

Determinants of Mechanization in Rice Production in Tanzania: Evidence from Panel Data

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Despite the increasing trend of using four-wheeled tractors (TR) and power-tillers (PT) to prepare the land, studies on agricultural mechanization are relatively scant in Sub-Saharan Africa. This study examines the determinants of machinery use by rice-growing households in Tanzania, using a household-level panel data set. We find that farmers who grow rice in areas with high wage rates for hired labor are more likely to use TR. Furthermore, we find that the existence of TR and PT rental markets in the village is positively associated with using them. Improving access to affordable machinery rental services would enhance machinery adoption.

Key words: mechanization, rice farming, Tanzania

1. Introduction

Technological transformation in agriculture is considered as a potential pathway to reduce poverty and enhance food security in Sub-Saharan Africa (SSA). Among staple crops grown in SSA, rice has emerged as the most important crop as its demand has nearly tripled in the past 30 years (USDA, 2020), mainly due to rapid urbanization, population growth, and shift in consumers' preference towards rice. In many countries of SSA, strategies for the transformation of rice production primarily focus on the adoption of Green Revolution type of technologies, such as yield-enhancing modern varieties, improved agronomic practices, and chemical fertilizer. This led to an increasing number of studies that examine how these technologies are being disseminated and adopted in SSA (Nakano *et al.*, 2018; Otsuka and Larson, 2016). Meanwhile, studies on mechanization in SSA remain scant, despite the recent increase in the use of four-wheeled tractors (TR) and power tillers (PT) among rice farmers (Kiriú and Braun, 2018).

Mechanization is expected to contribute to agricultural development by facilitating the expansion of cultivated area and by enhancing the performance of high-yielding modern varieties and chemical inputs (Daum and Birner, 2020; Pingali *et al.*, 1987). Although machinery use is gradually increasing in SSA, as we will discuss later, the agricultural mechanization has been slow compared to Asian countries. Therefore, it is important to understand what factors are

associated with machinery use among small-scale farmers in SSA to promote agricultural mechanization in the region.

This study aims to contribute to the literature on agricultural mechanization in SSA in two ways. First, we provide a brief overview of agricultural mechanization in SSA in comparison with South East Asia (SEA) and South Asia (SA), using macro statistics. Second, we investigate the determinants of machinery use by applying a household level three-year panel data set collected in Tanzania. Especially, we focus on the use of tractors (TR) and power tillers (PT) for land preparation of rice cultivation. By doing so, we aim to identify the constraints for small-scale rice farmers to adopt agricultural machinery.

According to the previous literature, there are two different potential reasons that can explain the use of machinery. First, the increased use of machinery can be caused by the rising rural wage rates, driven by an increase in rural non-farm income and job opportunities in nearby urban centers. This may induce pressure on farmers to use machinery as the substitute for labor (Hayami and Ruttan, 1985; Wang *et al.*, 2016; Yamauchi, 2016). The second possible reason can be the increased availability of affordable machines and the reduction in price for renting them (Binswanger and Rosenzweig, 1986). In Asian countries such as India and Bangladesh, rental service has been an essential factor in the widespread use of agricultural machines (Diao *et al.*, 2014).

With respect to the two driving factors for mechanization,

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our estimations show that village-level wage rates for hired labor increase the probability of using TR, suggesting that TR are used as a substitute for human power. We also find that farmers with large plots are likely to use TR and PT, indicating that mechanization can play a role in facilitating the cultivation of large rice area. Furthermore, we find that the existence of TR and PT rental markets in the village is associated with the probability of using them. Our results imply that improving access to affordable machinery rental services at the village level would enhance the adoption of machinery use.

The rest of the paper is organized as follows. Section 2 provides an overview of agricultural mechanization in Asia and SSA by using macro statistics. Section 3 explains the data and study sites, while Section 4 discusses the estimation strategy and the description of variables. The results and conclusions are respectively provided in Section 5 and Section 6.

