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Rising tractor use in sub-Saharan Africa: Evidence from Tanzania

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Abstract

After decades of persistently low use of agricultural mechanization, the proportion of African farmers using tractors has rapidly increased since 2005. The conventional wisdom is that tractor use in sub-Saharan Africa is confined mainly to large-scale commercial farms. However, there is mounting evidence of rapidly increasing use of tractor use by smallholder farmers, albeit through tractor rental markets in geographically concentrated areas. To date, the drivers of rising use of mechanization services on smallholder farms remains poorly understood which often attributed to state-led efforts to prematurely promote mechanization which is rarely considered to be a market-driven response to changing factors prices, however recent economic transformation in Africa may be providing these incentives. This study addresses this information gap by using four waves of data from the nationally representative National Panel Survey from 2009, 2011, 2013 and 2015 to identify the factors driving Tanzanian smallholders' use of mechanization and whether there is evidence of the potential role of larger-scale farms in promoting a movement to more capital-intensive forms of farming. Increase tractor use is dominated by the development of tractor rental markets and not through own acquisition where the largest participation was observed in the 2-4.99 and 5-9.99 hectares' land size categories. Estimation results uphold the importance of relative changes in factor prices following the induced innovation hypothesis, and also point to the importance of spillover effects from medium-scale farms. The concentration of medium-scale farms in the district positively and significantly increases the probability of smallholder participation in tractor rental markets. This study contributes to the growing literature examining potential spillover benefits accruing to smallholder farmers from their proximity to larger farms.

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

Rising Tractor Use in Sub-Saharan Africa: Evidence from Tanzania

1. Introduction

After decades of persistently low use, tractors are being utilized by a rapidly increasing number of African farmers since 2000 (International Trade Centre, 2017). Conventional perceptions are that tractor use in sub-Saharan Africa has been confined to large-scale commercial farms or has been driven by government-subsidized mechanization campaigns. However, there is mounting evidence of rising demand for tractor services by medium-scale and small-scale African farmers. For example, recent studies by Diao et al. (2014); Takeshima, Pratt, & Diao (2013); Chapoto et al. (2014); Sims & Kienzle (2016); Mrema (2016); and Adu-Baffour et al. (2018) have investigated the rising use of tractors in selected sub-Saharan African 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- and large-scale farms in driving tractor use and acting as nucleus change agents to promote a more commercialised smallholder sector (Takashima, Pratt and Diao, 2013; Chapoto et al., 2014).

To date, however, the causes of rising use of mechanization services on smallholder farms has received little attention and has yet to be linked to evidence on changing factor prices that might underlie market-driven changes in farm technologies. Few studies have explored the role of tractor rental markets in driving increased use of mechanization in Africa, and these markets remain poorly understood even though mounting evidence indicates that the rising use of tractors by smallholder farmers is largely driven by participation in rental markets.

This study addresses this information gap by identifying the factors associated with the rise of mechanization rental markets in Tanzania. Two specific hypotheses are explored: First, that medium-scale farms are promoting a movement to more capital-intensive forms of land preparation, not only on these farms but on smallholder farms as well through tractor rental markets. Second, we hypothesize that the rise in demand for mechanization services on smallholder farms reflects evolving trends in labor-capital factor price ratios, consistent with the Hayami-Ruttan induced innovation theory. These hypotheses are tested with tractor rental demand models using four waves of data from the nationally-representative National Panel Survey from 2009, 2011, 2013 and 2015.

The contribution of this study is to identify the factors driving increased use of tractor services by smallholder farmers through rental markets in Tanzania. Rental markets are the primary means by which Tanzanian small- and medium-scale farmers access tractor use. Our conceptual framework, drawing on the Hayami-Ruttan induced innovation hypothesis, explores the extent to which the increased demand for mechanization services reflect changes in farm factor prices associated with economic transformation. Our framework also examines the potential co-evolution of changes in farm size distributions and mechanization use. Recent studies have documented changes in farm size distributions in a number of African countries and it is possible that the rise of medium- and large-scale farmers owning tractors has encouraged the development of tractor rental markets utilized by nearby smallholders. The availability of tractor rental markets in some areas may have altered relative factor prices in ways favorable to the introduction of mechanization by smallholders.

The findings of this study underscores the importance of changing factor price ratios in driving incentives for increased tractor use by smallholder farmers through rental markets. The substitution of capital for family labor on smallholder farms may release labor from farming to other activities that provide higher returns to labor. We also find that, consistent with other recent studies, potential spillover benefits to smallholder households resulting from new nearby investments in mechanization associated with proximity to medium- and large-scale farms. While the recent rise of larger farms in Africa may pose serious challenges to smallholder farmers as often highlighted in international media, it is also possible that large-scale farms may be sources of labor productivity growth for smallholder households by improving their access to mechanization services that allow them to expand area under production while reducing labor input. Consistent with other studies (e.g., Adu-Baffour et al., 2018), we argue that state-led efforts to promote mechanization through subsidy programs are often confronted with severe governance challenges and that market demand-led initiatives may offer promising

alternatives, especially as the price of labor is anticipated to rise relative to capital as economic transformation processes continue. Of course, evidence from a wider number of countries is needed to test the robustness of these findings.

2. Trends in tractor use in Sub-Saharan Africa

Historically, mechanization use in Sub-Saharan Africa (SSA) has been very low, substantially lower than in other developing regions (Figure 1). In 2002, there were 1.3 tractors per 1,000 hectares of cultivated land in SSA, compared to 9.1 in South Asia and 10.4 in Latin America (Pingali, 2007). Agricultural tractors in use in Tanzania have declined by more than 50% over the period from the 1960's to the 1980's before a marginal recovery was observed towards the early 2000's.

