THREE ESSAYS ON LAND AND AN INTENSIVE FARMING SYSTEM IN SUB-SAHARAN AFRICA: EVIDENCE FROM KENYA

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ABSTRACT

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In light of the high rate of population growth and rapid urbanization, the arable land frontier in Sub-Saharan Africa countries has been exhausted and the land-labor ratio has been shrinking. Under this setting, access to land for smallholders and the landless and improvement of land productivity have critical implication for poverty reduction and food insecurity. This dissertation is composed of three essays that study the determinants and impacts of land access, land distribution, and an intensified farming system in the context of Sub-Saharan Africa using household survey data from rural Kenya.

The first essay utilizes household and parcel-level data from rural Kenya to explore the linkage between land access and food security. We find that a 10% increase in operated land size would increase household total food consumption per capita, cereal consumption per capita, non-cereal consumption, and home produced food consumption by 2.6%, 2.1%, 2.7% and 5.4%, respectively. We also find that land rental is the dominant mechanism that poor rural farmers use to access additional land for cultivation. However, the levels of long-term land investment (measured by application of organic fertilizer) and land productivity are significantly lower for rented parcels than for own parcels even after household fixed effect and parcel-level observed characteristics are controlled for. Furthermore, the amount of land actually rented in or out is found to be significantly below the amount of land desired if the land rental market is functioning perfectly. These findings point to the existence of problems with land rental markets that impede their ability to fully contribute to national food security and poverty reduction goals.

The second essay aims to explore the determinants of the new maize farming system, which is characterized by adoption of high-yielding maize varieties, application of chemical fertilizer and manure produced by stall-fed improved dairy cows, and intercropping, especially the combination of maize and legumes, and its impact on land productivity and household income. We examine not only the impacts of new technologies and production practices but also the impacts of the entire new maize farming system by generating an agricultural intensification index based on a principal component analysis. Our estimation results show that an increase in sub-location level population density and a decrease in the land-labor ratio of an individual household accelerate farming intensification, and that adoption of each new technology and production practice has positive and significant impacts on land productivity. These findings are further supported by the significantly positive impacts of the agriculture intensification index on land productivity.

The third essay attempts to assess the determinants of agricultural land distribution and the effects of land distribution on agricultural productivity, income and poverty based on micro-level long panel data in Kenya. The estimation results show that the village level population density is negatively correlated with the village level Gini coefficient of own farmland. The Gini coefficient of agricultural land is found to have significant and negative impacts on agricultural productivity, income and poverty. Specifically, an increase in the Gini coefficient by 0.1 would reduce the value of crop production per acre, net crop income per acre, net crop income per capita, the net livestock income per capita, the net non-farm income per capita, the net total income per capita, and chance of being out of poverty by 4.3%, 5.1%, 4.1%, 6.6%, 5.0%, 3.8% and 2.8%, respectively.

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INTRODUCTION

Eradication of poverty and hunger is one of the Millennium Development Goals (UN, 2014). Even though considerable policies and aids have been devoted to achieve this goal, levels of poverty and hunger still remain high in Sub-Saharan Africa. For instance, there are 26 countries where the number of people living in extreme poverty is equal to or more than 40 percent of the population in 2011 in the world and 24 out of 26 countries are from Sub-Saharan Africa (World Bank, 2015). Additionally, Sub-Saharan Africa has 239 million people who suffer from hunger/undernourished in 2010, which is 30% of its total population (FAO, 2010).

Due to the fact that the majority of rural households rely on agriculture to earn a livelihood in Sub-Saharan Africa (Quan, 2000), growth in agricultural sector is imperative for Sub-Saharan Africa countries to reduce hunger and poverty. When we consider strategies for agricultural development in Sub-Saharan Africa, a special attention needs to be paid to land by researchers and policy makers because land is one of the most important productive assets for agriculture. It has been considered for a long time that Africa is a land abundant continent and has the high land-labor ratio (Bilsborrow, 1987; Wood; 2003; Fenske, 2010). However, recent research shows that in fact, due to the high rate of population growth and the rapid urbanization, the arable land frontier has been exhausted in Sub-Saharan Africa and the land-labor ratio has shrunk in recent years (Jayne, Headey, and Chamberlin, 2014). Under this setting, access to land for smallholders and the landless and improvements of land productivity have critical implication for poverty reduction and food security. Therefore, this dissertation entitled "Three Essays on Land and an Intensive Farming System in Sub-Saharan Africa: Evidence from Kenya" studies the determinants and effects of land access, land distribution and an intensified farming system in the context of Sub-Saharan Africa using household survey data form rural Kenya.

