.

The demand function for tractor rental services is based on the binary response from households regarding renting a tractor, with a number of households and community characteristics, regional conditions and year dummies. The objective of the stipulated categorical variables is to illustrate the relationships and variations between sub-groups and categories. The model estimation results set out in Table 9 can be summarised as follows:

- $x1_{land_{cult}:2-4.99\ hectares}$: The land size groups in all four demand models are significant, at a 100% confidence level, with a positive coefficient, which denotes that there is a larger probability for a household located in the 2-4.99 hectare group to rent a tractor than in the base category of 0-1.99 hectares.

- $x1_{land_{cult}:5-9.99\ hectares}$: The 5-9.99 land size group in models 1 and 3 is significant, at a 100% confidence interval with a higher coefficient than in the 2-4.99 hectare group, which indicates that the probability of renting a tractor further increases as households cultivate more areas of land.

- $x1_{land_{cult}:>10\ hectares}$: Although only significant at a 96% confidence interval in model 1, and 93% confidence level in model 3, the positive coefficient of the >10 hectare group, together with the results for the 5-9.99 hectare land size group, formally provides evidence that land size is positively correlated with increased demand for tractor rentals in Tanzania. Hence, the persistent increase in the number of medium-scale farmers in SSA could entail that tractor rental markets will continue to develop and that farmers will continue to adopt these services. This is not only likely in Tanzania, but also likely in the region as well. The significance and relationship between the land size variables further indicate that the use of tractor rental services is not limited to large-scale producers only, and that small-scale agricultural households also use these services.

- $x2_{year}$: The year dummy variable provides evidence that tractor rental services have been increasing since 2008/09, which supports the statistics set out in Chapter 2 and reference the point that tractor use is increasing in Tanzania (Figure 7 and Figure 8). The 'year = 2012/13' variable is significant at a 99 - 100% confidence interval and '2014/15' at a 100% confidence interval with positive coefficients. Hence, the probability of renting a tractor is increasing over time, supported by the magnitude of the 2012/13 and 2014/15 year dummy coefficients.

- $x3_{head_{type}}$: The household head type variable is significant at a 96 - 98% confidence level in models 1 and 2, with a 99 - 100% confidence interval in models 3 and 4, which suggests that male household heads are more likely to rent a tractor than female household heads are. In regions associated with higher tractor rentals, the magnitude of coefficients was larger than in the full dataset estimation results.

- $x4_{head_{age}}$: The household head age categorical variable investigated whether younger individuals are more likely to rent a tractor than older household heads are. The estimation results did not deliver meaningful inference, except for model 2, which suggested that household heads older than 60 years of age are more likely to rent a tractor than individuals younger than 30 years are (92% confidence level).

- $x5_{logasset_{wealth}}$: The asset wealth variable investigated whether a positive relationship exists between the total value of the household assets and tractor rentals. The estimation results for all models were insignificant. An altered demand model, which considers the decision to own a tractor instead of renting one, may deliver different results.

- $x6_{logmarket_{distance}}$: The market distance variable is indirectly linked to the theory of agricultural intensification and the evolution of farming systems in SSA, as was discussed in Chapter 2. The theory suggests that agricultural transformation, growth and intensification, as a process, is conditional upon population growth and market access. The distance from the homestead to the market is often utilised as a proxy for market access. The estimation results for the pooled GLM Probit models suggested that there is no significance between market distance and the likelihood of renting a tractor. The hypothesis that underpins this relationship is that farming households who are in closer proximity to markets, whether rural or urban, may be incentivised to pursue increasingly intensive efforts in farming practice through increased input use and adoption of modern technologies, such as using mechanised power. This incentive is driven by the probability of increased demand or higher product prices.

- $x7_{logwage_{rate}}$: The wage rate in the estimation results is significant, at a 100% confidence interval, with a positive coefficient in all model outputs, which indicates that as wage rate increase, at some point the use of mechanical power through tractor rentals will become more competitive. Accordingly, farmer households will then decide to rent a tractor as opposed to continuing with manual labour. This relationship, together with the estimation results for the tractor rental variable, serves as initial evidence that the induced innovation hypothesis that explores relative changes in factor prices is functioning well in Tanzania. Figure 20, Figure 21 and Table A.1 in Appendix A set out evidence of the relative changes in factor prices in Tanzania.

- $x8_{logfert_{cost}}$: The cost of fertiliser variable was included to investigate whether a positive or a negative correlation can be found between inputs (in this case, fertiliser) and renting a tractor. A positive correlation could imply that a farmer perhaps exhibits an overall, best farming practice approach; hence, the farming household would make use of fertiliser. On the other hand, a negative correlation could entail that the household has limited financial resources, and the farmer needs to choose where he or she spends his or her resources. All model results reported a positive correlation between the cost of fertiliser and the decision to rent a tractor, with models 1 and 2 significant, at a 95 - 97% confidence level, and models 3 and 4 significant at a 91 - 93% level.

- $x9_{logmaize_{price}}$: The maize price is used as a proxy for farm profitability and investigates whether there is a positive relationship with tractor rentals in areas that are characterised with higher maize farm-gate price levels. In all model estimation outputs, the maize price variable was insignificant.

- $x10_{\mathrm{logtrac_{rent}}}$: The cost to rent a tractor was significant, at a 100% confidence interval, in all estimation results. In line with the induced innovation hypothesis, a negative coefficient suggests that there will be a negative correlation between the cost and the decision to rent a tractor or not. Figure 20 indicates the mean of median changes in district-level factor prices in Tanzania, and showed that, initially, the cost to rent a tractor had increased at a faster rate than the wage rate over the period from 2008/09 to 2012/13. However, the cost to rent a tractor then reported a decline for the 2012/13 to 2014/15 survey period, with wage rates continuing to increase at district level. This occurrence might suggest that the availability of rental tractors has increased, with more competitive pricing for tractor rentals relative to the wage rate, followed by an increase in participation in tractor rental markets.

- $x11_{\mathrm{share_{medium}}}$: The concentration of medium-scale farms per district variable was initially calculated as comprising all farms larger than 5 hectares, which yielded a confidence interval of 95%, with a positive coefficient. The approach was then amended by introducing 3 concentration variables, firstly by including only the medium-scale farms that range between 5 – 10 hectares, next followed by 10 – 20 hectares, and larger than 20 hectares concentration variables. The objective of the adjusted approach was to determine whether significance levels could be improved by considering different levels of concentration of medium-scale farms by district. In the adjusted approach, the variable for the concentration of medium-scale farms between 5 and 10 hectares was significant, at a 99 - 100% confidence level, in all estimation results. The positive coefficient, the magnitude of the coefficients, and the significance level formally provide evidence that in districts where there is a larger concentration of medium-scale farms, the probability of renting a tractor will increase, not only by larger-scale producers, but also by small-scale farming households as well. The argument is that medium-scale farms are likely to be considered as more commercialised producers, which are characterised by increased use of inputs such as hybrid seeds and fertilisers. The increased levels of intensification of farming operations might create a scenario where increased levels of demand for rental tractors will also attract the supply thereof. Based on the Hayami-Ruttan induced innovation framework, in the event that larger-scale farmers use tractors on their own farm, and when downtimes in use occur, it might be anticipated that tractor owners would rent out tractor services to farms in nearby communities, if the rental costs per hectare are competitive with manual or animal traction-based land preparation. Under such conditions, there are mutual synergies, transferring from large farms to small farms. This occurs through the development of tractor rental markets, whereby larger farms more fully use the capacity of expensive capital investments, and whereby smallholder farmers gain access to cost-cutting land preparation technology that simultaneously frees up labour for reallocation to higher-return off-farm activities.

- $x12_{region}$: The region variable is significant, which entails that regional adoption of tractor rental services will vary across Tanzania. In particular, highly commercialised regions, such as Arusha and Kilimanjaro, are all significant at a 100% confidence interval, which further provides evidence that regions associated with an influx of medium-scale producers are more likely to have small-scale farmers renting tractors. Regions such as Manyara, Morogoro and Pwani also reported significance levels between 99.9% and 100% confidence intervals.

Table 9: Pooled GLM Probit model estimations summary and average marginal effects (dydx*)

	Pooled GLM Probit estimation results and average marginal effects							
	Full Dataset		Full Dataset & Limited to HH located in 0-5 ha		2% tractor rental regions		2% rental regions & limited to HH located in 0-5ha	
	Estimation results (1.1)	Margins (dydx*) (1.2)	Estimation results (2.1)	Margins (dydx*) (2.2)	Estimation results (3.1)	Margins (dydx*) (3.2)	Estimation results (4.1)	Margins (dydx*) (4.2)
Variables:								
Total Cultivated Land Size Distribution = 0 – 1.99 hectares	**BASE**							
Total Cultivated Land Size Distribution = 2 - 4.99 hectares	0.41***	0.04***	0.43***	0.04***	0.44***	0.07***	0.46***	0.07***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Total Cultivated Land Size Distribution = 5 - 9.99 hectares	0.51***	0.05***	-	-	0.62***	0.10***	-	-
	(0.00)	(0.00)	-	-	(0.00)	(0.00)	-	-
Total Cultivated Land Size Distribution = > 10 hectares	0.48**	0.04**	-	-	0.52*	0.08*	-	-
	(0.04)	(0.04)	-	-	(0.07)	(0.07)	-	-
Year = 2008-09	**BASE**							
Year = 2010-11	0.06	0.01	0.08	0.01	0.05	0.01	0.07	0.01
	(0.53)	(0.53)	(0.45)	(0.45)	(0.65)	(0.65)	(0.53)	(0.53)
Year = 2012-13	0.29***	0.03***	0.33***	0.03***	0.31***	0.05***	0.36***	0.06***
	(0.01)	(0.01)	(0.00)	(0.00)	(0.01)	(0.01)	(0.00)	(0.00)
Year = 2014-15	0.59***	0.05***	0.65***	0.06***	0.59***	0.10***	0.64***	0.10***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Household head sex = Female	**BASE**							
Household head sex = Male	0.17**	0.01**	0.19**	0.02**	0.24***	0.04***	0.26***	0.04***
	(0.04)	(0.04)	(0.02)	(0.02)	(0.01)	(0.01)	(0.00)	(0.00)
Household head age categories = younger than 30 years	**BASE**							
Household head age categories = 30-45 years	0.06	0.01	0.12	0.01	0.07	0.01	0.12	0.02
	(0.59)	(0.59)	(0.32)	(0.32)	(0.58)	(0.58)	(0.37)	(0.37)
Household head age categories = 46-60 years	0.03	0.00	0.10	0.01	0.05	0.01	0.13	0.02
	(0.79)	(0.79)	(0.43)	(0.43)	(0.72)	(0.72)	(0.37)	(0.37)