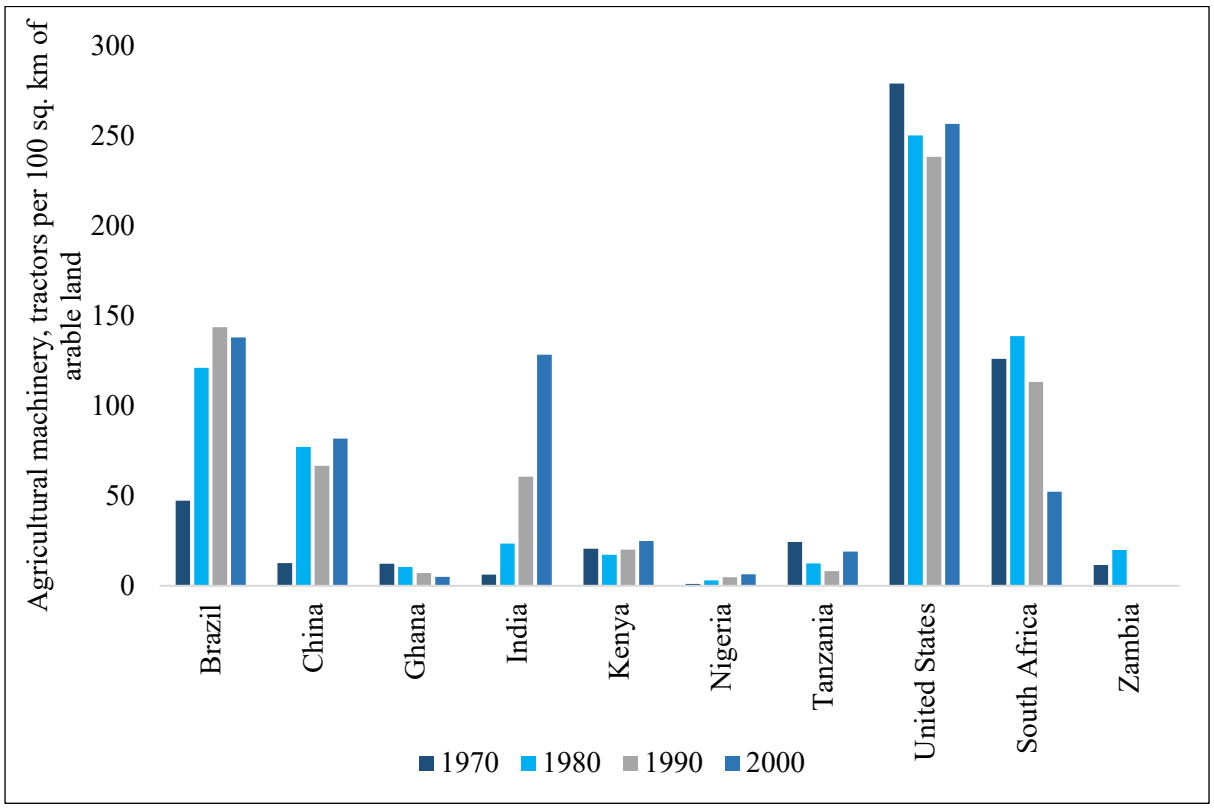

Figure 1: Agricultural machinery, tractors per 100 sq. km of arable land
Source: World Bank, 2016

Information on tractor use in Sub-Saharan Africa remains limited; many sources discontinued reporting data after 2000. A more consistent measure of annual tractor demand in recent years is provided by the International Trade Centre's TradeMap database, which uses national revenue statistics on bilateral tractor trade and importation into Africa. Figure 2 presents TradeMap data on the nominal value of tractor imports (referred to as tractors, parts thereof, and accessories) in Sub-Saharan Africa in US dollars over the period 2001 to 2015. Figure 2 indicates that imports of tractors into Sub-Saharan African have increased substantially over this period. The period 2006 to 2010 was characterized by high agricultural commodity prices. West Africa shows a noteworthy increase in the value of imports, driven mainly by Nigeria.

Except for North Eastern Africa, all other regions reported a decline in imports from 2014 to 2015. Figure 3 illustrates tractor imports into Ghana, Nigeria, Kenya, Tanzania and Zambia. The value of tractor imports into Kenya reported a firm upward trend in contrast to other focus countries. Tractor imports into Tanzania reflected a noteworthy increase from 2009 to 2011 (growing by 54% per annum).[2] Over the period, Nigeria reflected robust imports, however reported a substantial decrease since 2013. Mrema (2016) stated that the annual imports of tractor units into Tanzania reported an increasing trend over the period from 2005 to 2014. Imports peaked in 2014, amounting to 1,212 tractors, substantially higher than the 356 units reported in 2005.

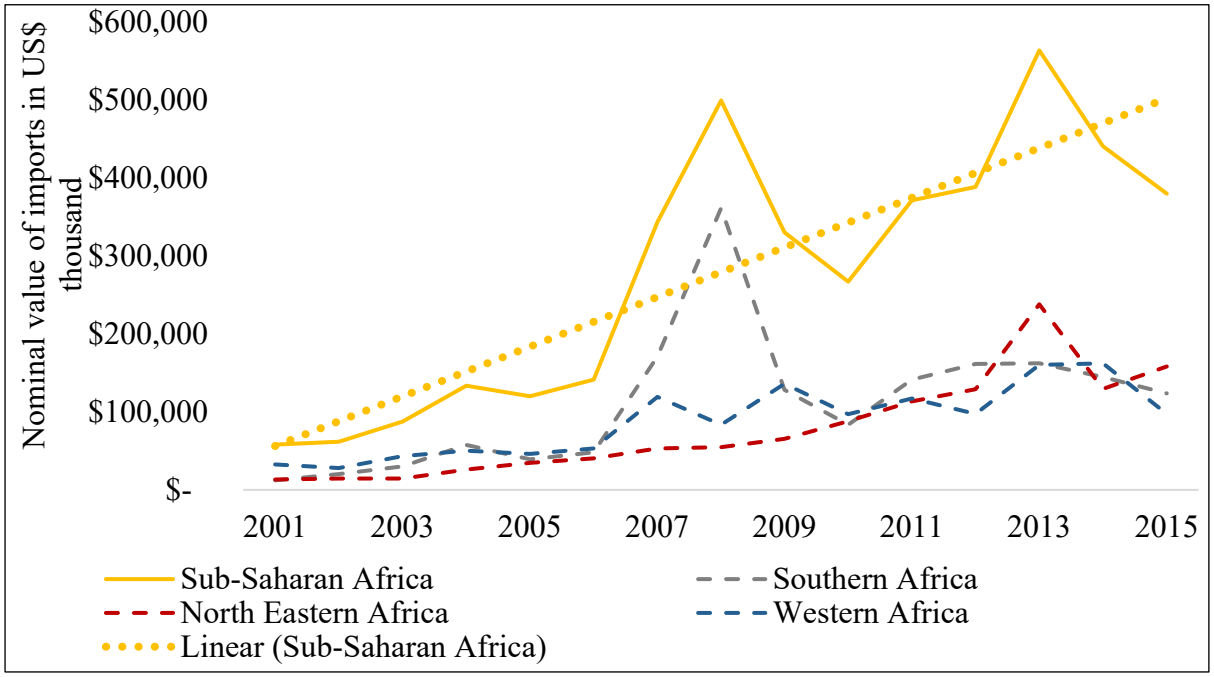

Figure 2: Nominal value of tractor imports in Sub-Saharan Africa excluding South Africa (HS870790) in US$ (2001-2015)[3]

Source: International Trade Center & Trademap, 2016

[2] These short-term changes suggest potential policy effects, e.g., efforts in Tanzania related to the launch of Kilimo Kwanza in 2009 and the 2010 election, and, in Nigeria reduced government resources to subsidise tractor imports with the decline in world oil prices.

[3] The Harmonised Commodity Description and Coding System (HS) is an internationally standardised system of names and numbers to classify traded products and is maintained by the World Customs Organisation (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.