The first essay (chapter 1) is entitled "Land Access, Land Rental, and Food Security: Evidence from Kenya." Though quite a few studies examine the roles of land access with focus on the land rental markets, the relationship between land access and food security is not well assessed. Therefore, this essay attempts to assess the relationship between land access and household income and food consumption, to compare land productivity and investment differences between owned and rented-in parcels, and to investigate the extent which households are able to access the optimal amount of operational land size through rental markets.

This essay is based on the combination of parcel level data and household level panel data that covers 713 households in rural Kenya from 2004 and 2007. First, in order to quantify the relationship between land access and income and food consumption, we rely on the fixed effects estimator and the instrumental variable estimator to overcome the endogeneity issue of land access. Second, within-household estimation based on parcel level data in 2007, which could eliminate unobservable of a household, is conducted to estimate the difference in land productivity and investment between owned and rented-in parcels. Finally, we adopt the switching regression in order to assess the extent to which farmers could adjust their operational farm size to the optimal level through land rental markets if the land markets were to function perfectly.

The estimation results show several interesting findings. First, land access is significantly and positively related to food security. An increase in operational land size of 10% would raise household total food consumption per capita, cereal consumption per capita, and non-cereal consumption per capita, and self-produced food consumption by 2.6%, 2.1%, 2.7%, and 5.4% respectively. Second, though land rental is found to be the single most important mechanism through which households access an additional land, it is found that land productivity and investment are significantly lower for rented-in parcels than owned parcels. Lastly, our estimation results indicate that land rental markets in rural Kenya do not allow farmers to adjust their farm size up to the optimal level. Tenants (landlords) rented in (out) 67% (50%) of the size of land they would like to rent in (out) if the land markets are working perfectly.

The second essay (chapter 2) is entitled "The Possibility of a Maize Green Revolution in the Highland of Kenya: An Assessment of an Emerging Intensive Farming System." As population pressure on land grows rapidly in Kenya, rural farmers have started to intensify land use, which has led to the emergence of a new maize farming system. The new system is characterized by adoption of high-yielding maize varieties, application of chemical fertilizer and manure produced by stall-fed improved dairy cows, and intercropping, especially the combination of maize and legumes. However, very few studies assess the determinants and productivity impacts of this new farming system in Sub-Saharan Africa. Therefore, the objective of this study is to explore the determinants and impacts of the new maize farming system.

This essay is based on the combination of plot level data and household level panel data that covers 622 households, who grew maize on at least 20% of their farms, in rural Kenya in 2004 and 2012. The advantage of this dataset is the parcel panel data in which we could trace the same parcel from 2004 and 2012. This makes us possible to compare the change in input intensification and land productivity for the same parcel over time, controlling for time-invariant household and parcel level unobservable. Furthermore, a parcel may have several plots in a year, which makes it able to compare the differences in input intensification and land productivity for the same parcel in the same year, controlling for time variant parcel level unobservable. Taking advantage of this parcel panel data, we estimate the parcel level fix effect models to assess the determinants and impacts of the new maize farming system. Additionally, we adopt the household level fix effect model in order to quantify the effect of it on household agriculture, non-farm, and total income.

Our results show that an increase in sub-location level population density raises the rate of hybrid maize seed adoption and the extent of agricultural intensification, meanwhile a decrease in the land-labor ratio increases chemical fertilizer application and the degree of agricultural intensification. These findings suggest that population pressure accelerates farming intensification. Furthermore, it is found that the adoption of hybrid maize seed, intercropping legumes with maize, manure application, and chemical fertilizer application have positive and significant effects on land productivity. These effects are confirmed by the consistent and the significantly positive impacts of the agriculture intensification index not only on land productivity in terms of value of production and net income per hectare but also on the household total income per capita.