2. Mechanization Trend in SSA

To present the trend of mechanization in SSA, we use statistical data from Food and Agriculture Organization and the World Bank (FAO, 2020; World Bank, 2020). The data contains information on the number of tractors, including both TR and PT, from 1961 to 2002. Figure 1 shows the number of tractors in use in SA and SEA started to increase rapidly in the early 1970s and in the 1990s, respectively, while that in SSA does not have such an increasing trend. It increased steadily from 170,980 in 1961 to the peak at 246,320 in 1981, then decreased to 136,550 in 2002. Please note that the data from FAO and World Bank is available only up to 2002.

According to Pingali *et al.* (1987), tractors were introduced in SSA in three phases. The first phase was under the colonial rule between 1945 and 1955, when Zimbabwe, Kenya, Zambia, and Malawi started to introduce tractors. The second phase was from the late 1950s to the 1970s, when countries such as Tanzania, Ethiopia, Ghana, and Côte d'Ivoire started to promote state-sponsored mechanization schemes after their independence. The third phase was between the 1970s and the 1980s when countries rich in oil and other exportable natural resources such as Nigeria, Cameroon, and the Democratic of Congo started to make efforts to increase tractor use. However, most of the state-sponsored tractor rental schemes were discarded under the structural adjustment programs, resulting in the decline of machinery

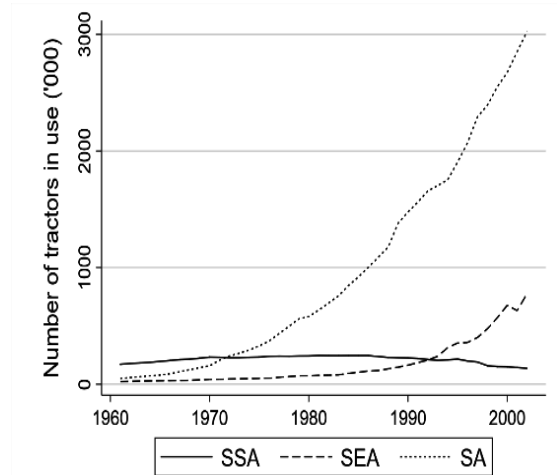


Figure 1. Number of tractors in use from 1961 to 2002

Source: Authors, using data from FAO (2020) and World Bank (2020).

use in the 1990s (Pingali, 2007). Although the data from FAO and the World Bank is not available, Kiri and Braun (2018) show that the machinery use in SSA has been increasing in the 2000s and the 2010s.

3. Study Area and Data

In the following sections, we investigate the determinants of machinery use in Tanzania by using household-level data. The data were collected in 45 villages in four districts from Morogoro and Mbeya regions in 2009, 2012, and 2018. In each village, ten rice-growing households were randomly selected, generating a total sample of 450 at the baseline. We replaced households if the original household at the baseline is missing in the following surveys. We dropped outliers and some observations that had missing values in key variables. As a result, we obtained unbalanced panel data with the number of observations of 1,312 households in three years, which include both rain-fed and irrigated areas. During the surveys, we asked farmers to identify the most important plot for rice production (hereafter called sample plot) and asked in detail about the machinery use and other technological adoption for rice cultivation.

Table 1 shows the changes in the use of farm appliances for land preparation, such as plowing and harrowing from 2009 to 2018 among our sample farmers (Panel A). We also present other key village-level variables such as the number