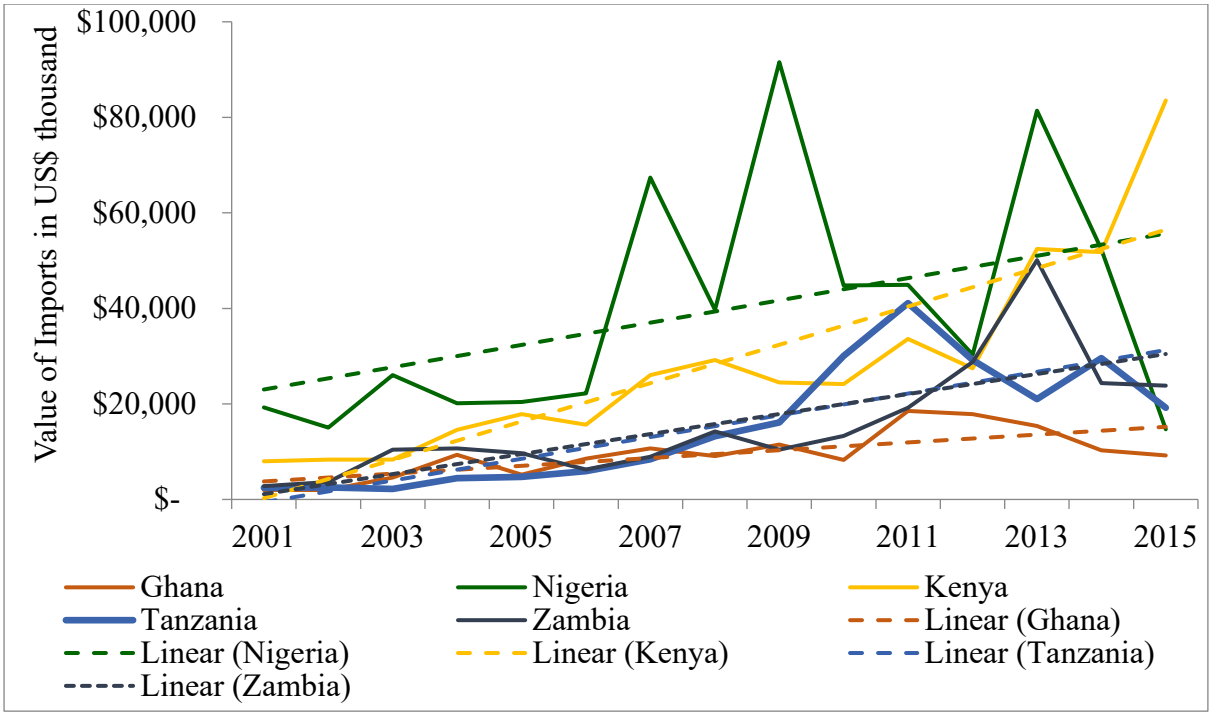

Figure 3: Nominal value of tractor imports in selective Sub-Saharan African countries (HS870790) in US$ (2001-2015)
Source: International Trade Center & Trademap, 2016

3. Conceptual Framework: Causes of Rising Tractor Use in Sub-Saharan Africa

The influential theory behind agricultural transformation and intensification of farming systems developed by Boserup (1965) and Ruthenberg (1980) suggests that labor-abundant and capital-scarce African countries were not ready for widespread mechanization during the 1980's and 1990's (Diao et al. 2014). Binswanger et al. (1988) investigated the causes of slow adoption where emphasis was placed on the slow evolution of African farming systems. More recent demographic and macro trends suggest that farming systems are evolving rapidly in many parts of Sub-Saharan Africa, which may be altering the trends in factor price ratios and increasing the potential for technological innovation (e.g., AGRA 2016; Richards et al., 2016; United Nations, 2017; Jayne et al., 2018). Due to the region's increasing dependence on imported foods, higher international commodity prices and consequently regional food prices stimulated investment in food production and supply chains. The incentives to expand area under cultivation have stimulated the demand for technologies to facilitate the increase in production. The transformation of food systems and supply chains has further stimulated off-farm employment opportunities (Tschirley et al., 2015; Yeboah and Jayne, 2018), which has in turn raised the opportunity cost of labor in farming, especially in areas experiencing economic dynamism and growth (Yeboah and Jayne, 2018). 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 Sub-Saharan Africa (Andrianaivo and Yartey, 2009; Ojah and Odongo Kodongo, 2015). For these reasons, and consistent with the induced innovation hypothesis, mounting evidence is pointing to

increased capital-intensive and labor-saving forms of agricultural production in at least parts of Africa, including rising use of herbicides and pesticides (Haggblade et al., 2017); lower use of labor per hectare cultivated (Olwande, 2018); an increasing share of national cultivated land and agricultural output on medium-scale farms (Jayne et al., 2016), and, most relevant for this study, rising use of mechanization in agricultural production (Diao et al. 2014).

Binswanger et al. (1988) contend that the development of an agricultural machinery industry and the economic costs of using tractors instead of human or animal labor is sensitive to a number of agro-climatic- and economic factors, including farm size, the utilization of land capacity, interest rates, and the relative costs of labour and capital. AGRA (2016) and Jayne et al (2016) report changes in the distribution of farm sizes featuring a rapid rise of farmland under medium scale farms, while Deininger and Byerlee (2011) report a rise in large-scale, often foreign-owned farms in Africa. Bishop-Sambrook quoted in Sims & Kienzle (2016) has investigated the relationship between farm size and mode of land preparation and found that farming households using manual labour typically cultivate 1-2 hectares per annum, draft animal power service providers typically cultivate 2 hectares per annum, households owning draft animal power cultivate between 3-4 hectares per annum, tractor service providers cultivate about 8 hectares and households owning a tractor cultivates more than 20 hectares.

Because of substantial spatial variation 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 farms own and use tractors on their own farm but there exist times of slack use, 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 mechanization rental services, which improve market access conditions for surrounding smallholder farms. Under such conditions, we might anticipate smallholder farmers gain access to cost-cutting land preparation technology that simultaneously frees up labor for reallocation to higher-return off-farm activities.

4. Data and Methods

Annual data on tractor importation from 2001 to 2015 for 40 sub-Saharan African countries is sourced from the International Trade Centre's Trademap Database. The Harmonized Commodity Description and Coding System (HS) is an internationally standardized system of names and numbers to classify traded products and is maintained by the World Customs Organization (WCO).

The Tanzanian National Panel Survey (NPS) for 2008/09, 2010/11, 2012/13 and 2014/15, implemented by the National Bureau for Statistics with support from the World Bank is a series of nationally representative household surveys that collect information on a wide range of topics including agricultural production, non-farm income generating activities, consumption expenditures and other household characteristics (Tanzania National Bureau of Statistics,

2015). 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.

To estimate a demand function for tractor rental services, we specified generalized linear models (GLM), which provided a flexible generalization 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, we used a PROBIT model, which assumes a normal cumulative distribution, to estimate the likelihood of renting a tractor. The PROBIT model relates the predictors to the response through the respective link function (Econometric Methods, 2017):

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

We estimate and present pooled probit and Correlated Random Effects probit model results. While pooled probits can control for unobserved regional effects through the use of regional dummies, there still remains the issue of unobserved heterogeneity at the household level. To address this, we incorporate the Mundlak-Chamberlain device (Mundlak 1978; Chamberlain 1984) into the models, which provides an estimator that Wooldridge (2010) refers to as the Correlated Random Effects (CRE) model. The CRE 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-averaged variables. For the binary response model, the unobserved effects probit model can be specified as follow:

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

We assume strict exogeneity and specify the Mundlak-Chamberlain device as follow:

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

where ψ is a scalar and λ is a $K\ x\ 1$ vector of coefficient parameters to estimate (Wooldridge, 2010). $\overline{X_i}$ is denoted as time-averages and is added 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 $\mathrm{X_{it}}$ which assumes that a_i is uncorrelated with $\mathrm{X_{it}}$, for all t and therefore $\overline{X_i}$. CRE requires unique interpretations for the time-varying and time-constant explanatory variables, i.e., effects on the dependent variable for a given household *i* resulting from a change in X_{it}, vs. effect on the dependent variable based on time-constant differences in $\overline{X_i}$ across households (Burke and

Jayne, 2014). The within- household effects refer to the time-varying explanatory variables' coefficients or β, where these estimates are identical to the fixed effects estimator under assumptions of strict exogeneity (Wooldridge, 2010). The CRE estimated coefficients on all time-averaged components of the model represents the between-household effects or λ.