The third essay (chapter 3) is entitled "The Effect of Land Distribution on Income and Poverty Reduction: Evidence from Kenya." Unequal distribution of agricultural lands could negatively affect agricultural productivity, income and poverty through imperfect credit and factor markets, political economy, and the inverse land size-productivity relationship. Though quite a few studies have explored the relationship between asset distribution and agricultural productivity, income growth, or poverty, most of them are based on country level data. While country level analysis is informative, it is not possible to provide an answer for how asset inequality affects household income and poverty. Therefore, this essay attempts to explore the relationship between land inequality and household income and poverty based on household survey data.

We will estimate the impact of land distribution on agricultural productivity, income and poverty of rural households in Kenya based on household level panel data from 5 rounds of repeated household survey from 1997 to 2010. The long-panel data allows us to estimate the first-differencing model that controls for household level time-invariant unobservable. We further explore whether effects of land inequality differ across households of different socio-economic backgrounds by adding interaction terms between the inequality variable and household wealth and land endowment. Additionally, the determinants of land distribution are assessed by panel regression models based on village panel data.

The regression analyses yield several interesting results. First, the community level population density is negatively related to the community level land distribution. As the village population density increases by 100 persons per square kilometer, the Gini coefficient of own farmland would decrease by 0.001. Second, unequal land distribution is found to have negative impact on agricultural land productivity. An increase in the Gini coefficient of own farmland of 0.1 would reduce the value of crop production per acre and net crop income per acre by 4.3% and 5.1% respectively. Third, land inequality has significant and negative effects on household income and poverty. An increase in the Gini coefficient of 0.1 would decrease the net crop income per capita, net livestock income per capita, net non-farm income per capita, net total income per capita, and the probability of being out of poverty by 4.1%, 6.6%, 5.0%, 3.8% and

2.8%, respectively. Lastly, the negative effects of land inequality are larger and more significant for the poorer households.

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CHAPTER 1: LAND ACCESS, LAND RENTAL AND FOOD SECURITY: EVIDENCE FROM KENYA

1.1 Introduction

Despite the considerable efforts by national governments and the international community to reduce food insecurity and improve nutrition over the years, food insecurity and malnutrition still persist worldwide. For example, 1.4 billion people lived on less than $1.25 a day, the international poverty line in 2005 (Chen and Ravallion, 2008). And according to FAO (2010), 925 million people suffered from food insecurity in 2010.[1] While the largest number of under-nourished people is in Asia and Pacific (578 million), Sub-Saharan Africa has the highest incidence of under-nourishment where 30% of its total population (roughly 239 million people) suffers from chronic hunger, compared to 16% in Asia and Pacific. Furthermore, Sub-Saharan Africa is the only region where the number of malnourished children has increased in the past 10 years (Ezzati et al., 2002). The number of underweight children is very large and malnutrition is the major cause of child death in Sub-Saharan Africa (UN SCN, 2004; Black et al., 2003). The situation of African women and children is particularly serious, as well as the situation among female teenagers who receive less food than their male counterparts in the same households (Albert, 2012).

These problems of food insecurity are likely to be exacerbated in densely populated and poverty-stricken areas of Africa where the arable land frontier has been exhausted, and where farm sizes are small and declining due to increased population pressures and sluggish structural

[1] According to FAO, food security is defined as having physical and economic access to sufficient safe and nutritious food for people to meet their dietary needs and food preferences for a healthy and active life (Pinstrup-Anderson 2009).

transformation processes (Jayne et al., 2014). This situation characterizes many areas of rural Kenya (Muyanga and Jayne, 2014). In such settings, many land-constrained rural households rely on land markets as an important means for increasing their access to land (Holden et al., 2009; Yamano et al., 2009; Jin and Jayne, 2013). However, the potential of land rental markets to support poor households' ability to improve their access to food is poorly understood. This study is motivated by the need to more accurately understand the potential of land rental markets to improve rural households' access to land and their food security status.