Table 1. Descriptive statistics of sample villages and households

Variables	Morogoro			Mbeya		
	2009	2012	2018	2009	2012	2018
<i>A: Use of farm appliances by sample households to prepare rice plots:</i>						
Use of PT or TR (%)	44.40	54.95	62.13	9.31	12.92	26.19
Use of TR (%)	42.67	50.45	54.47	7.35	6.70	7.62
Use of PT (%)	1.72	4.50	7.66	1.96	6.22	18.57
Use of DA (%)	4.31	12.16	18.30	82.84	81.34	67.14
Use of only handheld tools (%)	51.29	32.88	19.57	7.84	5.74	6.67
<i>B: Number of TR and PT stationed in the village:</i>						
Number of TR in the village	0.79	2.03	3.67	0.00	0.99	1.62
Number of PT in the village	0.56	1.48	3.16	0.00	6.39	9.33
<i>C: Machinery rental market and wage rates of hired labor for land preparation at village level:</i>						
Village has TR rental market (dummy)	0.41	0.96	1.00	0.33	0.76	0.67
Village has PT rental market (dummy)	0.08	0.61	0.54	0.52	0.86	0.71
Village has DA rental market (dummy)	0.32	0.47	0.59	1.00	1.00	0.77
TR rental rate ('000 Tsh/acre)	35.61	32.42	24.67	43.38	49.08	29.68
PT rental rate ('000 Tsh/acre)	35.00	30.86	22.63	41.03	54.07	32.62
DA rental rate ('000 Tsh/acre)	39.54	35.91	41.16	44.03	50.34	28.37
Village-level wage rates ('000 Tsh/day)	29.49	28.87	21.12	30.75	28.61	24.14
<i>D: Other rice cultivation variables:</i>						
Paddy price (Tsh/kg)	391.39	472.59	289.79	512.83	526.11	329.99
Paddy yield (tons/ha)	2.44	2.16	2.92	2.52	2.35	3.03
Village has irrigated area (dummy)	0.38	0.52	0.62	0.29	0.57	0.57
<i>E: Household and plot characteristics:</i>						
Number of working age adults	3.08	3.14	3.21	3.30	3.54	3.27
Years of schooling of household head	6.99	6.36	6.56	5.68	5.33	5.97
Female headed household (dummy)	0.12	0.13	0.11	0.11	0.11	0.12
Age of household head	46.01	47.74	51.52	46.40	49.07	52.72
Landholdings in lowland area (ha)	2.76	2.21	2.74	3.59	2.12	2.39
Landholdings in upland area (ha)	0.55	0.55	1.09	0.72	0.78	0.50
Number of bulls owned	0.03	0.20	0.33	1.64	1.79	1.70
Value of non-farm household assets (million Tsh)	0.61	0.53	0.88	0.76	0.93	0.82
Income from business and wage activities ('00,000 Tsh)	2.67	3.52	4.47	2.52	1.13	0.78
Amount of credit received by the household ('00,000 Tsh)	0.18	0.25	0.77	0.60	0.25	0.48
Bundled plot (dummy)	0.24	0.36	0.42	0.51	0.46	0.55
Irrigated plot (dummy)	0.20	0.22	0.30	0.48	0.42	0.11
Size of the plot (ha)	1.07	1.29	1.50	1.39	1.37	1.29
Number of observations (households)	232	222	235	204	209	210

Source: Authors (2020).

Notes: 1) TR, PT, and DA stand for four-wheeled tractors, power tillers, and draft animals respectively.

2) All the monetary values are adjusted for inflation using the 2009 value of Tanzanian Shilling (Tsh).

3) Since not all villages have machinery rental market, the rental rates for TR and PT are based on villages where their market exist.

of tractors and power tillers available in the village, wage rates of hired labor for land preparation activities, machinery rental rates, average paddy yield, and village-level paddy prices (Panels B, C, and D). Panel E shows household and plot characteristics by survey year for each region.

As shown in Panel A, in Morogoro region, about 42 percent of the surveyed farmers already used TR in 2009, but the use of PT and draft animals (DA) was not common. Since

then, the use of TR has continued to increase, reaching about 54 percent of the total sample households in 2018. In the same year, the use of PT and DA has also reached about 8 and 18 percent, respectively. The increase of DA use in Morogoro region is mainly attributed to the inflow of nomadic herders into this region in the mid-2000s. In Mbeya, 83% of farmers used DA in 2009, but the ratio has declined by 16 percentage points between 2009 and 2018. During the

same period, the use of TR remained fairly unchanged at about 7 percent, while the use of PT has increased by 16 percentage points. Our descriptive results are in line with the findings of Kiriu and Braun (2018), who show the high growth rate of farm mechanization in some SSA countries, including Tanzania.