The household tractor rental probit model contains a set of exogenous household-level, community-level regional, and year variables. Household-level variables include household cultivated area categories ($Land_{cult}$) with sub-population defined as 0-1.99 hectares, 2-4.99 hectares, 5-9.99 hectares and >10 hectares land size groups. Community regressors include the district-level median of wage rates for land preparation ($Wage_{rate}$) and tractor rental cost per hectare ($Trac_{rent}$) as reported by households in the surveys. We expect that agricultural wage rates (tractor rental rates) will be positively (inversely) related to the probability that a farmer will rent tractor services. $Maize_{price}$ and $Fert_{cost}$ represent the median district-level price of maize and inorganic fertilizer per kilogram, respectively. $Asset_{wealth}$ refers to the total value of household assets. It is expected that wealthier households are better able to rent a tractor than poor households. $Market_{dist}$ represents the distance from the farm to the nearest district town, which serves as a proxy for market access. We hypothesize that farmers will be more likely to rent a tractor if located closer to district towns, where such services are typicaly located. $Head_{type}$ refers to the gender of the household head (1=male). $Head_{age}$ represent four dummy variables signifying the age category of the household head (15-25, 25-35, 35-45 over 45 years of age). The purpose is to test whether younger household heads are more likely to make use of technology oppose to older 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 to 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 spillover 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.

The induced innovation hypothesis test to determine the correlation between changes in factor prices and households renting tractors was estimated by denoting the dependent variable as Y = percentage change in the number of households renting tractors and 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 fertilizer, 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).

4. Descriptive results

We first show trends in farm size distributions and tractor adoption over the period from 2008/09 to 2014/15[4] using National Panel Survey (NPS) data for Tanzania. Farms were

[4] It is important to note that the National Bureau for Statistics in Tanzania has redesigned the sample design for the 2014/15 survey to ensure proper representation of estimates and maintaining a sufficient primary sample. It is therefore expected that variation can occur in the 2014/15 survey results and does not necessarily entail that trends have shifted. Secondly, the questionnaire in 2014/15 for land ownership details has changed from the 2008/09 to 2012/13 questionnaires where the 2014/15 description on ownership allowed for more categories which may cause

categorized according to the following categories by cultivated area: 0-1.99 hectares, 2-4.99 hectares, 5-9.99 hectares and over 10 hectares. Figure 4 illustrates the land size distribution per category by reporting the percentage of households located in each group and their respective cultivated area. In 2008/09, the 5-9.99 and >10 hectares' land size categories have cultivated 32.1% of total land but only accounted for 5.5% of total households. By 2014/15, these groups have controlled more than 40% of the total cultivated land and consisted of 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.

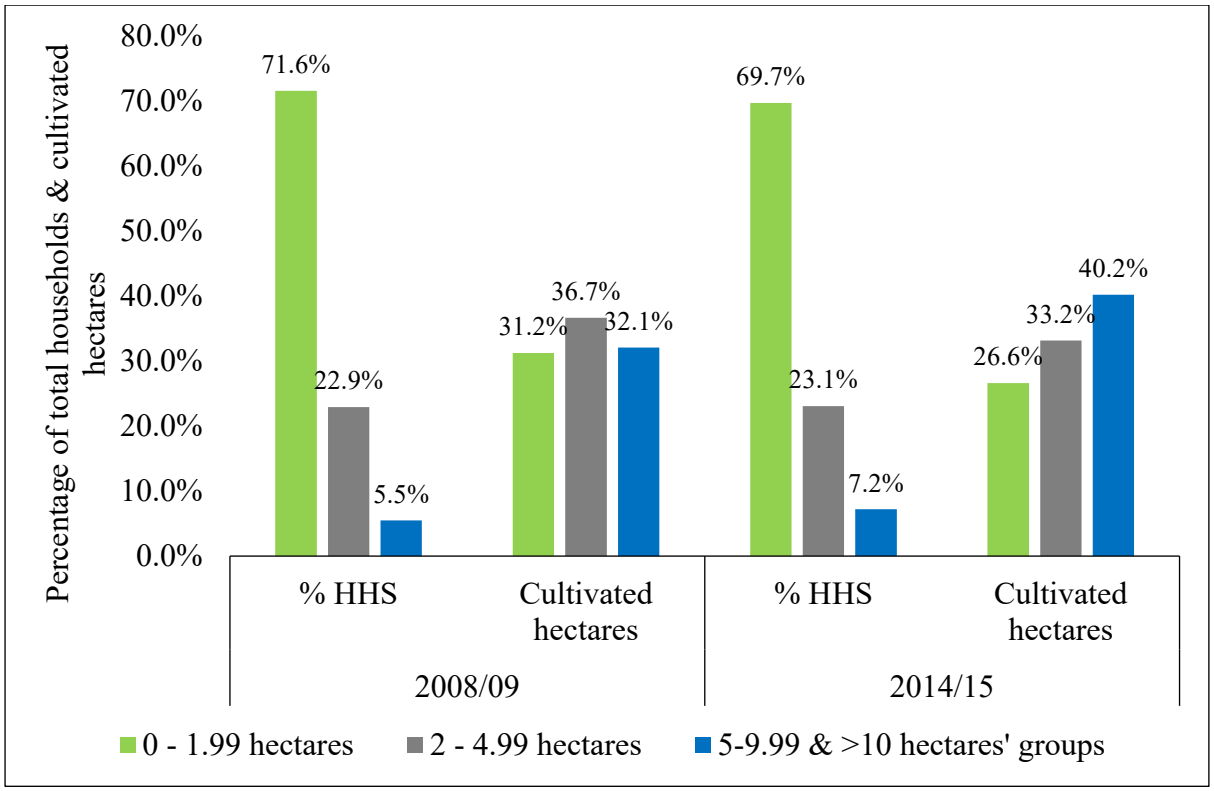

Figure 4: Cultivated land in Tanzania: % of households and cultivated hectares per land size category

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

The largest increase in area cultivated since 2008/09 occurred in the >10 hectares' group (+76%) and 5-9.99 hectares' category (+54%). In absolute terms, the two groups have cultivated more than 2.3 million hectares more in 2014/15 than in 2008/09. The mean farm size for the 5-9.99 hectares' group has increased from 6.60 hectares in 2008/09 to 6.91 hectares in 2014/15, the only group to have experienced consecutive increases over the period. Farm sizes in the 0-1.99 hectares category remained relatively constant.

Figure 5 illustrates tractor use in Tanzania over the period from 2008/09 to 2014/15 and represents the number of households using tractors and the hectares of cultivated area where

drastic variations from 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 stipulated ownership status of farming households.

tractors were likely utilized. The secondary axis reports the percentage of small-scale households using tractor rental services. The graph indicates that the number of households that made use of tractors have increased by 201% over the period from 2008/09 to 2014/15 (an increase of 327,320 farm households). The hectares of cultivated area where a tractor was used (on either the entire field or only a fraction of it[5]) reflected an increase of 546,578 (+74%) hectares. 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 producer, but also on small-scale farms as well. The percentage of small-scale agricultural households who made use of tractor rental services has increased from 2.7% in 2008/09 to 6.9% in 2014/15.