Household head age categories = older than 60 years	0.17	0.01	0.24*	0.02*	0.19	0.03	0.27*	0.04*
	(0.19)	(0.19)	(0.08)	(0.08)	(0.18)	(0.18)	(0.08)	(0.08)
log_asset_wealth	0.01	0.00	0.01	0.00	0.00	0.00	0.01	0.00
	(0.61)	(0.61)	(0.42)	(0.42)	(0.81)	(0.81)	(0.61)	(0.61)
log_market_dist	0.01	0.00	-0.00	-0.00	0.01	0.00	-0.01	-0.00
	(0.63)	(0.63)	(0.97)	(0.97)	(0.75)	(0.75)	(0.88)	(0.88)
log_wage_rate_LP	0.23***	0.02***	0.23***	0.02***	0.19***	0.03***	0.19***	0.03***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
log_fert_cost	0.17**	0.01**	0.19**	0.02**	0.16*	0.03*	0.18*	0.03*
	(0.05)	(0.05)	(0.03)	(0.03)	(0.09)	(0.09)	(0.07)	(0.08)
log_maize_price	0.05	0.00	0.03	0.00	0.09	0.02	0.07	0.01
	(0.37)	(0.37)	(0.58)	(0.58)	(0.14)	(0.14)	(0.25)	(0.25)
log_trac_rent_cost_m	-0.25***	-0.02***	-0.35***	-0.03***	-0.22***	-0.04***	-0.31***	-0.05***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
hh_5_10_ha	2.70***	0.24***	2.90***	0.25***	4.37***	0.71***	4.14***	0.65***
	(0.01)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
hh_10_20_ha	1.62	0.14	0.75	0.06	0.47	0.08	-0.49	-0.08
	(0.47)	(0.47)	(0.80)	(0.80)	(0.88)	(0.88)	(0.90)	(0.90)
hh_20_ha	-2.00*	-0.18*	-1.43	-0.12	1.15	0.19	2.29	0.36
	(0.09)	(0.10)	(0.24)	(0.24)	(0.46)	(0.46)	(0.15)	(0.15)
Summary of Tanzania mainland regions: Significant regional variables								
Dodoma					**BASE**			
Arusha	0.88***	0.08***	0.87***	0.07***	0.76***	0.12***	0.79***	0.12***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Kilimanjaro	0.94***	0.08***	0.93***	0.08***	0.95***	0.16***	0.96***	0.15***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Morogoro	0.70***	0.06***	0.80***	0.07***	0.59***	0.10***	0.74***	0.11***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Pwani	0.67***	0.06***	0.67***	0.06***	0.77***	0.13***	0.79***	0.12***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Lindi	-0.46**	-0.04**	-0.58**	-0.05**	-0.48	-0.08	-0.70**	-0.11**
	(0.03)	(0.03)	(0.01)	(0.01)	(0.10)	(0.10)	(0.03)	(0.04)
Ruvuma	-0.85***	-0.08***	-0.83***	-0.07***	-0.85***	-0.14***	-0.66**	-0.10**
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.01)	(0.04)	(0.04)

Iringa	0.04	0.00	0.09	0.01	0.37*	0.06*	0.46**	0.07**
	(0.82)	(0.82)	(0.62)	(0.62)	(0.06)	(0.06)	(0.03)	(0.02)
Mbeya	-0.52**	-0.05**	-0.55**	-0.05**	-0.32	-0.05	-0.35	-0.06
	(0.02)	(0.02)	(0.02)	(0.02)	(0.24)	(0.24)	(0.24)	(0.24)
Singida	-0.34	-0.03	-0.57**	-0.05**	-0.46*	-0.08*	-0.64**	-0.10**
	(0.12)	(0.13)	(0.02)	(0.02)	(0.06)	(0.06)	(0.02)	(0.02)
Mwanza	-1.09***	-0.10***	-1.23***	-0.11***	-0.72**	-0.12**	-0.75**	-0.12**
	(0.00)	(0.00)	(0.00)	(0.00)	(0.03)	(0.03)	(0.05)	(0.05)
Manyara	0.98***	0.09***	1.02***	0.09***	0.91***	0.15***	1.00***	0.16***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Constant	-3.11***		-2.30**		-3.32***		-2.47**	
	(0.00)		(0.03)		(0.00)		(0.04)	
Observations	8,332	8,332	7,755	7,755	3,728	3,728	3,524	3,524

pval in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Source: Own calculations using World Bank LSMS online data: Tanzania National Panel Survey, 2008/09, 2010/11, 2012/13 & 2014/15

For the remainder of this section, and to discuss average marginal effects and predicted probabilities, the output for model 3 was utilised, with the output summarised as follows:

$$F(x) = \Phi(\mathrm{x}) = \Phi(-3.11 + 0.44x1_{land_{cult:\,2-4.99ha}} + 0.62x1_{land_{cult:\,5-9.99ha}} + 0.52x1_{land_{cult}:\,>10ha} + 0.05x2_{year_{2010-11}} + 0.31x2_{year_{2012-13}} + 0.59x2_{year_{2014-15}} + 0.24x3_{headtype_{male}} + 0.07x4_{headage_{30-45}} + 0.05x4_{headage_{46-60}} + 0.19x4_{headage_{>60}} + 0.00lnx5_{logasset_{wealth}} + 0.01lnx6_{logmarket_{dist}} + 0.19lnx7_{logwage_{rate}} + 0.16lnx8_{logfert_{cost}} + 0.09x9_{logmaize_{price}} - 0.22lnx10_{\mathrm{logtrac}_{\mathrm{rent}}} + 4.37x11_{\mathrm{share}_{medium_{5-10}}} + 0.47x12_{\mathrm{share}_{medium_{10-20}}} + 1.15x13_{\mathrm{share}_{medium_{>20}}} + 0.76x14_{region_{Arusha}} + 0.95x14_{region_{Kilimanjaro}} + 0.91x14_{region_{Manyara}} + 0.59x14_{region_{Morogoro}} + 0.77x14_{region_{Pwani}} + x14_{region_{other(see\ \text{Error! Reference source not found.})}})$$

Table 9 further illustrates the marginal effects (dy/dx) at mean values for model specification 1. Marginal effects illustrate the change in probability when the covariates increase by one unit. The use of marginal effects assist in the understanding of the magnitude of change. It therefore supports arguments between the relative change between models- and model variables by using predictions.

For continuous variables, the effects represent the instantaneous change, whereas for the categorical variables, the change is from zero to one. For the purpose of this study, a post-estimation approach, through prediction analysis, will be utilised to provide additional inferences on the relationships between rented tractor demand and the corresponding covariates.

Table 10 (also Table 9) illustrates the sensitivity between variables by using predicted probabilities and average marginal effects (dy/dx) at the data means. The objective of the sensitivity analysis is to illustrate the outcome on the decision of a household to rent a tractor by controlling for certain variables. For example, the objective is to compare the overall model prediction at the data means to a scenario where a household is located in a larger land size category or to an area where there is a larger presence of medium-scale farming households.

The overall model fit (at the respective means) suggested an 8.7% probability that a household would rent a tractor. However, when starting to control for certain variables, while holding other variables at their means, the results indicate interesting trends. The highest percentage change in probability of renting a tractor in a land size categorical variable was observed in the $x1_{land_{cult:\,5-9.99ha}}$ group (an increase of 10.4% in the probability of renting a tractor, if a household was located in this group). For the $x1_{land_{cult:\,2-4.99ha}}$ group, the probability increases by 5.8%. Wage rate reported only a marginally positive response as wage rate increases. The overall probability of renting a tractor increases from 8.7% to 10.0%, if the 2014 75^{th} percentile wage rate is considered. Similarly, the cost to rent a tractor also reflected a marginal response on the decision to rent a tractor, decreasing by 1.6%, if the 75^{th} percentile tractor rental cost for 2014 is considered.

The variable that reflects the concentration of medium-scale farms (5-10 hectares) in a district indicates a positive correlation with the probability that a farmer would rent a tractor. The 25^{th} percentile, median, 75^{th} and 90^{th} percentiles for 2014 were considered to compute the change in probability as the number of medium-scale farms per district fluctuate. The predicted probabilities indicate that, as the concentration of 0 to 5 hectare producer per district increases, the probability of renting a tractor would also increase (from 7.1% to 18% between the 25^{th} and 90^{th} percentiles for 2014, and keeping all other variables at the data means).