4. Estimation Strategy

To examine the determinants of machinery use for land preparation, we use the pooled multinomial logit (MNL) model, which is commonly used for categorical dependent variables with outcomes that have no natural ordering. We combine the MNL model with Mundlak-Chamberlain approach, where the averages of household-level explanatory variables over time (Mundlak-Chamberlain device) are included as additional regressors (Wooldridge, 2010). This approach makes it possible to control for time-invariant household-level heterogeneity that may be correlated with observed covariates. Initially, we intended to examine the causal effect of different types of household-level and village-level characteristics on mechanization. However, due to the lack of proper instrumental variables, we decided to explore the statistical association between household and village-level characteristics and farmer's choice of machinery use. Thus, our results should be interpreted with caution.

In this study, our dependent variable is a categorical variable which takes one if the household used TR for preparation of sample plot, two if PT was used (but no TR was used), three if DA was used (but no TR or PT was used), and zero if only handheld tools were used. We examine the determinants of TR, PT, or DA use, keeping the use of handheld tools as the base outcome.

Our independent variables of interest are village-level wage rates of hired labor for land preparation activities and whether the village has a rental market for TR, PT, or DA. We also include interaction terms of year and district dummy variables. We control for household characteristics such as the age of household head, years of education of household head, the number of adult members in the household, landholdings in lowland and upland areas, number of bulls owned, the value of non-farm household assets which is used as a proxy variable for wealth, amount of credit received by the household, and income from business and wage activities. The value of the household asset is used as a proxy variable for wealth. We also control for plot-level variables such as the

size of the plot, whether the plot is surrounded by bunds or irrigated.

Bunds are constructed by piling soil around the paddy plot for water and soil nutrients management. Although bunds are common in irrigated lowlands, they are applied less frequently in rainfed lowlands. Irrigation and bunds can be important factors for machinery use and other farm decisions. For example, large TR may not be used in bundled plots because it can destroy bunds. Furthermore, plots with irrigation and bunds cannot be easily expanded even if farmers use TR. Therefore, we expect TR to be negatively associated with irrigated plots and plots with bunds.

5. Results

Table 2 shows our estimation results for the determinants of machinery use for land preparation. We present the estimations in three columns. Column 1 shows the results for the use of TR, while columns 2 and 3 respectively show those for the use of PT and DA. The base category is the use of handheld tools only. Our estimates show that high wage rates for land preparation are associated with a high probability of using TR, indicating the possibility of TR being used as a substitute for human power. Furthermore, we find that the existence of the TR and PT rental market in the village increases the probability of farmers using them, while the existence of the DA rental market decreases the probability of using TR. This suggests that the accessibility to rental machinery markets is an important factor for the farmers to adopt agricultural machines.

We also find that TR are less likely to be used in plots with bunds and irrigated plots. Since TR is large and heavy, it is difficult for TR to be moved to the farm and maneuvered within the plot without destroying bunds and irrigation channels. Our estimations show that farmers with large plots are likely to use TR and PT. This result suggests that mechanization is helpful in facilitating the cultivation of large rice area. We do not find any significant relationship between machinery use and other household characteristics.

6. Conclusion

This study aims to examine factors associated with machinery use in rice production in SSA. We begin by discussing the trend of agricultural machinery use in SSA and Asia by using macro statistics. We find that the use of agricultural machinery in SSA has remained low compared to Asia and has not increased much from the 1960s to the

Table 2. Determinants of mechanization on rice production (Multinomial logit model)