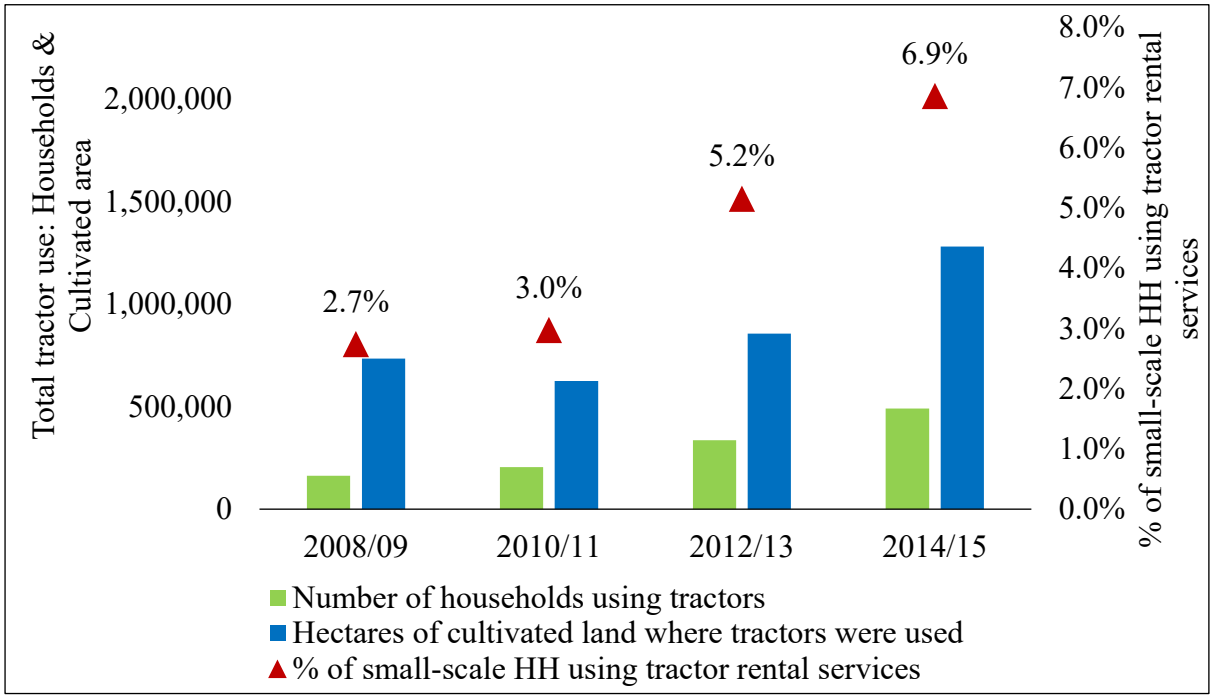

Figure 5: Total tractor use (own & rented) in Tanzania: Number of households & cultivated hectares: 2008/09, 2010/11, 2012/13 & 2014/15
Source: World Bank online data: Tanzania National Panel Survey, 2008/09, 2010/11, 2012/13 & 2014/15

Figure 6 and Figure 7 illustrates rented tractor use in Tanzania among land size categories over the period from 2008/09 to 2014/15. Figure 6 indicates the percentage of households in a particular land size category that rented tractor services whereas Figure 7 illustrates the percentage of cultivated area where a tractor was likely used. 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 are not limited to relative large farms only, although use rates are indeed positive correlated with farm size category.

[5] The survey questionnaire only requests the respondent to provide a binary response whether a tractor was used or not and does 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.

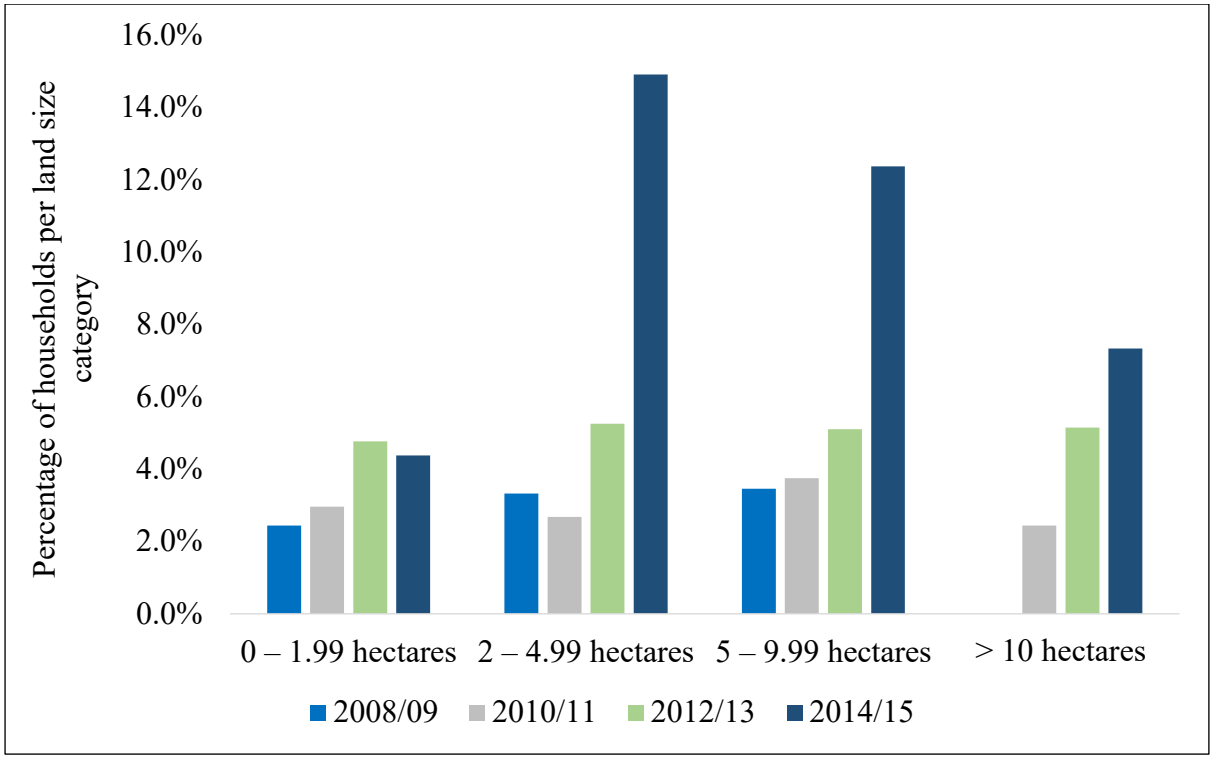

Figure 6: Percentage of households renting tractor services by operated farm size category – 2008/09, 2010/11, 2012/13 & 2014/15