While there are many studies of land access with focus on the determinants of land rental market participation in numerous countries, the relationship between land access and food security has not been well explored in the literature. This study relies on the combination of parcel level data and panel household data covering 713 rural Kenya households from 2004 and 2007 to explore the relationship between land access and food security. Specifically, our analysis aims to achieve the following three objectives: (1) to assess and quantify the relationship between operated land size, household income and food consumption (a proxy for food security); (2) to use the parcel level data from households that cultivate both owned parcels and rented parcels to compare land productivity and investment differences between these two types of parcels; and (3) to investigate the extent to which households are able to access the optimal amount of operational land size[2] through land rental markets.

Our descriptive and econometric analyses yield several important findings. First, we find a strong positive relationship between land access and food security. A 10% increase in operated

[2] The optimal amount of operational land size is defined as the land size which would maximize value of output per unit of land given the level of the household's labor and other resources under the assumption of perfect land markets.

land size would increase household total food consumption per capita, cereal consumption per capita, non-cereal consumption, and home produced food consumption by 2.6%, 2.1%, 2.7% and 5.4%, respectively. Second, we find that land rental is the single most important mechanism that land-poor households use to access additional land for cultivation. However, our analysis also highlights considerable concerns with the performance of rental markets in Kenya. We find that land productivity of rented parcels is significantly lower than owned parcels and farmers tend to apply less organic fertilizer to rented land than to own land. Furthermore, land rental markets are not able to allow farmers to achieve the optimal amount of operated land size, as suggested by the fact that tenants rented in 67% of the amount of land they would like to rent in and landlords rented out in 50% of the amount of land they would like to rent out.

The organization of this paper is as follows. Section 1.2 reviews the literature on the performance of land rental markets in developing areas and in Kenya. Section 1.3 presents our estimation strategy. The data used in this research is discussed in Section 1.4, followed by descriptive statistics. Section 1.5 discusses estimation results. Finally, Section 1.6 summarizes the major findings and draws policy implications.

1.2 Background

1.2.1 Land Rental and Sales Markets in the Presence of Market Failures

If all markets function perfectly and farming technology exhibits constant return to scale, the initial endowment of land would not matter in terms of production efficiency because land-labor ratio would be equalized across all households through market equilibration (Feder, 1985; Bardhan and Udry, 1999). Even if there is no land market, efficient outcomes could be achieved as long as other factor markets function perfectly. However, there is ample evidence pointing toward imperfection of rural factor markets in developing areas (De Janvry et al, 1991; Binswanger and Rosenzweig, 1986). One of the reasons why factor markets do not function well in developing areas is the presence of high monitoring costs of hired labor, which makes farmers prefer to use family labor rather than hired labor on their farms. When labor and other factor markets do not function well, households with surplus labor (or other excess assets relative to land) can benefit from acquiring additional land. Land sales and land rental markets are therefore potentially important means for enabling land-poor households to improve agricultural production efficiency when labor market fails to function perfectly (Deininger, 2003).

There are several reasons why land rental markets may achieve these gains for poor rural households more effectively than land sales market. First, land purchases require a much greater up-front payment than renting land. Hence, land rental markets are more accessible for farmers, especially poor farmers facing credits constraints (Hayami and Otsuka, 1993). Second, rental payment sometime can be paid after harvest, which makes renting land by poor farmers possible (Jin and Deininger, 2009). Third, rental markets are more flexible in terms of duration. Finally, rental markets are less risky than sales markets. Distress sale is an example that farmers sold land at a very cheap price to cope with emergency conditions and they ended up losing the land forever (Rawal, 2001; Gaspart et al., 2007). These considerations partially explain why land sales markets are generally much less active than rental markets in Africa (Holden et al., 2009). For the same reasons, rental markets are widely promoted by the Government of Kenya (Government of Kenya, 2007, paras 162 and 163) and many other developing countries (Deininger, 2003).