To elaborate on the importance of geographic locations and participation in tractor rental markets, we further control for specific variables to illustrate the sensitivity between regions. The lower part of Table 10 illustrates the probabilities for key tractor-rental regions, while controlling the land size category = 5-9.99 hectares, year = 2014, household head type is a male, and the concentration of farmers between 0 and 5 hectares is set at the 2014 median value, while all other variables are set at their data means over time. What is noteworthy is the substantial increase in the probability of renting a tractor in these regions. The highest positive responses were observed in Kilimanjaro, Manyara and Arusha, which all indicated a probability exceeding 55%. The prediction analysis results for Kilimanjaro reported an increase from 8.7% to nearly 63% in the probability of renting a tractor. These regional effects indicate that important developments are occurring with regard to using more capital-intensive forms of farming, which could be attributed to the presence of medium-scale farms and their associated approach to farming practices.

Table 10: Predicted probabilities sensitivity analysis: Pooled GLM Probit

Controlled variable	Variable category / scenario	Model prediction: % probability that a HH will rent a tractor	Percentage change from general model prediction at data means
General model prediction	All variables set at data means	8.7%	-
Cultivated land size category	0-1.99 hectares	6.7%	-2.0%
	2-4.99 hectares	14.5%	+5.8%
	5-9.99 hectares	19.2%	+10.4%
	>10 hectares	16.5%	+7.7%
Head type	Male	8.7%	-
Wage rate	2014 25th percentile	8.5%	-0.2%
	2014 median	9.4%	+0.7%
	2014 75th percentile	11.1%	+2.4%
Tractor rental cost	2014 25th percentile	9.7%	+1.0%
	2014 median	8.4%	-0.3%
	2014 75th percentile	7.8%	-0.9%
Concentration of 5-10ha HH per district	2014 25th percentile	7.1%	-1.7%
	2014 median	7.1%	-1.7%
	2014 75th percentile	11.7%	+3.0%
	2014 90th percentile	13.4%	+4.7%
	2014 95th percentile	18.0%	+9.3%
	2014 99th percentile	21.2%	+15.5%
Predicted probabilities for regions where land size = 5-9.99 ; year =2014 ; head type = male & concentration of 5-10 ha producers = 2014 median	Dodoma	26.3%	+17.6%
	Arusha	55.1%	+46.3%
	Kilimanjaro	62.6%	+53.8%
	Morogoro	48.5%	+39.7%
	Pwani	55.6%	+46.9%
	Manyara	61.0%	+52.3%

Source: Own calculations using World Bank LSMS online data: Tanzania National Panel Survey, 2008/09, 2010/11, 2012/13 & 2014/15

The prediction analysis provided inferences on the correlation between key independent variables and, despite a low overall prediction rate, conclusive results are obtained when certain variables are controlled for. The results highlighted the importance of scale and the likelihood of making use of rental services. A clear trend is evident in the uptake of rented tractors after 2008/09, which provides formal evidence that increasing tractor use through rental markets is observed among farming households in Tanzania, similar to other references and national statistics. The factor price variation also provided formal proof that the induced innovation hypothesis is valid and functions well to explore how the change in factor prices, such as labour, influences the adoption of technology in the case study of Tanzania. The results further suggested that the number of medium-scale farms per district, which are typically considered as highly commercialised operating units, do have an influence on the adoption of technology and that a positive spill-over effect to neighbouring, smaller scale producers does exist.

4.2.3 Summary: Pooled GLM and MC CRE Probit Estimation Results

The characteristics of successful tractor-rental operations include private ownership by producers, the concentration of power-intensive operations (where ploughing seasons are short), the solution of the capacity-utilisation problem through migration of tractors in agro-climatic zones, and the continued use of animal traction for less power-intensive operations (Pingali et al., 1988). The combined model results for household tractor rental, derived from the pooled GLM and MC CRE Probit estimations, are presented in Table 11. The land size categorical variables $x1_{land_{cult}:2-4.99\ hectares}$, $x1_{land_{cult}:5-9.99\ hectares}$ and $x1_{land_{cult}:>10\ hectares}$ were all significant in the pooled GLM estimation output, with the positive coefficients indicating that land size is coupled with tractor use through rental services, particularly in the 5-9.99 hectare group. For the MC CRE model, the robustness of the $x1_{land_{cult}:>10\ hectares}$ variable has improved substantially, indicating that, as we controlled for unobserved time-constant heterogeneity, the impact of large-scale farms becomes more prominent. The persistent increase in the numbers of medium-scale farmers in SSA could entail that tractor rental markets will continue to develop, not only in Tanzania, but likely in the region as well. The results provide evidence that the use of tractor rental services is not limited to medium-scale producers only, but also includes small-scale agricultural households. The year variable, $x2_{year}$, concludes the hypothesis that tractor use is increasing in Tanzania, as suggested by regional and national import data shown in Figure 7 and Figure 8.

Table 11: Estimation output: Pooled GLM and MC CRE Probit results

Estimation approach	Pooled GLM Probit		MC CRE	
Dataset	2% tractor rental regions		2% tractor rental regions	
	All land size categories	Limited to HH located in 0-5 ha	All land size categories	Limited to HH located in 0-5 ha
Dependent Variable: Households rented a tractor	.	.	.	.
	(.)	(.)	(.)	(.)
Cultivated land size category: 2 - 4.99 hectares	0.44***	0.46***	0.33*	0.33*
	(0.00)	(0.00)	(0.06)	(0.09)
Cultivated land size category = 5 - 9.99 hectares	0.62***		0.41	
	(0.00)		(0.43)	
Cultivated land size category = > 10 hectares	0.52*		1.00***	
	(0.07)		(0.00)	
Year = 2010/11	0.05	0.07	0.13	0.18
	(0.65)	(0.53)	(0.24)	(0.13)
Year = 2012/13	0.31***	0.36***	0.50***	0.52***
	(0.01)	(0.00)	(0.00)	(0.00)
Year = 2014/15	0.59***	0.64***		
	(0.00)	(0.00)		
Household head sex: Male	0.24***	0.26***	0.18	0.26
	(0.01)	(0.00)	(0.37)	(0.25)
Household head age categories = 30-45 years	0.07	0.12	-0.19	-0.12
	(0.58)	(0.37)	(0.24)	(0.48)
Household head age categories = 46-60 years	0.05	0.13	-0.33	-0.27
	(0.72)	(0.37)	(0.37)	(0.47)
Household head age categories = older than 60 years	0.19	0.27*	-0.24	-0.18
	(0.18)	(0.08)	(0.21)	(0.39)
log_asset_wealth	0.00	0.01	0.01	0.03
	(0.81)	(0.61)	(0.56)	(0.33)
log_market_dist	0.01	-0.01	-0.20*	-0.18
	(0.75)	(0.88)	(0.07)	(0.19)
log_wage_rate_LP	0.19***	0.19***	0.21***	0.19***
	(0.00)	(0.00)	(0.00)	(0.00)
log_fert_cost	0.16*	0.18*	0.08	0.09
	(0.09)	(0.07)	(0.54)	(0.55)
log_maize_price	0.09	0.07	0.00	0.03

Estimation approach	Pooled GLM Probit		MC CRE	
Dataset	2% tractor rental regions		2% tractor rental regions	
	All land size categories	Limited to HH located in 0-5 ha	All land size categories	Limited to HH located in 0-5 ha
	(0.14)	(0.25)	(0.99)	(0.85)
log_trac_rent_cost	-0.22***	-0.31***	-0.30**	-0.31*
	(0.00)	(0.00)	(0.03)	(0.06)
hh_5_10_ha	4.37***	4.14***	0.63	0.35
	(0.00)	(0.00)	(0.82)	(0.89)
hh_10_20_ha	0.47	-0.49	-4.35	-5.79
	(0.88)	(0.90)	(0.22)	(0.28)
hh_20_ha	1.15	2.29	-6.00*	-7.37
	(0.46)	(0.15)	(0.08)	(0.33)
Region = Arusha	0.76***	0.79***	0.95*	1.23**
	(0.00)	(0.00)	(0.07)	(0.03)
Region = Kilimanjaro	0.95***	0.96***	1.00**	1.27**
	(0.00)	(0.00)	(0.03)	(0.03)
Region = Tanga	0.33	0.36		
	(0.14)	(0.12)		
Region = Morogoro	0.59***	0.74***	1.44***	1.72***
	(0.00)	(0.00)	(0.00)	(0.00)
Region = Pwani	0.77***	0.79***	1.57*	1.77**
	(0.00)	(0.00)	(0.05)	(0.01)
Region = Dar es Salaam	-0.13	-0.03		
	(0.61)	(0.91)		
Region = Lindi	-0.48	-0.70**		
	(0.10)	(0.03)		
Region = Mtwara	0.24	0.29		
	(0.24)	(0.19)		
Region = Ruvuma	-0.85***	-0.66**	-1.03***	-0.95**
	(0.00)	(0.04)	(0.00)	(0.02)
Region = Iringa	0.37*	0.46**		
	(0.06)	(0.03)		
Region = Mbeya	-0.32	-0.35		
	(0.24)	(0.24)		
Region = Singida	-0.46*	-0.64**		