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

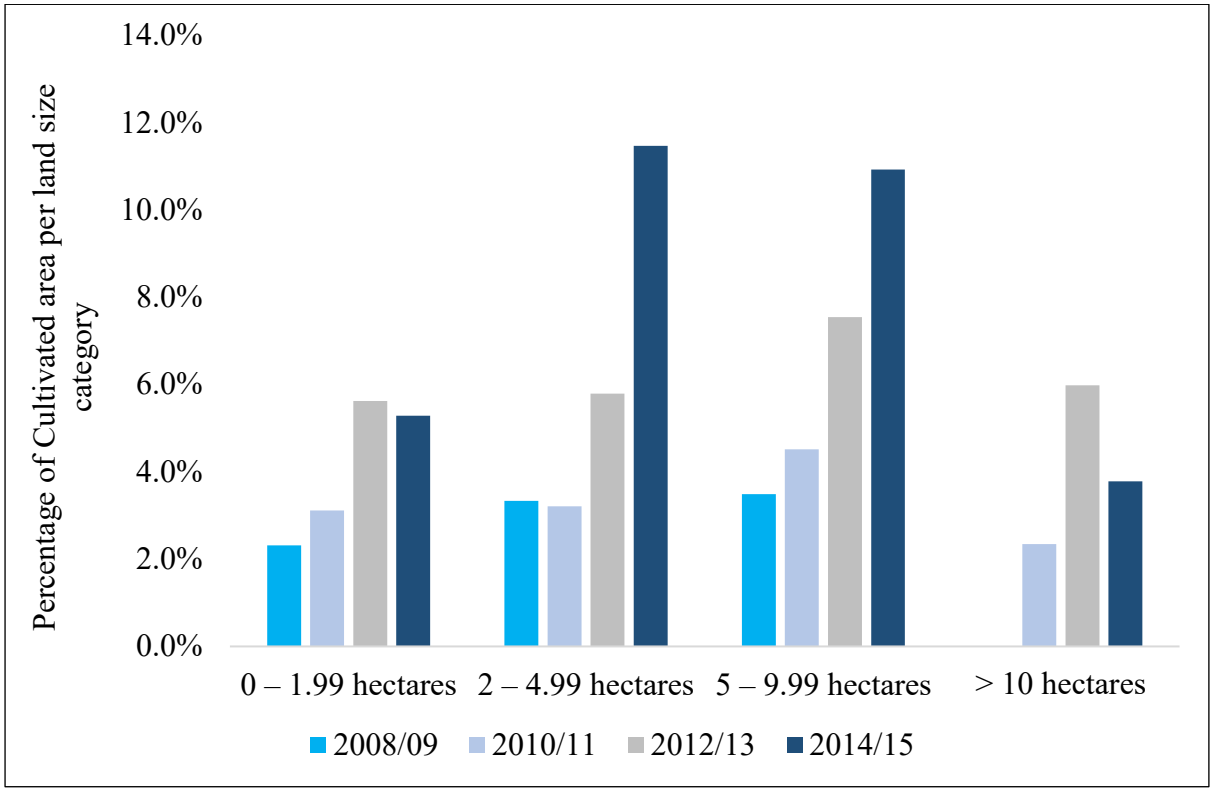

Figure 7: Percentage of cultivated area using rented tractor services by operated farm size category – 2008/09, 2010/11, 2012/13 & 2014/15

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

Table 1 indicates that remarkable growth has occurred in the number of households making use of tractor rental markets over the period from 2008/09 to 2014/15. Both the 2-4.99 and 5-9.99 hectares' land size groups reported increases exceeding 300% over the period. Table 2 summarizes 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 in both the percentage of farmers using tractors as well as 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 to use a tractor. The proportion of cultivated hectares utilizing 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 in making use of a tractor, an increase of nearly 12% from 2008/09.

Table 1: Rental tractor use & percentage change over time: Households (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: World Bank online data: Tanzania National Panel Survey, 2008/09 & 2014/15

The land dynamics analysis has reported an increase of 840,000 hectares cultivated by the 5-9.99 hectares' 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, 6.17% of total households located in this group. The 5-9.99 hectares' 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 hectares' 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 2: Tractor use in Tanzania: Percentage of households & 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: World Bank online data: Tanzania National Panel Survey, 2008/09, 2010/11, 2012/13 & 2014/15

Figure 8 shows the regional variation in tractor use. Arusha and Manyara regions have 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 reportedly rented a tractor, a 15% increase in Arusha alone since 2008/09. Kilimanjaro and Morogoro also reported shares of 20% and 19% respectively. Arusha has reported a substantial increase in the amount of farmers located in the >10 hectares' group since 2008/09. By 2014/15, an additional 8 568 households have entered this group which have cultivated nearly 240,000 hectares of agricultural land. A similar trend was observed in Manyara. 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%) represented the highest tractor use regions in Tanzania.

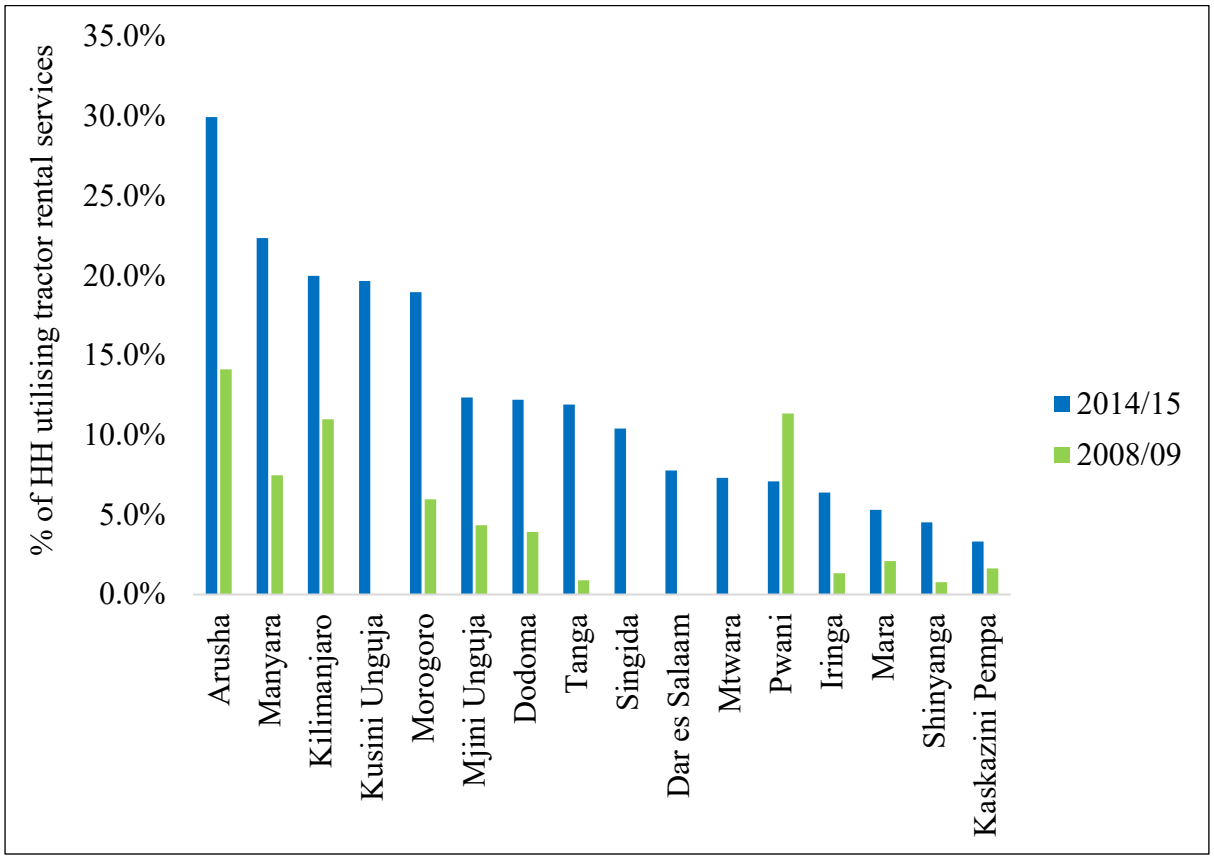

Figure 8: Regional rented tractor use: Percentage of households per region: 2008/09 & 2014/15

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

Factors associated with tractor rental use among Tanzanian farmers

Based on standard input demand models, we specified and estimated probability regression (PROBIT) models 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. We dropped from the sample households in regions where less than two percent of households rented tractors because 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 4 reports the estimation results for pooled GLM probits and MC CRE. Since the National Bureau for Statistics in Tanzania has redesigned the sample design for the 2014/15 survey, panel econometrics 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 on the additional wave of survey data (2014/15) and 2) to leverage on panel data econometrics to address the issue of unobserved heterogeneity at the household level. To address these objectives, we made use of the pooled GLM probit estimation technique and the MC CRE approach to control for unobserved household effects. The joint interpretation of these approaches could validate the coefficients of key variables of interest and provide useful insights on the interaction between them. By limiting the data set to households located in the 0 to 5 hectares' 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 decision to rent a tractor among smallholders and whether positive spill-over effects exists.