1.2.2 Empirical Evidence on Land Rental Markets

For the past decade or so, land rental markets have been actively studied although there is considerably more evidence to draw upon from South and East Asia than from Africa (Holden et al., 2009). A few highly consistent and important findings have emerged from the large number of studies covering a large number of countries. First, with few exceptions, land rental markets have been found to be a major way -- if not the only way -- for enabling land-poor households to access land (Jin and Deininger 2009 and Kimura et al. 2011 on China, Deininger and Jin 2008 on Vietnam; Deininger et al. 2008 on India, Pender and Fafchamp 2001, Deininger et al. 2008, and Gebregziabher and Holden 2011 on Ethiopia, Migot-Adholla et al. 1994 on Ghana; Holden et al. 2006 on Malawi; Yamano et al. 2009, and Jin and Jayne 2013 on Kenya; Andre and Platteau 1998 on Rwanda; Deininger and Mpuga 2009 on Uganda). Second, land rental markets are generally found to enhance farm productivity. (Jin and Deininger, 2009; Deininger and Jin, 2008, Deininger et al., 2007; Deininger and Mpuga, 2009; Jin and Jayne, 2013). Third, many studies identified the presence of significant transaction costs associated with participating in land rental markets. When uncertainty and imperfection information prevails, transaction costs such as search costs to identify suitable tenants and agency costs to avoid moral hazard problem in land use by tenants could lead imperfections in land rental market (Binswanger and Rosenzweing, 1986; Bardhan, 1989). In this regard, past studies found that the existence of the transaction costs typically does not allow farmers to fully adjust their operated land size to the optimal level (Skoufias, 1995; Deininger, Ali and Alemu, 2008; Yamano et al., 2009; Kimura et al., 2011).

1.2.3 Land Rental Markets in Kenya

Unlike many countries in Africa, Holden et al. (2009) point out that both land sales and rental markets are allowed in Kenya. Rural households' participation in rental markets appears to be rising. Less than 10% of rural households rented land in several districts in Kenya in the late 1990s (Wangila, 1999). However, Yamano et al. (2009) find that 17.9% households rented land in 15 districts in Kenya in 2004. Jin and Jayne (2013) show that the proportion of households renting in land increased from 18% to 20% from 1997 to 2007 in 24 districts in Kenya. The data used in this study (which is a panel of the 2004 data used by Yamano et al. (2009) in their analysis) showed that 22.3% of households rented in land in 2007, suggesting that the proportion of households renting in land increased by 5% in 3 years.

The Government of Kenya's National Land Policy (2007) states that "the potential to provide access to land to those who are productive but own little or no land" and also says that government should "encourage the development of land rental markets while protecting the rights of smallholders by providing better information about transactions to enhance their bargaining power" (Government of Kenya, 2007, paras 162 and 163). Given the fact that the Kenyan government takes a positive stance to promote land rental markets and that a significant proportion of Kenya farmers are participating in land rental markets, it is important to understand how well the current land rental markets are functioning in terms of allowing farmers to access additional land for agriculture and the ensuing effects on household income and food security.

1.3 Estimation Strategy

To estimate the effect of operated land size on crop production, income, and consumption based on household level panel data, we specify the following reduced form

$$Y_{ilt} = \alpha_i + \beta_1 Land_{ilt} + \beta_2 X_{ilt} + \beta_3 Loc_l + \beta_4 D_t + \beta_5 Loc_l * D_t + \varepsilon_{ilt} \qquad (1)$$

where Y_{it} is one of eight output variables of interest (total food consumption per capita, total cereal consumption per capita, total non-cereal consumption per capita, amounts of purchased food per capita, amounts of home produced food per capita, value of crop production per capita, net crop income per capita which is the difference between value of crop production and all paid costs associated with crop production, and net total income per capita which is the sum of net crop income, net livestock income, wage income, net income from self-owned business and transfer income such as remittances and pensions) of household *i* in location *l* in time $t.$[3] $Land_{it}$ is operated land size. X_{it} is a vector of househol control variables including household size, total value of assets, household head's age, a dummy for female head, and a dummy for head with primary education, D_t is a year dummy variable which seizes time trend, Loc_l is location dummies which capture the time-invariant regional characteristics, and $Loc_l * D_t$ is a vector of interaction terms between a year dummy and location dummies that are expected to capture time-specific regional shocks. α_{il} is a household fixed effect that captures household farmer management ability, household risk preferences, unmeasured household wealth, and so on, that are correlated with operated land size and production/food consumption. The existence of α_{il} would cause OLS estimates to be biased and inconsistent. To purge α_{il}, we take advantage of