Estimation approach	Pooled GLM Probit		MC CRE	
Dataset	2% tractor rental regions		2% tractor rental regions	
	All land size categories	Limited to HH located in 0-5 ha	All land size categories	Limited to HH located in 0-5 ha
	(0.06)	(0.02)		
Region = Shinyanga	-0.15	-0.31		
	(0.60)	(0.42)		
Region = Mwanza	-0.72**	-0.75**		
	(0.03)	(0.05)		
Region = Mara	0.04	0.01		
	(0.85)	(0.97)		
Region = Manyara	0.91***	1.00***	1.67**	1.85***
	(0.00)	(0.00)	(0.02)	(0.00)
Region = KASKAZINI UNGUJA	0.36	0.30	0.01	0.32
	(0.13)	(0.22)	(0.98)	(0.48)
Region = Kusini Unguja	0.12	0.13		
	(0.72)	(0.70)		
Region = MJINI/MAGHARIBI UNGUJA	0.19	0.17	-0.90***	-0.62
	(0.52)	(0.56)	(0.01)	(0.21)
Region = KASKAZINI PEMBA	-0.00	-0.02	-0.24	0.06
	(1.00)	(0.94)	(0.60)	(0.88)
Region = Kusini Pemba	0.03	0.02		
	(0.91)	(0.95)		
log_asset_wealth_mean			0.00	0.01
			(0.93)	(0.73)
log_market_dist_mean			0.28	0.29
			(0.18)	(0.24)
log_wage_rate_LP_mean			0.16	0.14
			(0.36)	(0.34)
log_fert_cost_mean			0.21	0.25
			(0.64)	(0.59)
log_maize_price_mean			0.70***	0.63***
			(0.00)	(0.00)
log_trac_rent_cost_mean			-0.80**	-0.83*
			(0.04)	(0.06)
hh_5_10_ha_mean			8.90*	12.21***

Estimation approach	Pooled GLM Probit		MC CRE	
Dataset	**2% tractor rental regions**		**2% tractor rental regions**	
	All land size categories	**Limited to HH located in 0-5 ha**	**All land size categories**	**Limited to HH located in 0-5 ha**
			(0.05)	(0.00)
hh_10_20_ha_mean			-18.29	-19.39
			(0.12)	(0.13)
hh_20_ha_mean			48.18	48.66
			(0.11)	(0.13)
Constant	-3.32***	-2.47**	-0.03	0.02
	(0.00)	(0.04)	(1.00)	(1.00)
Observations	3,728	3,524	1,644	1,564
pval in parentheses				
***** p<0.01, ** p<0.05, * p<0.1**				

Source: Own calculations using World Bank LSMS online data: Tanzania National Panel Survey, 2008/09, 2010/11, 2012/13 & 2014/15

The increase in the magnitude of the coefficient from 2008/09 to 2014/15 implies that the probability of renting a tractor is accelerating. The variable $x3_{head_{type}}$ suggests that male household heads are more likely to rent a tractor than female household heads when the pooled GLM estimation results are considered. The household head age variable in the MC CRE model results indicates that household heads older than 60 years of age are less likely to rent a tractor than household heads younger than 30.

The negative coefficient for the market distance variable in the MC CRE model might suggest that areas closer to towns are the areas that would experience the greatest labour shortages, as these areas are those where tractor rental markets are relatively more developed.

The wage rate variable, $x4_{logwage_{rate}}$, indicates that, as wage rates increase, a shift towards renting a tractor would be considered. As expected, the negative coefficient in the tractor rental cost variable, $x5_{\mathrm{logtrac_{rent}}}$ implies a negative relationship with renting a tractor. These results uphold the importance of relative changes in factor prices, which is consistent with the induced innovation hypothesis.

The variable for the number of medium-scale farms (between 5 and 10 hectares) per district, $\mathrm{x}11_{hh\_5\_10ha}$, is significant at the 95% confidence interval, which indicates a positive relationship between the percentage share of medium-scale farms per district and the decision to rent a tractor made among small-scale producers. The hypothesis is that medium-scale farmers are likely to be considered as more commercialised producers and perhaps to utilise improved inputs such as hybrid seeds and fertiliser. As farming operations intensify and mechanisation services are attracted, the availability of these services may become useful to neighbouring small-scale farmers. The coefficient of the time-constant covariate, $hh\_5\_10\_ha\_mean$, in the MC CRE estimation results show that districts that experience, over time, a higher concentration of farmers working between 5 and 10 hectares indicate a higher probability of renting a tractor, as opposed to districts that are less concentrated with medium-scale farms.

The between-household effects for the variable $log\_maize\_price\_mean$ suggest that areas that experience higher maize prices, on average, are more likely to experience tractor rentals, which could serve as a proxy for profitability and incentivise producers to increase their areas under production. The significance of selective regions, as presented by the regional variable $x7_{region}$, suggests that tractor adoption and use will vary between regions. Highly commercialised regions such as Arusha and Kilimanjaro will comprehend a higher probability of renting a tractor, as opposed to less commercialised regions.

To address the study hypotheses, Chapter 1 listed three specific hypotheses to be tested in this Chapter. Hypothesis 2 states that increased tractor use is observed at farm-level in Tanzania and is driven by the development of tractor rental markets, instead of owning tractors. The increased use is exceedingly correlated with farm size. The descriptive statistics in Chapter 3 have already partially proven that this hypothesis might be accepted. The estimation results showed, firstly, that rented tractor use is increasing over time, and secondly, that farm size is closely correlated with the decision to participate in tractor rental markets, with statistically significant coefficients for both variables. Thus, Hypothesis 2 can be formally accepted, to the effect that tractor use in Tanzania is increasing over time, which is coupled with the increased participation of medium-scale farmers.

Hypothesis 3 states that the availability of tractor rental markets in specific areas may have altered relative factor prices in ways that are favourable to the introduction of mechanisation use by smallholders. Although this hypothesis will be formally tested in the next section, the sign of the coefficients of the wage rate and tractor rental cost variables have already provided proof that factor prices are operating in the manner predicted under the induced innovation hypothesis. Hence, if the wage rate increases, there will be a larger participation in tractor rental markets. Similarly, if the cost to rent a tractor increases, there will be farmers who shift to manual labour.

Hypothesis 4 has identified the covariates that are coupled with the demand for rented tractors in Tanzania. The hypothesis states that land size distribution, wage rate, tractor rental cost, asset wealth, market distance, household head type, household head age, the cost of fertiliser, maize price, the share of medium-scale producers in a district, and year and regional dummy variables can all be considered as covariates of a household decision to rent a tractor. The estimation results in Table 9 suggested that parts of the hypothesis can be accepted, and others rejected. No statistical significance was found between asset wealth, market distance, maize price and the concentration of larger-scale farms of 10-20 hectares and larger than 20 hectares.

However, robust estimation results were obtained for the land size distribution variables, the year dummy variables, household head type, wage rate, the cost of fertiliser, the cost to rent a tractor, and the concentration of medium-scale farms (5-10 hectares) per district.

4.3 The Induced Innovation Hypothesis: Changes in Relative Factor Prices in Tanzania

Hayami and Ruttan (1970) have described the induced innovation framework as representing an occurrence where farming practices are impacted upon by the economic system that determines the relative costs of agricultural land, labour, and capital inputs. The rapid changes that are observed in the demographic, economic and political landscapes in SSA may alter the historic ratios that underpin this framework in favour of capital-intensive forms of farming. For instance, rapid population growth that is concurrent with rapid urbanisation, urban population growth, and labour shifting to off-farm employment in rising secondary cities may impact upon the cost of rural wages and land prices, and may promote changes in farm structures.

As a point of departure for theoretically investigating whether the induced innovation hypothesis is valid for Tanzania, as is defined in Hypothesis 3 of this study, the trend of factor prices over the period from 2008/09 to 2014/15 in Tanzania was computed, which measures the implication on the percentage of farms at district-level renting of tractors. In order to test the induced innovation hypothesis, a pooled ordinary least squares (POLS) regression is utilised to statistically validate this aspect of the study. Figure 20 illustrates an index (base year = 100 = 2008/09) for wage rate (land preparation), tractor rental cost, and the trend for the number of households renting tractors. According to the data, the cost to rent a tractor declined from 2012/13 to 2014/15, whereas the wage rate continued increasing. The number of households renting tractors also reported an increase over the period, consistent with the findings from the econometric analysis in the previous section. According to theory and in line with the induced innovation framework, one would anticipate that, in the case of Tanzania, the change in the factor price ratio would favour the use of rented tractors.