Econometric results

The household tractor rental model results from the pooled GLM and MC CRE probit estimation are presented in Table 4. 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 hectares' 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 amount of medium-scale farmers in Sub-Saharan Africa 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 on 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 in Figure 2 and Figure 3. The increase in the magnitude of the coefficient from 2008/09 to 2014/15 implies that the probability to rent a tractor is accelerating. $x3_{head_{type}}$ suggests that male household heads are more likely to rent a tractor oppose to female household heads when the pooled GLM estimation results are considered. The household head age variable in the MC CRE model results indicates that heads older than 60 years of age are less likely to rent a tractor opposed to heads younger than 30. The negative coefficient for the market distance variable in the MC CRE model might suggests that areas closer to towns are the areas that experience the greatest labor shortages which are also the areas 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 will 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 number of medium-scale farms (between 5-10 hectares) per district variable, $x11_{hh\_5\_10ha}$, is significant at 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 among small-scale producers. The hypothesis is that medium-scale farms are likely to be considered as more commercialized producers and perhaps utilizing improved inputs such as hybrid seeds and fertilizer. As farming operations intensify and mechanization services are attracted, availability of these services may become available to neighbouring small-scale farmers. The coefficient of the time-constant covariate, $hh\_5\_10\_ha\_mean$, in the MC CRE estimation results indicates that districts that experience a higher concentration of farmers between 5 and 10 hectares over time have a higher probability of renting a tractor opposed to districts which is less concentrated with medium-scale type farms. The between-household effects for the variable, $log\_maize\_price\_mean$, suggests that areas that experience higher maize prices on average are more likely to rent a tractor which could serve as a proxy for profitability and incentivise producers to increase the area 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 commercialized regions such as Arusha and Kilimanjaro will comprehend a higher probability to rent a tractor oppose to lower commercialized regions.

Table 3 illustrates the sensitivity between variables by using predicted probabilities (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 their respective means) suggested a 8.7% probability that a household will rent a tractor. However, when starting to control for certain variables whilst holding other variables at their means, the results indicate interesting responses. The highest percentage change in probability to rent a tractor in the land size categorical variable was observed in the $x1_{land_{cult:\,5-9.99ha}}$ group (an increase of 10.4% in the probability to rent 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 marginal positive response as wage rate increases. The overall probability to rent a tractor increases from 8.7% to 10.0% if the 2014 75th percentile wage rate is considered. Similarly, the cost to rent a tractor reflected also a marginal response on the decision to rent a tractor, decreasing by 1.6% if the 75th 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 rents a tractor. The 25th percentile, median, 75th and 90th percentiles for 2014 were considered to compute the change in probability as the number of medium-scale farms per district are fluctuating. The predicted probabilities indicate that as the concentration of 0 to 5 hectares producer per district is increasing, the probability to rent a tractor is also increasing (from 7.1% to 18% between the

25th and 90th percentiles for 2014 and keeping all other variables at the data means). Based on the Hayami-Ruttan induced innovation framework, in the event that larger farms own and use tractors on their own farm but there exist times of slack use, 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. Under such conditions, we might anticipate mutual synergies between large farms to small farms through the development of tractor rental markets, whereby larger farms more fully utilize the capacity of expensive capital investments, and whereby smallholder farmers gain access to cost-cutting land preparation technology that simultaneously frees up labor for reallocation to higher-return off-farm activities.

Table 3: 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	7.1%	-1.6%
	2014 median	8.7%	-
	2014 75th percentile	10.0%	+1.3%
Tractor rental cost	2014 25th percentile	10.5%	+1.8%
	2014 median	9.0%	0.3%
	2014 75th percentile	7.1%	-1.6%
Concentration of 5-20ha 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	18.0%	+9.3%
Predicted probabilities for regions where land size = 4-9.99 ; year =2014 ; head type = male & concentration of 0-5 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: World Bank online data: Tanzania National Panel Survey, 2008/09, 2010/11, 2012/13 & 2014/15

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 4 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 to rent a tractor in these regions. The highest positive response was 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 to rent a tractor. These regional effects indicates that important developments are occurring with regards 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.

Estimation results uphold the importance of relative changes in factor prices consistent with the induced innovation hypothesis

A key element to be tested in this study is the impact of changing factor price ratios on the adoption of more capital-intensive forms of farming, hence the theory behind the induced innovation framework and whether it is applicable for the case in Tanzania. The approach is to compute the trend of factor prices over the period from 2008/09 to 2014/15 and determine the implication on the percentage of farms at district-level renting tractors. In order to test the induced innovation hypothesis, pooled ordinary least squares (POLS) regression is utilized to statistically validate this aspect of the study. Figure 11 illustrates an index (base year = 100 = 2008/09) for wage rate for land preparation, the cost to rent a tractor and the trend for households renting tractors. According to the data, the cost to rent a tractor has 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. According to theory and in line with the induced innovation framework, one would anticipate that in the case for Tanzania, the change in the factor price ratio would favor the use of tractor rentals.