[3] Location is the administrative unit in Kenya. There are 86 locations in the sample data

household panel data and estimate equation (1) using a panel fixed effect estimation approach (or first-differenced estimation approach).[4] This is equivalent to estimating the following equation:

$$Y_{ilt} - \overline{Y_{\iota l}} = \beta_1\left(Land_{it} - \overline{Land_{\iota l}}\right) + \beta_2(X_{ilt} - \overline{X_{\iota l}}) + \beta_4(D_t - \overline{D})$$

$$+\beta_5(Loc_l * D_t - \overline{Loc_l * D}) + (\varepsilon_{ilt} - \overline{\varepsilon_{\iota l}}) \qquad (2)$$

where $\overline{Y_\iota}$, $\overline{Land_\iota}$, and $\overline{X_\iota}$ are the mean values over the two time periods for the corresponding variable. In equation (2), household fixed effect (α_{il}) has been dropped. β_1 is the key parameter of interest to be estimated.

However, even after α_{il} is purged, the existence of possible time varying unobservables and the reverse causality issues (i.e., income level could also affect a rural household's ability to access to operational land size) could still lead to biased and inconsistent OLS estimates of equation (2). To obtain consistent estimates, we also estimate equation (1) by an instrumental variable (IV) approach based on pooled cross sectional household data. Operated land area in year *t* is instrumented by inherited land area (accumulative prior to time *t*) because land inheritance is likely to be correlated with operated land size but unlikely to affect the outcome variables of interest directly except through its effect on operated land size. The reason why IV estimation of equation (1) instead of IV estimation of equation (2) is adopted is that there are very few households who inherited land between the two rounds of survey (only 20 of households did so).

To examine the yield and input use intensity differences between own and rented parcels based on the parcel level data in 2007,[5] we use the following reduced form:

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[4] Given that the panel data covers two time periods, the fixed effect and first-differenced estimation approaches give the same estimation results.

[5] We only use 2007 data because 2004 data does not have the parcel characteristics variables.

$$Yield_{ij} \text{ or } Input_{ij} = \gamma_i + \delta_1 Rent_{ij} + \delta_2 Z_{ij} + \epsilon_{ij} \tag{3}$$

where $Yield_{ij}$ is either value of crop production per acre of land or net crop income per acre of land of parcel *j* belonging to household *i*, $Input_{ij}$ is input use intensity variable (either the amount of organic fertilizer or that of chemical fertilizer per acre of land), $Rent_{ij}$ is a dummy variable for land ownership (equal to 1 for rented parcels, and 0 for owned parcels), Z_{ij} is a vector of parcel characteristics including steepness, irrigation condition, and distance to homestead, and γ_i is a household level fixed effect capturing unobserved household level factors that simultaneously affecting farmer's productivity/input use intensity and household's tendency to rent land (e.g., farming skills, access to technology, and wealth). We note that OLS estimation of δ_1 will be biased because γ_i is correlated with $Rent_{it}$ (or $E(c_i|Rent_{it}=1)\neq 0$). To deal with this, we take advantage of the fact that all the households who rented in land also happen to own land, so we can use the owner-cum-tenants subsample to perform within-household estimation to eliminate γ_i, an approach that is widely adopted in parcel-level analysis (Shaban, 1987; Jacoby and Mansuri, 2009; Deininger et al. 2013). The fixed effects model of (2) could be written as follows:

$$\left(Yield_{ij} - \overline{Yield_i}\right) \text{ or } \left(Input_{ij} - \overline{Input_i}\right) = \delta_1\left(Rent_{ij} - \overline{Rent_i}\right) + \delta_2\left(Z_{ij} - \overline{Z_i}\right) + \left(\epsilon_{ij} - \overline{\epsilon_i}\right)$$

(4).