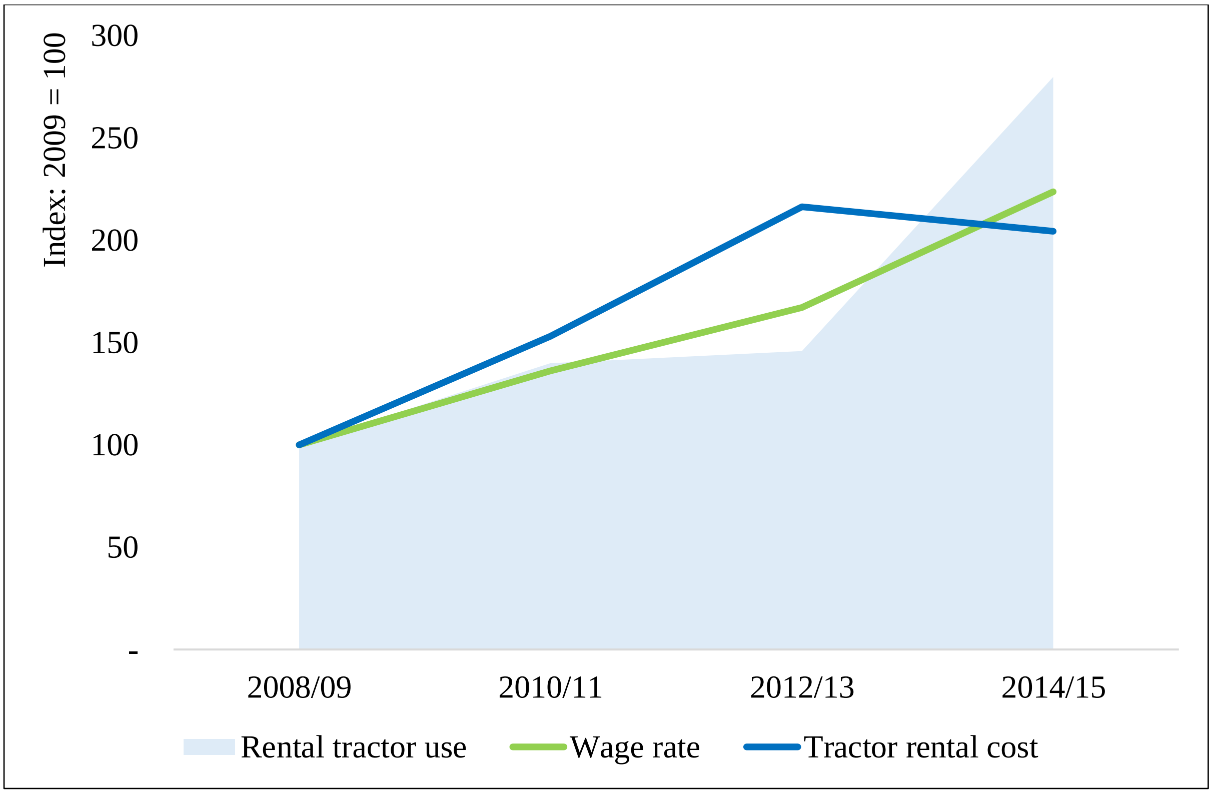

Figure 20: Mean of median changes in district-level factor prices & rental tractor use
Source: Own calculations using World Bank LSMS online data: Tanzania National Panel Survey, 2008/09 - 2014/15

Figure 21 illustrates the change in the factor price ratio (y-axis, where the factor price ratio is computed by dividing wage rate by the tractor rental cost) and the respective change in the percentage of households renting tractors per district from 2008/09 to 2014/15. The positive trend line in all figures suggests that the change in factor prices favours the adoption of tractor rental markets, which according to theory is in line with the induced innovation framework. However, by considering the bottom-right quadrant, which denotes factor price change in favour of utilising manual labour, we see that, in some cases, the use of rented tractors is still pursued. This occurrence suggests that other factors, apart from changes in factor prices, are promoting the adoption of tractor rental markets.

Table 12 illustrates the estimation results for the pooled ordinary least squares regression, which is utilised to statistically test the induced innovation hypothesis. The dependent variable is denoted as the percentage change in the number of households renting tractors per district. The covariates are defined as the change in the factor price ratio over the survey periods, lagged asset wealth, market distance, quantity harvested, maize price, fertiliser cost, and the concentration of 5 to 10 hectare producers per district. The change in the factor price ratio is statistically significant, with a positive coefficient, which favours the adoption of tractor rental services as the wage rate increases, relative to the cost to rent a tractor. The quantity of maize harvested was positively associated with tractor rental adoption, which has the ability to serve as a proxy for commercialisation, and accordingly, profitability among maize producers. Although the significance of these variables suggests that the induced innovation framework is valid in Tanzania, the robustness of the model should be further investigated to determine whether the correlation between the exogenous and dependent variables could be improved.

The results obtained from the induced innovation hypothesis test suggest that Hypothesis 3 – "The availability of tractor rental markets in specific areas may have altered relative factor prices in ways favourable to the introduction of mechanisation by smallholders" – can formally be accepted, in conjunction with the estimation results from the household rented tractor demand models.

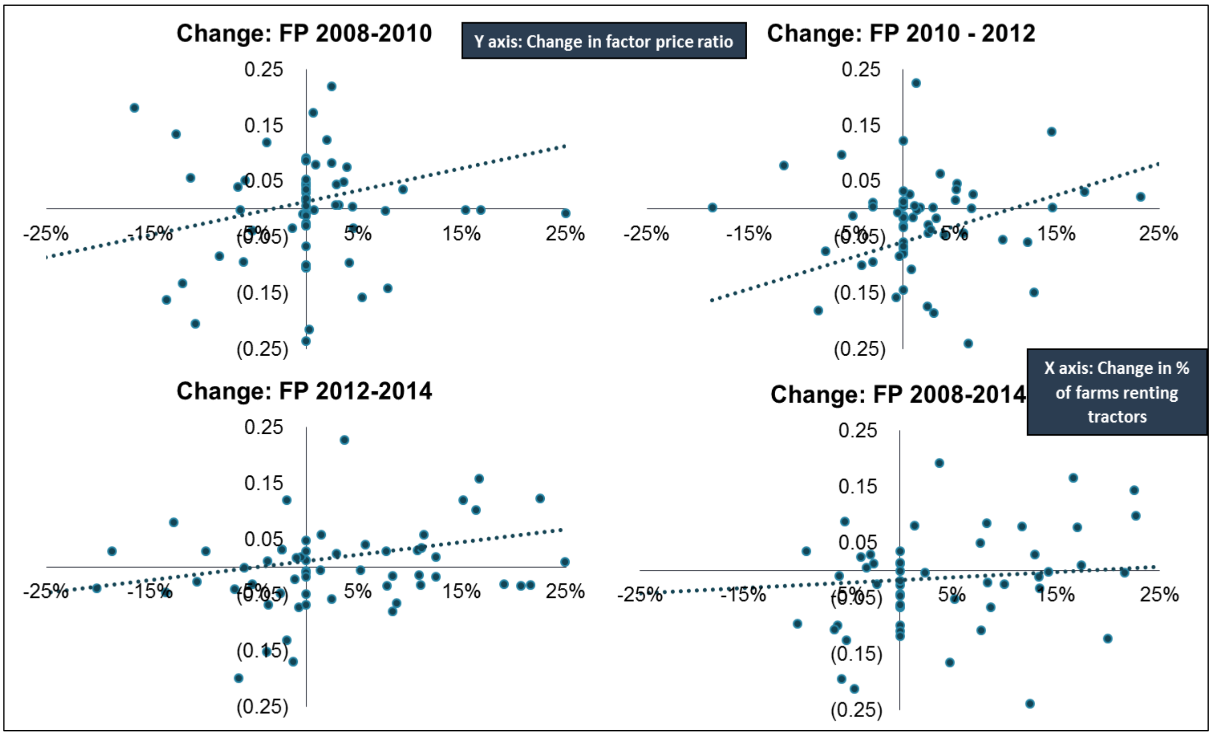

Figure 21: Relative change in factor prices vs. change in share of farms renting tractors at district-level
Source: Own calculations using World Bank LSMS online data: Tanzania National Panel Survey, 2008/09 & 2014/15

Table 12: Induced innovation hypothesis test: POLS regression results - Percentage change in the number of HH renting tractors: Δ 2008-2010; Δ2010-2012 & Δ2012-2014

Dep. Var.: Percentage change in the number of households renting tractors per district	Coef.	P > t
Δ in factor price (FP) ratio: Δ 2008-2010; Δ 2010-2012 Δ 2012-2014	0.08	0.00
Lagged asset wealth	0.00	0.77
Lagged market distance	0.00	0.33
Lagged quantity harvested	0.00	0.01
Lagged maize price	0.00	0.31
Lagged **fertiliser** cost	0.00	0.61
Lagged 5-10 ha farming households per district	0.10	0.38
_cons	0.00	0.75
Number of observations	360	

Source: Own calculations using World Bank LSMS online data: Tanzania National Panel Survey, 2008/09, 2010/11, 2012/13 & 2014/15

4.4 Conclusions

To conclude, the descriptive statistics discussed in Chapter 3 provided adequate evidence that land dynamics have rapidly changed in Tanzania, with the observation that medium-scale producers are increasingly controlling larger areas of agricultural land. The results indicated that the use of rented tractors by farming households is increasing, underpinned by the entrance of the medium-scale investor farmer. However, it was found that participation in tractor rental markets is not only limited to the producer who is cultivating 5 hectares or more, but also includes a rise in the use of tractors by smaller-scale producers, typically cultivating less than 5 hectares. As expected, the demand model in this Chapter has suggested that a larger cultivated land size is coupled with increased uptake of tractor rental services, most prominently in the 5 – 9.99 hectare land size distribution group. The estimation results also found a positive relationship between the concentration of medium-scale producers by district and the use of tractor rental services, not only by the larger land size groups, but also by small-scale farmers as well. This provides evidence of positive spill-over effects between medium- and small-scale producers where, in districts where there is a larger concentration of medium-scale producers, the adoption of tractor rental services by small-scale producers is also higher. The demand for tractor rentals is not only influenced by land size and the density of medium-scale farmers, but is also subject to relative changes in factor prices, as is underpinned by the framework for induced innovation. The estimation results have found statistically significant relationships between labour and capital, with increased participation in tractor rental markets in districts where the cost to rent a tractor has become more competitive, relative to the cost of manual labour.

Chapter 5:
Conclusions and Recommendations

5.1 Conceptual Framework and Approach of the Study

There exists a renewed interest from governments and donor stakeholders in mechanisation in SSA, however, the underlying foundations that underpin demand growth in the use of tractors remain complex. Anecdotal studies have highlighted potential relationships between mechanisation adoption and the drivers that promote agricultural transformation and growth, however, there remains uncertainty on the determinants of tractor adoption in many countries on the continent.