Variables	(1) TR	(2) PT	(3) DA
Wage rate of using hired labor for land preparation ('000 Tsh/day)	0.147** (0.066)	0.086 (0.080)	0.054 (0.064)
Village has TR rental market (dummy)	1.136*** (0.243)	0.795 (0.500)	-0.218 (0.301)
Village has PT rental market (dummy)	0.335 (0.241)	2.382*** (0.549)	0.224 (0.269)
Village has DA rental market (dummy)	-0.943*** (0.274)	-0.458 (0.481)	4.021*** (0.438)
Number of working age adults	0.020 (0.123)	0.299 (0.265)	0.058 (0.153)
Years of schooling of household head	0.010 (0.080)	0.012 (0.135)	0.072 (0.098)
Female headed household (dummy)	-1.149 (2.522)	0.725 (4.218)	-2.780 (2.767)
Age of household head	-0.037 (0.028)	-0.027 (0.044)	-0.014 (0.029)
Landholdings in lowland area (ha)	0.117 (0.111)	0.034 (0.188)	0.185 (0.117)
Landholdings in upland area (ha)	-0.030 (0.143)	0.135 (0.236)	-0.080 (0.145)
Number of bulls owned	0.018 (0.243)	0.140 (0.297)	0.168 (0.204)
Value of non-farm household assets (million Tsh)	0.409 (0.300)	0.509 (0.411)	0.657* (0.350)
Income from business and wage activities ('00,000 Tsh)	-0.009 (0.018)	-0.020 (0.040)	0.024 (0.029)
Amount of credit received by the household ('00,000 Tsh)	0.155 (0.148)	0.248 (0.174)	0.120 (0.150)
Bunded plot (dummy)	-1.116*** (0.321)	0.706 (0.587)	0.236 (0.298)
Irrigated plot (dummy)	-1.551*** (0.575)	-0.854 (0.702)	-1.700*** (0.659)
Size of the plot (ha)	0.461** (0.230)	0.431 (0.268)	0.516** (0.247)
Kilombero district x Year=2018 (dummy)	1.075*** (0.365)	0.166 (1.400)	0.558 (0.403)
Mvomero district x Year=2018 (dummy)	1.236*** (0.401)	1.454** (0.662)	-1.732 (4.761)
Mvomero district x Year=2012 (dummy)	-0.113 (0.326)	-1.048 (5.732)	-1.986 (5.183)
Kyela district x Year=2018 (dummy)	-0.772 (6.853)	1.165 (8.016)	2.648 (2.888)
Kyela district x Year=2012 (dummy)	-4.023 (8.252)	-13.791** (6.040)	3.103 (5.682)
Mbarali district x Year=2018 (dummy)	0.268 (0.728)	2.834*** (0.786)	0.972 (0.712)
Mbarali district x Year=2012 (dummy)	1.650*** (0.488)	1.918*** (0.653)	1.207*** (0.425)
Constant	-0.535 (0.828)	-5.914*** (1.355)	-3.149*** (0.882)
Mundlak-Chamberlain device	YES	YES	YES
Observations (households)	1,312	1,312	1,312

Source: Authors (2020).

Notes: 1) *** denotes significant at 1%, ** at 5% and * at 10%.

2) TR, PT, and DA stand for four-wheeled tractors, power tillers, and draft animals respectively.

3) All the monetary values are adjusted for inflation using the 2009 value of Tanzanian Shilling (Tsh).

4) Bootstrapped standard errors clustered at household-level in parentheses (200 replications).

5) In this estimation, the categorical value for handheld tools is used as the base outcome.

2000s, although some increasing trend after the 2000s is observed. Then, we investigate the determinants of machinery use for land preparation for rice cultivation, using a three-year panel data set collected in Tanzania.

Our estimation results show that the wage rate of hired labor for land preparation is positively associated with the probability of using TR. This result is consistent with previous studies conducted in Asia, such as Wang *et al.* (2016) and Yamauchi (2016). Availability of TR and PT rental market increases the probability of using them. We also find that farmers who grow rice in plots with bunds or irrigation tend not to use TR.

Our findings suggest that enhancing the availability of affordable machinery rental services is important in order to promote agricultural mechanization in Tanzania. In this regard, we recommend the mitigation of supply-side constraints such as increasing access to machinery spare parts and repair services in rural areas, which may help machinery rental service providers to expand their operations and reach many smallholder farmers. Our results also imply that we should consider not only socioeconomic characteristics but also agronomic practices used by rice farmers.

The limitation of our study is that due to the lack of proper instruments, we examine the association between the village and household characteristics and the farmer's choice of machinery use, rather than causal effect. Although we attempt to improve the estimations by controlling for unobservable household-level heterogeneity, the problem of endogeneity could not be fully addressed in this study.

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