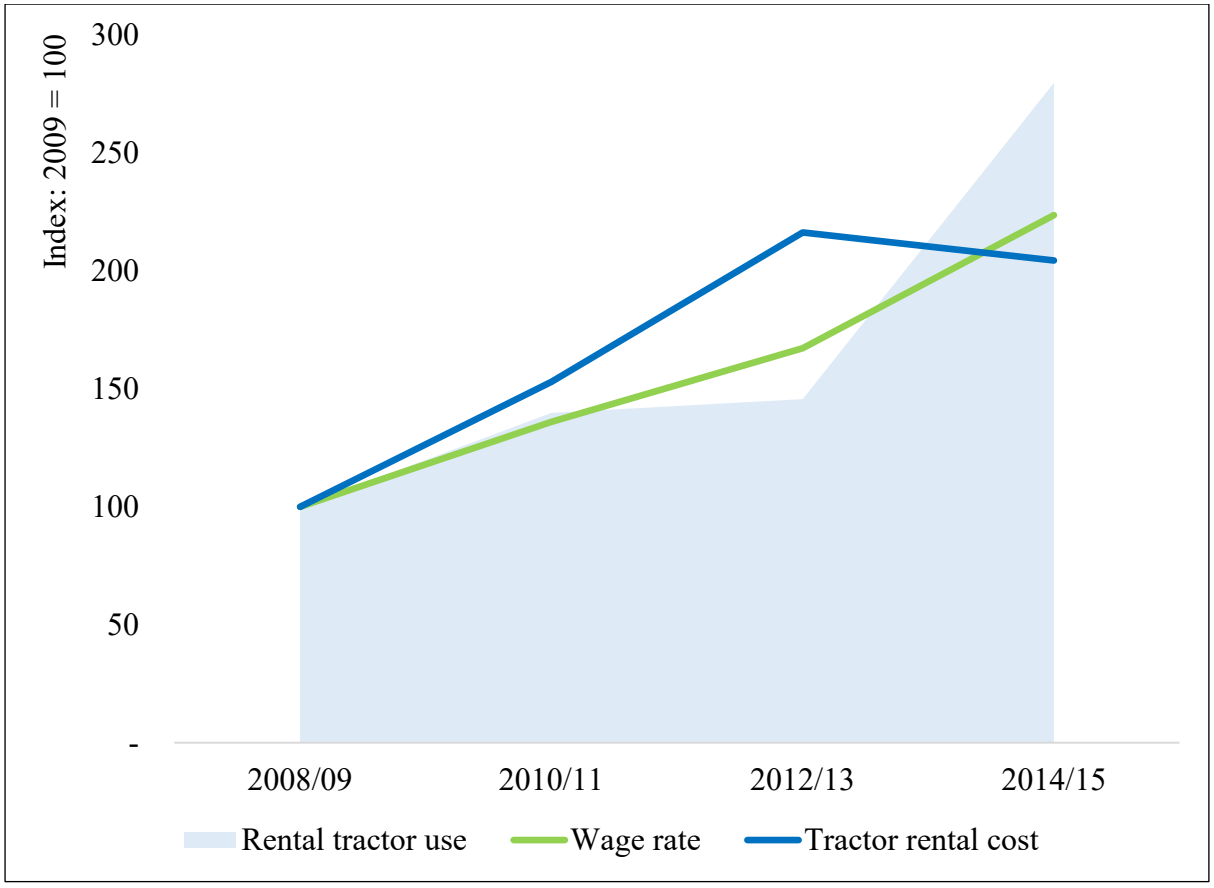

Figure 9: Mean of median changes in district-level factor prices & rental tractor use
Source: World Bank online data: Tanzania National Panel Survey, 2008/09 & 2014/15

Figure 12 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 favors 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 favor of utilizing manual labour, we see that in various cases that the use of rented tractors is still pursued. This occurrence suggests that other factors, apart from changes in factor prices, are supporting the adoption of tractor rental markets.

Table 3 illustrate the estimation results for pooled ordinary least squares regression which is utilized to formally 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, fertilizer cost and the concentration of 5 to 10 hectares' producer per district. The change in the factor price ratio is statistically significant with a positive coefficient, which favors the adoption of tractor rental services as wage rate increases relatively to the cost to rent a tractor. The quantity of maize harvested was also positively associated with the adoption of tractor rental markets, which could serve as a proxy for commercialization and hence, profitability among maize producers.

The estimation results thus formally validate that the induced innovation hypothesis is valid for the Tanzania case.

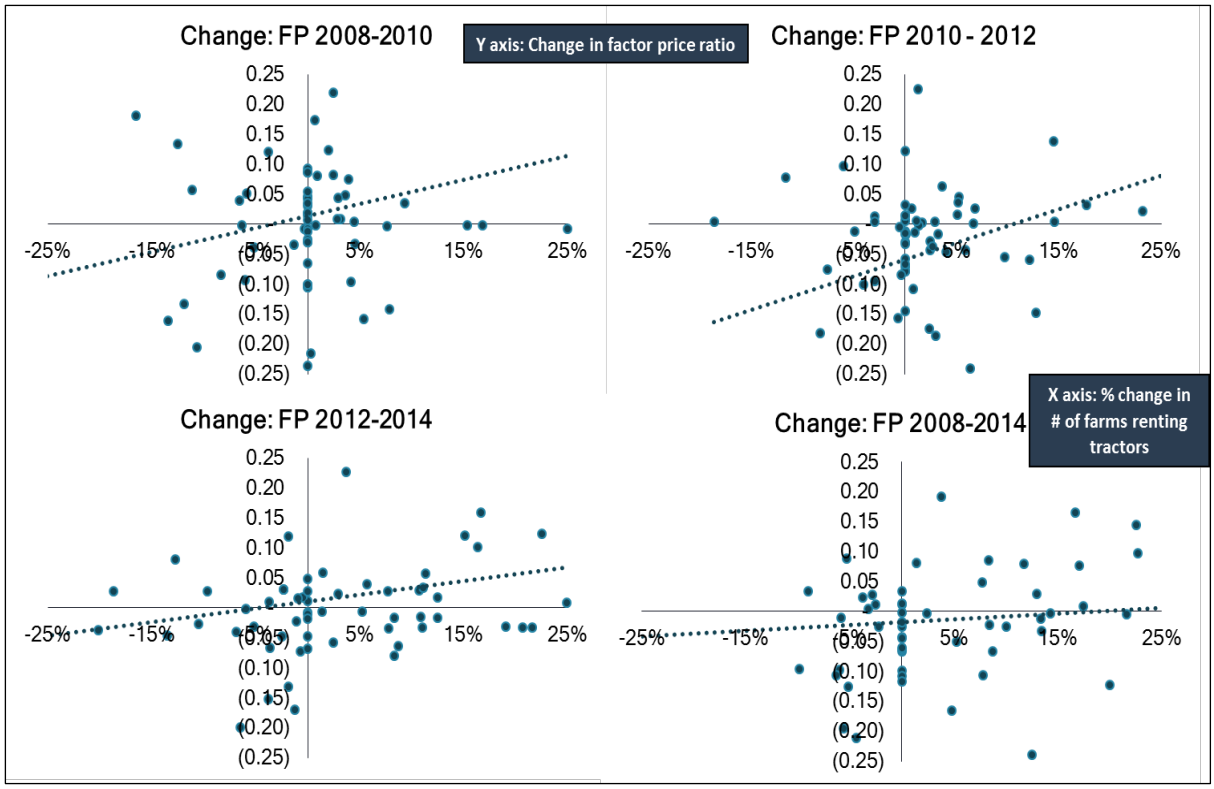

Figure 10: Relative change in factor prices vs. change in share of farms renting tractors at district-level

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

Table 4: Induced innovation hypothesis test: OLS 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 fertilizer 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	
R squared	0.050	

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

5. Conclusions, Recommendations and Policy Implications

This study is motivated by the observation that tractor use for land preparation has risen rapidly in recent years in specific areas of Tanzania. The increase in the number of households making use of tractors is not limited to larger-scale producers, but is also observed among small-scale agricultural households. 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 hectares' land size categories. The spatial illustration and regional analysis indicated significant regional variation in regional tractor adoption with only a few regions indicating remarkable growth in rental services over the period.

The main finding of this study is that the increase use of tractor rental services by smallholder farmers in Tanzania is significantly associated with the concentration of medium-scale farms in the district. In areas where there is a high concentration of medium-scale farms, such as in Arusha, Morogoro and Manyara, for example, over 20 percent of small-scale farmers make use of tractor rental services, compared with under five percent in most other districts of the country. Our findings also indicate an overall rising rate over time in the use of tractor rental services on smallholder farms.

The findings of this study provided evidence about the potential role of large-scale farms in promoting a movement to more capital-intensive forms of farming, not only on large farms but on smallholder farms as well. This study points to potential spillover benefits to smallholder households resulting from new nearby investments in mechanization by medium and perhaps large-scale farms. The substitution of capital for family labor on smallholder farms may release labor from farming to other activities that provide higher returns to labor. While the recent rise of larger farms in Africa may pose important challenges to smallholder farmers that are well covered in international media, it is also possible that medium-scale farms may contribute to diversification of income sources off the farm and be sources of labor productivity growth for rural households. Of course, evidence from a wider number of countries is needed to test the robustness of this story.

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Table 5: Estimation output: Pooled GLM & 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**
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
	(0.14)	(0.25)	(0.99)	(0.85)

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**
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**		
	(0.06)	(0.02)		
Region = Shinyanga	-0.15	-0.31		

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**
	(0.60)	(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***
			(0.05)	(0.00)
hh_10_20_ha_mean			-18.29	-19.39

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**
			(0.12)	(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: World Bank online data: Tanzania National Panel Survey, 2008/09, 2010/11, 2012/13 & 2014/15