This study has focused on rising tractor use and corresponding spill-over effects in Tanzania, however relied on the broader mechanisation adoption principles and evidence from many parts of SSA. The reason for this approach was to assist in the development of a conceptual framework to investigate farm-level analysis on tractor adoption in Tanzania where the results in turn, may be relevant to inform the complexities of mechanisation adoption in other parts of the continent.

The conceptual framework, the design of the study objectives and hypotheses and the order of the research agenda were structured in a way to establish a sound point of departure that sets the scene for the case study in Tanzania that investigates the determinants of rising tractor use and spill-over effects. The departure point was underpinned by understanding the broader demographic- and economic drivers that positively impact the transformation of agricultural food systems in many parts of SSA.

These trends and drivers were discussed in the context of 1. agricultural mechanisation adoption and 2. the underlying theory of agricultural transformation that was developed in the 1980s followed by a thorough stock-take of the current status- and trends in agricultural mechanisation. Based on the findings from the literature, a framework for demand and supply for mechanisation was developed for parts of SSA.

To investigate the determinants of increased tractor use and spill-over effects in Tanzania, an analysis on land dynamics and tractor use were conducted to establish whether farm sizes are increasing, whether land size distribution is changing, whether tractor use among agricultural households is increasing and if so, whether it is through the acquisition of own tractors or through the development of rental markets. The results of these outcomes were further integrated into the development of demand models for tractor rentals and the induced innovation framework.

5.2 General Comments, Contributions and Results

5.2.1 The Broader Principles on Mechanisation Adoption in SSA

The introduction of this study raised the question as to why, after decades of persistently low use of tractors in SSA, there is now mounting evidence of farming households increasingly making use of mechanisation. Conventional perceptions are that tractor use in SSA is confined to large-scale commercial farms; however, various studies have identified evidence of the increasing use of tractors by smallholders as well. To date, evidence on the causes of rising use of mechanisation in the SSA region, and particularly on smallholder farms, remains limited. Consequently, it is possible that limitations on the knowledge of supply and demand principles in agricultural mechanisation markets in SSA may have contributed to state-led efforts in the past, to prematurely promote mechanisation, which is rarely considered to be a market-driven response to changing factor prices.

In recent years, governments have taken increasing interest in promoting agricultural mechanisation, which in many countries led to the introduction of official mechanisation strategies and policy framework designs to facilitate the use of mechanisation. The promotion of state-led efforts is rarely considered to be an appropriate market-driven response to changing factor prices or structural changes in the economic and demographic landscape, which underpin the theory of change as developed in the 1960s and 1980s. Apart from designing and implementing specific mechanisation policy reforms, the broader policy debate refers to agricultural development in SSA and whether policies in agriculture should be directed towards small-scale vs. larger-scale producers.

From the early 2000s, the SSA region has experienced significant dynamism, with structural changes occurring in the agro-ecological, demographic and economic landscapes in many countries, which has raised the need to revisit past literature on agricultural intensification and mechanisation. The structural shift that is caused by the interaction between a number of primary and secondary drivers of agricultural transformation, intensification and growth has the potential to reshape Africa's economies, its institutional environment, its agricultural environment, and its value chains. Hence, it has the potential to serve as a catalyst for agricultural development, growth and intensification, with a number of interesting consequences. Examples include rapid changes in farm structures, with the observations that medium-scale farms are increasingly controlling more areas of land in the region and that farm sizes in certain geographical regions are increasing. The increased profitability of medium-scale commercial farmers normally boosts the effective demand for technologies in mechanisation, and through them, augments tractor rental services used by small-scale farmers.

Apart from changing land dynamics, there is evidence of structural changes in areas such as rural- and urban-population dynamics, accelerated economic growth, an end of a downward trend in prices for agricultural commodities, growing regional and domestic demand for food, a rising middle-income consumer segment, positive agricultural growth, transformation, and investments in value chains.

To date, evidence on the causes of rising use of mechanisation in the SSA region, and particularly on smallholder farms, remains limited. Uncertainty exists regarding: the spatial representation of mechanisation; the profile of tractor users and adopters; whether changes in factor prices have led to labour-saving technologies; the role of changing farm structures and the evolution of the medium-scale farmers in promoting agricultural transformation in rural areas; and the interrelationship between structural changes and the adoption of technology. It is important to note that mechanisation is only one agricultural input and cannot be observed in isolation. For instance, mechanisation in isolation cannot correct the productivity and yield gap challenge in SSA. It should rather be observed in combination with other input uses in the context of best farm practices.

The knowledge gap, based on these high-level arguments, is that there are compelling arguments that the landscape in many African countries are changing rapidly and although mechanisation adoption has remained fairly low to date, there exists emerging evidence that the preconditions for demand growth are slowly being met in pockets of the SSA region.

The theory behind agricultural transformation, growth and farming systems intensification was developed by Boserup (1965) and Ruthenberg (1980) followed by various studies in SSA that documented the conditions that are required to activate similar trends, as was observed during the Green Revolution in Asian countries. The Green Revolution is often referred to as a period which facilitated a shift to profitable commercial farming. The theory has been described as stating that Africa was not ready for widespread mechanisation during the 1980s to 1990s. It was argued that the Boserup-Ruthenberg model for intensification is often conditional upon the occurrence of rapid population growth and improving market access conditions that could encourage higher utilisation of inputs and higher investment in mechanisation and irrigation infrastructure. Although recent economic transformations in many parts of Africa may be providing these incentives to mechanise, there remain complexities in the understanding of mechanisation adoption which perhaps were beyond the foundations and conditions that were developed in the 1980s.

Based on these complexities defined in previous theories in the context of modern developments, as is currently evident in many regions, the general objective of this study was to investigate the potential causes and farm-level spill-over effects of tractor adoption and rising use in Tanzania. The broader research problems relate to (1) the point that the historic low use of mechanisation in SSA remains a longstanding puzzle, as was recorded by Pingali, Bigot and Binswanger, and (2) the point that the recent rise in mechanisation adoption and use in SSA remains poorly understood, especially regarding the adoption of tractors among small-scale producers.

The conceptual framework that underpins increased tractor use is based on the framework of agricultural intensification, which considers population growth and market access as important drivers to enable agricultural intensification, growth and capital investment. Secondly, it reflects the evolution of farming systems which has structured the stages, shifting from the hand-hoe to animal traction, and eventually, tractorisation.

A key anchor of this study was based on the recent rapid change in farm structures, with the observation that the numbers of medium-scale farmers in certain regions continue to increase. Lastly, the induced innovation framework that outlines the relationships between relative factor prices and their respective impacts on the economic system is fundamentally important in explaining evolutionary trends in Tanzania.

The framework for demand and supply of mechanisation is underpinned by the observation that farming systems in certain pockets of SSA are evolving rapidly, which has the potential to alter trends in factor price ratios and so increase the potential for technological innovation. The increasing dependence on imported foods in the Africa region, together with higher international commodity prices and the consequent higher regional food prices, has stimulated investment in food production and supply chains. Hence, over the past decade, various incentives have existed to increase production, which created the demand for the technologies to facilitate this.

This occurred during a period associated with agricultural growth, per capita GDP growth, transformation of food and supply systems, and the creation of opportunities for off-farm labour activities, which in turn raised the opportunity cost of labour in farming systems. The literature further states that the costs of capital were at historic lows as a result of low borrowing rates and rapid financial market developments in the SSA region. In line with the induced innovation hypothesis, there is mounting evidence of increased capital-intensive and labour-saving forms of agricultural production.

Pingali et al. (1988) stated that the development of an agricultural machinery industry and the economic costs of using tractors, instead of human or animal labour, are sensitive to a number of agro-climatic and economic factors, including farm size, the utilisation of land capacity, interest rates, and the relative costs of labour and capital. The combination of these evolving trends has stimulated investment in agriculture, which also explains the increasing trend of medium-scale producers entering farming and expanding areas under production. Due to spatial variations in factor market conditions across the region, and even within countries, multiple forms of agricultural intensification in SSA should be anticipated, based on the Hayami-Ruttan induced innovation framework. In the event that larger-scale farms or entrepreneurs own and use tractors on their own farms, but downtimes in their use occur, we might anticipate that these tractor owners would rent out tractor services to farms in nearby communities, if the rental costs per hectare are competitive with manual or animal traction-based land preparation. It is also possible that medium-scale farming households are attracting investment by the suppliers of production inputs, including mechanisation rental services, which improve market access conditions for surrounding smallholder farms. Under such conditions, we might anticipate that smallholder farmers would gain access to cost-cutting land preparation technology that simultaneously frees up labour for reallocation to higher-return, off-farm activities.

5.2.2 The Determinants of Increased Tractor Use and Spill-over Effects in Tanzania

The findings in this study indicate that, apart from changes in average land and cultivated land sizes, medium-scale farmers are increasingly controlling more areas of land in Tanzania. In 2008/09, the 5-9.99 and >10 hectare land size categories cultivated 32.1% of total land, but only accounted for 5.5% of total households. By 2014/15, these groups controlled more than 40% of the total cultivated land and comprised 7.2% of total households. Farms in the 0-1.99 and 2-4.99 hectare categories experienced a decline in the share of national cultivated hectares over the period. The largest increases in area cultivated since 2008/09 occurred in the >10 hectare group (+76%) and the 5-9.99 hectare group (+54%). In absolute terms, the two groups cultivated more than 2.3 million hectares more in 2014/15 than in 2008/09. The mean farm size for the 5-9.99 hectare group increased from 6.60 hectares in 2008/09 to 6.91 hectares in 2014/15, and this was the only group to have experienced consecutive increases over the period. Apart from key trends observed in the medium-scale farming group, the study also found a continuous increase in the number of households engaging in arable production. The descriptive statistics on land dynamics in Tanzania provided evidence that mean farm sizes in the 5-9.99 hectare group and the larger than 10 hectare groups increased over the period from 2008/09 to 2014/14. There is also evidence that the number of households located in these land size groups, and the area under cultivation by them, indicated an increase over the same period.

This study hypothesised that if Tanzania follows a similar trend in rapidly changing farm structures, and if tractor use is coupled with increased area under cultivation, the adoption and continuous use of tractors should also be observed. If a positive correlation exists between what is observed at national- and farm-levels, the question arises as to who the tractor adopters and continuous users are, and as to what driving forces define the increased uptake of mechanisation. This is then followed by a question whether it is possible that medium-scale farms have a positive spill-over effect to the adoption of tractors by neighbouring small-scale producers, and whether increased tractor utilisation is visible through the use of own tractors, or through the development of tractor rental markets.

This study indicates that the number of households who made use of tractors increased by 201% over the period from 2008/09 to 2014/15 (an increase of 327 320 farm households). The increase in tractor use was driven mainly by the development of tractor rental markets, and not through the use of the farm's own tractor. The results furthermore indicate that tractor use was not confined to larger-scale producers, and that small-scale farmers also utilised tractors. The percentage of small-scale agricultural households who made use of tractor rental services increased from 2.7% in 2008/09 to 6.9% in 2014/15. When analysing rented tractor use over time, the largest percentage change occurred in the 2-4.99 and 5-9.99 hectare land size categories, with a percentage change exceeding 300% since 2008/09. Moreover, the 0-1.99 and >10 hectare groups also reported remarkable growths in rented tractor use. Hence, the adoption of rented tractor use over the period was the highest for the larger land size categories, further supporting the argument that tractor use is coupled with land sizes.

When observing spatial representation of rented tractor use in Tanzania, it was clear that rentals are concentrated mainly along the northern and eastern parts of mainland Tanzania. These regions are often referred to as being the more commercialised agricultural producing regions. The Arusha and Manyara regions recorded the highest household participation in tractor rental markets. In 2014/15, approximately 30% of households cultivating agricultural land in Arusha, and 22.4% in Manyara, reported having rented a tractor, being a 15% increase in Arusha alone since 2008/09. Kilimanjaro and Morogoro reported shares of 20% and 19%, respectively. Arusha reported a substantial increase in the number of farmers located in the >10 hectare group since 2008/09. By 2014/15, an additional 8 568 households had entered this group, which has cultivated nearly 240 000 hectares of agricultural land. The same trend was observed for Manyara, which reported an increase of 2 364 households in the >10 hectare group, which had cultivated 67 642 hectares in 2014/15. Interesting to note is that, despite the high share of households making use of rented tractors in Kilimanjaro, the sample suggested that there were no households located in the 5-9.99 and >10 hectare groups in 2014/15. When observing the weighted results of rentals per region, it can be concluded that Morogoro (15.47%), Arusha (15.46%), Kilimanjaro (12.02%) and Dodoma (10.23%) are the regions with the highest participations in tractor rental markets.

The descriptive results, therefore, validated the point that increasing tractor use in Tanzania is observed among farming households in Tanzania. The increase in the number of households making use of tractors is not limited to larger-scale producers, and is also observed among small-scale agricultural households. While observing the respective tractor usages among land size categories, there is evidence that land size is positively coupled with tractor use.

The descriptive statistics described in Chapter 3 provided adequate evidence that land dynamics have rapidly changed in Tanzania, with the observation that medium-scale producers are increasingly controlling larger areas of agricultural land. The results indicated that the use of rented tractors by farming households is increasing, underpinned by the entrance of the medium-scale investor farmer.

However, it was found that participation in tractor rental markets is not limited to producers cultivating 5 hectares or more, and that a rise in the use of tractors is also seen among smaller-scale producers, typically cultivating less than 5 hectares. The characteristics of successful tractor-rental operations include private proprietorship by producers or small entrepreneurs, the concentration of power-intensive operations (where ploughing seasons are short), the solution of the capacity-utilisation problem through migration of tractors among agro-climatic zones, and the continued use of animal traction for operations that are less power intensive.

The results of the household tractor rental combined model, derived from the pooled GLM and MC CRE Probit estimation, indicated that land size is coupled with tractor use through rental services, particularly in the 5-9.99 hectare group. For the MC CRE model, the robustness of the land size variable with farm size above 10 hectares has improved substantially, indicating that, as we controlled for unobserved time-constant heterogeneity, the impact of large-scale farms becomes more prominent.

The persistent increase in the numbers of medium-scale farmers in SSA could entail that tractor rental markets will continue to develop, not only in Tanzania, but likely in the region as well. The results provide evidence that the use of tractor rental services is not limited to medium-scale producers, and that small-scale agricultural households also use tractor rental services. The estimation models also validated the point that tractor use is increasing in Tanzania, as suggested by regional and national import data.

Male household heads are more likely to rent a tractor than female household heads are, when the pooled GLM estimation results are considered. The household head age variable in the MC

CRE model results indicates that household heads older than 60 years of age are less likely to rent a tractor than household heads younger than 30 are.

The negative coefficient for the market distance variable in the MC CRE model might suggest one reason why areas closer to towns, which are the areas that experience the greatest labour shortages, are the areas where tractor rental markets are relatively more developed.

The wage rate variable has indicated that, as wage rates increase, a shift towards renting a tractor would be considered. As expected, the negative coefficient in the tractor rental cost variable implies a negative relationship with renting a tractor. These results uphold the importance of relative changes in factor prices, which is consistent with the induced innovation hypothesis.

The variable for the number of medium-scale farms (between 5-10 hectares) per district reported a positive relationship between the percentage share of medium-scale farms per district and the decision to rent a tractor among small-scale producers. The hypothesis is that medium-scale farmers are likely to be considered as being more commercialised producers and would perhaps utilise improved inputs such as hybrid seeds and fertiliser. As farming operations intensify and mechanisation services are attracted, the availability of these services might become feasible for use by neighbouring small-scale farmers. In districts that experience a higher concentration of farms between 5 and 10 hectares over time, a higher probability exists of renting a tractor, as opposed to districts that are less concentrated with medium-scale farms. The between-household effects of the maize price suggest that areas that experience higher maize prices, on average, are more likely to experience tractor rentals, which could serve as a proxy for profitability and incentivise producers to increase their areas under production. Tractor adoption and use will vary between regions. Highly commercialised regions, such as Arusha and Kilimanjaro, will comprehend a higher probability of renting a tractor, as opposed to less commercialised regions.

At national level, the use of tractors among farming households remained low (8.7% of nationally representative survey correspondents); however, a post-estimation analysis has revealed that, once certain demographic indicators are controlled for, the probability of renting a tractor could exceed 50% in certain regions.

The demand for tractor rentals is not only influenced by land size and the density of medium-scale farmers, but is also subject to relative changes in factor prices, as underpinned by the framework for induced innovation. The estimation results have found statistically significant relationships between labour and capital, with increased participation in tractor rental markets being experienced in districts where the cost to rent a tractor has become more competitive, relative to the cost of manual labour.

The understanding of the potential role that medium-scale farmers can play in SSA could reform the thinking behind public-sector policy frameworks and private-sector market engagements. It further promotes the idea of redesigning academic research and information/data sources.

The findings of this study have the potential to inform the private sector and governments of the potential role of larger-scale farms in promoting a movement to more capital-intensive forms of farming, not only on large farms but also on smallholder farms. The study findings remind researchers and policy decision-makers of the reasons why state-led efforts in promoting mechanisation largely failed during the 1980s. Sims and Kienzle (2016) have stated that farm power and agricultural mechanisation are key to increasing the land and labour productivity rates so as to end poverty and hunger, as is stipulated by the Sustainable Development Goals. The demand for mechanisation from the small-scale farming sector needs to be raised to stimulate the product value chain and active input supply. The importance of mechanisation and its ability to accelerate the transformation process in agriculture cannot be emphasised enough. It remains an essential input, not only for agricultural production, but also throughout food systems value chains.

The substitution of mechanisation for family labour on smallholder farms may release labour from farming to other activities that provide higher returns to labour. In South Africa, however, employment on farms continued to increase with the adoption of tractors for land preparation after the Second World War until combine harvesters were introduced from the late 1960s because more land was ploughed and more labour was required to harvest the crop. While the recent rise of larger farms in Africa may pose important challenges to smallholder farmers, which are well covered in international media, it is also possible that large-scale farms may contribute to diversification of income sources off the farm and provide sources of labour productivity growth for rural households. Of course, evidence from a wider number of countries is needed to test the robustness of this view.

5.3 Recommendations for Future Studies

Future research on the topic of mechanisation in SSA can use the same methodology and study objectives for other countries in the region with the intend to compare the results across countries that have experienced a combination of economic dynamism and stagnation coupled with high and low population densities. Although the use of large surveys assists in generating important evidence at farm-level, it remains difficult to draw inferences about changes over time when one has only a few survey ways. The lack of data availability in SSA often restricts the use of time series analysis. It is therefore important to continuously update the results, as new survey waves become available. There is also a strong motivation to revisit traditional approaches to large surveys in Africa with the objective to more accurately account for farms larger than 10 hectares. Innovation in econometric techniques in exploring the characteristics and spill-over effects of tractor adoption can be enhanced if more detail was available on tractor use in Tanzania. For instance, the LSMS survey- and questionnaire design only captures limited information on tractor use at household level. Examples of innovative techniques include a double-hurdle estimation approach in order to link the use of tractors with area under cultivation.

There is also a continuous demand to explore the determinants of tractor use and non-use with the objective to investigate farm-level data and trends in Tanzania, Ghana, Zambia and Kenya for instance where survey data is available. The approach can investigate patterns that can inform mechanisation trends of continuous users and adopters, either through own tractor acquisition or the participation in rental markets and continuous non-users and dis-adopters. Specific objectives of these studies can include to generate cross-country descriptive statistics on the characteristics of tractor using households and provide inference on the potential enabling environment for increased tractor use in these countries with a market-led approach for tractor demand. The research can also focus on the counterpart, hence, those households that do not make use of tractors. The findings can inform governments and the private sector on the successes and failures that are experienced at farm-level and can further guide policy and identify private sector interventions that could promote mechanisation use in SSA.

To inform supply side dynamics, an attempt can be made to model macro-level covariates that drive tractor use through a multi-country fixed effects approach. The objective could be to explore whether national demand models can be constructed to investigate potential relationships with commodity prices, macro-economic indicators such as economic growth, oil price, exchange rates and interest rates, policy variables (such as ease of doing business and import barriers) and other variables including proxies for commercialisation, market access, changing farm structures, availability of credit, labour dynamics and property rights.

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Appendix A

Appendix A1:

Table A.1: Estimation output: Pooled GLM & MC CRE Probit results

Variable:	Definition:	Units of observation:	Categorical / Continuous	Mean:	Description of variables: Percentile				
2008/09									
					Percentile: Hectare distribution per group				
					10%	**25%**	**50%**	**75%**	**90%**
Land cult	Land size category on cultivated hectares	0-1.99 hectares	Categorical	0.81	0.12	0.41	0.81	1.22	1.62
		2-4.99 hectares	Categorical	2.99	2.03	2.23	2.84	3.75	4.25
		5-9.99 hectares	Categorical	6.60	5.27	5.67	6.38	7.29	8.10
		>10 hectares	Categorical	30.90	10.53	12.15	17.01	25.11	47.79
Head type	Household head is male or female	Male / Female	Categorical	Male	Female	Male	Male	Male	Male
					Percentile: Age group distribution				
					10%	**25%**	**50%**	**75%**	**90%**
Head age	Household age group	>30 years; 30-45; 46-60 & older than 60 years	Categorical	Between 30-45 & 46 – 60 years of age	>30 years	30-45 years	30-45 years	46-60 years	Older than 60
					Percentile:				
					10%	**25%**	**50%**	**75%**	**90%**
Asset wealth	Total household asset value	TSH	Continuous	676 080	3 500	10 000	24 000	74 000	384 000
Market distance	Total distance to closest market	Kilometres	Continuous	7.99	1.00	3.00	5.50	11.00	18.00
Tractor rental cost	The cost to rent a tractor per acre	TSH	Continuous	50 237	13 000	24 000	40 000	60 000	105 000
Wage rate	The wage rate per worker per day	TSH	Continuous	4 697	833	1 429	2222	4 327	7500
Fertiliser cost	The cost of fertiliser per kilogram	TSH	Continuous	1 585	500	720	1 100	2 000	2 800
Maize price	The price for maize per kilogram	TSH	Continuous	319	111	150	200	291	369
Share: Medium-scale in region	The percentage share of farms >5 hectares in a district	Percentage	Continuous	21.80	0.00	3.57	14.42	29.55	87.51
2010/11									
					Percentile: Hectare distribution per group				
					10%	**25%**	**50%**	**75%**	**90%**
Land cult	Land size category on cultivated hectares	0-1.99 hectares	Categorical	0.76	0.00	0.41	0.81	1.22	1.62
		2-4.99 hectares	Categorical	2.90	2.03	2.23	2.63	3.44	4.05
		5-9.99 hectares	Categorical	6.50	5.27	5.57	6.08	7.29	8.10
		>10 hectares	Categorical	17.84	10.53	11.54	12.15	19.44	29.57
Head type	Household head is male or female	Male / Female	Categorical	Male	Female	Male	Male	Male	Male
					Percentile: Age group distribution				
					10%	**25%**	**50%**	**75%**	**90%**
Head age	Household age group	>30 years; 30-45; 46-60 & older than 60 years	Categorical	Between 30-45 & 46 – 60 years of age	>30 years	30-45 years	46-60 years	46-60 years	Older than 60
					Percentile:				
					10%	**25%**	**50%**	**75%**	**90%**
Asset wealth	Total household asset value	TSH	Continuous	925 968	5 000	12 500	31 500	84 000	530 000

Market distance	Total distance to closest market	Kilometres	Continuous	12.47	2.00	4.00	7.25	14.63	29.00
Tractor rental cost	The cost to rent a tractor per acre	TSH	Continuous	69 007	20 000	30 000	45 000	80 000	150 000
Wage rate	The wage rate per worker per day	TSH	Continuous	5 284	1 000	1 667	3 000	5 179	9 500
Fertiliser cost	The cost of fertiliser per kilogram (averaged for all types used)	TSH	Continuous	1 381	380	600	980	1 520	2 500
Maize price	The price for maize per kilogram	TSH	Continuous	279	150	180	240	300	400
Share: Medium-scale in region	The percentage share of farms >5 hectares in a district	Percentage	Continuous	21.65	4.33	8.56	12.17	20.31	70.42
2012/13									
					Percentile: Hectare distribution per group				
					10%	**25%**	**50%**	**75%**	**90%**
Land cult	Land size category on cultivated hectares	0-1.99 hectares	Categorical	0.75	0.00	0.32	0.65	1.22	1.62
		2-4.99 hectares	Categorical	3.03	2.03	2.43	2.84	3.65	4.17
		5-9.99 hectares	Categorical	6.75	5.27	5.67	6.40	8.06	8.51
		>10 hectares	Categorical	20.16	10.53	11.75	15.39	20.25	31.63
Head type	Household head is male or female	Male / Female	Categorical	Male	Female	Female	Male	Male	Male
					Percentile: Age group distribution				
					10%	**25%**	**50%**	**75%**	**90%**
Head age	Household age group	>30 years; 30-45; 46-60 & older than 60 years	Categorical	Between 30-45 & 46 – 60 years of age	>30 years	30-45 years	46-60 years	46-60 years	Older than 60
					Percentile:				
					10%	**25%**	**50%**	**75%**	**90%**
Asset wealth	Total household asset value	TSH	Continuous	945 572	5 000	12 000	31 500	99 000	1 104 000
Market distance	Total distance to closest market	Kilometres	Continuous	12.05	2.00	3.43	7.00	15.00	27.00
Tractor rental cost	The cost to rent a tractor per acre	TSH	Continuous	104 589	20 000	30 000	65 000	120 000	225 000
Wage rate	The wage rate per worker per day	TSH	Continuous	8 173	1 071	2 143	4 000	7 500	15 333
Fertiliser cost	The cost of fertiliser per kilogram (averaged for all types used)	TSH	Continuous	1 976	640	1 000	1 500	2 600	3 850
Maize price	The price for maize per kilogram	TSH	Continuous	458	240	278	350	500	625
Share: Medium-scale in region	The percentage share of farms >5 hectares in a district	Percentage	Continuous	18.70	2.27	10.57	11.79	24.73	29.17
2014/15									
					Hectare distribution per group				
					10%	**25%**	**50%**	**75%**	**90%**
Land cult	Land size category on cultivated hectares	0-1.99 hectares	Categorical	0.81	0.20	0.41	0.81	1.22	1.62
		2-4.99 hectares	Categorical	2.95	2.03	2.23	2.84	3.65	4.05
		5-9.99 hectares	Categorical	6.91	5.47	5.83	6.68	8.10	8.51
		>10 hectares	Categorical	21.28	10.73	12.15	12.96	22.28	40.10
Head type	Household head is male or female	Male / Female	Categorical	Male	Female	Female	Male	Male	Male
					Percentile: Age group distribution				
					10%	**25%**	**50%**	**75%**	**90%**
Head age	Household age group	>30 years; 30-45; 46-60 & older than 60 years	Categorical	Between 30-45 & 46 – 60 years of age	>30 years	30-45 years	30-45 years	46-60 years	Older than 60
					Percentile:				
					10%	**25%**	**50%**	**75%**	**90%**

Asset wealth	Total household asset value	TSH	Continuous	1 199 380	7 500	18 000	45 000	145 000	2 076 000
Market distance	Total distance to closest market	Kilometres	Continuous	9.69	1.75	3.00	6.00	10.33	21.33
Tractor rental cost	The cost to rent a tractor per acre	TSH	Continuous	119 386	45 000	60 000	131 674	131 674	178 000
Wage rate	The wage rate per worker per day	TSH	Continuous	6 846	1 333	2 500	4 800	8 000	15 000
Fertiliser cost	The cost of fertiliser per kilogram (averaged for all types used)	TSH	Continuous	1 626	860	1 000	1 400	2 000	3 000
Maize price	The price for maize per kilogram	TSH	Continuous	365	200	250	300	400	500
Share: Medium-scale in region	The percentage share of farms >5 hectares in a district	Percentage	Continuous	20.85	4.54	7.37	24.50	27.51	30.35

Source: Own calculations using World Bank LSMS online data: Tanzania National Panel Survey, 2008/09, 2010/11, 2012/13 & 2014/15