A second source of bias is that $E(\epsilon_{ij}|Rent_{ij}=1) \neq 0)$; in fact, it is argued in the literature that the rented parcels are generally of lower quality than owned ones (Jacoby and Mansuri 2009). We include all the main parcel-level variables collected in the survey (e.g., irrigation, distance, and steepness) to control parcel heterogeneity. Without being able to fully control for the unobserved factors, our land productivity estimate can be regarded as an upper bound (i.e., if the bias could be eliminated the coefficient estimate would be smaller). A third estimation challenge stems from the fact that a large number of households that do not apply organic or chemical fertilizer. To account for the zero value of fertilizer or organic manure and the time invariant heterogeneity, we adopt the semi-parametric trimmed LAD approach (Honore, 1992) to estimate a fixed effect Tobit model for the input use regressions.

Finally, we adopt a switching regression to estimate the extent to which farmers are able to adjust their operated land size to the optimal level through participating in land rental markets based on cross sectional household level data in 2007. Following Skoufias (1995) and Deininger et al. (2008), the switching regression with three rental participation regimes can be specified as the following:

$$y_i = \begin{cases} -\alpha_{out} + \beta_{out}L_i + \gamma_{out}Z_i + \varepsilon_i & if \quad \varepsilon_i < \alpha_{out} - \beta_{out}L_i - \gamma_{out}Z_i \\ 0 & \text{if } \alpha_{out} - \beta_{out}L_i - \gamma_{out}Z_i \le \varepsilon_i \le \alpha_{in} - \beta_{in}L_i - \gamma_{in}Z_i \\ -\alpha_{in} + \beta_{in}L_i + \gamma_{in}Z_i + \varepsilon_i & if \quad \varepsilon_i > \alpha_{in} - \beta_{in}L_i - \gamma_{in}Z_i \end{cases} \quad (5)$$

where y_i is the amount of net land area leased-in; subscript *out* and *in* denote the rental market participation status of household *i* with negative net area leased-in and positive area leased-in, respectively. Households who rented-in lands have positive *y* and those who rented-out lands have negative *y*. In our sample, there is one household who rented-in and rented-out lands at the same time and this household was omitted from this estimation. L_i is household's land endowment (the key variable of interest); Z_i is a vector of household characteristics including land endowment (e.g., ownership of bullocks, labor endowment, value of total assets, household head age, number of dependents, average number of owned steep land parcels, average number of owned irrigated land parcels, average distance from homestead to owned land parcels); α_{in} and α_{out} are the constant terms and β_{in} and β_{out} are the coefficients on land endowment, γ_{in} and

γ_{out} are vectors of other coefficients to be estimated. The coefficients of land endowment (β_{in} and β_{out}) are the key coefficients of interest. The magnitude of these coefficients allows us to test whether and to what extent land rental allows households to optimally adjust operated land size. Specifically, a fully functioning rental market without transaction costs would imply β_{in} equals to -1 and β_{out} equals to 1. So to test whether $\beta_{in} = -1$ (or $\beta_{out} = 1$) is to test whether the rental market allows tenants (landlords) to rent-in (rent-out) the amount of land they would like to rent in absence of transaction costs. A detailed description on the derivation of the hypothesis can be found in Skoufias (1995). Equation (4) is estimated by maximum likelihood estimation (MLE). In the programing of MLE, first, it divides samples in two groups, one with 0 or positive values of net land leasing-in and another with 0 or negative values of it and then starting values for the iterations are provided. Then, single censored Tobit regressions in two sub-samples are applied.

1.4 Data Source and Descriptive Evidence

1.4.1 Data

The household- and parcel-level data used in our analysis are from a survey called RePEAT.[6] The data is jointly collected by the National Graduate Institute for Policy Studies (GRIPS), the World Agroforestry Center, and Tegemeo Institute of Agricultural Policy and Development. The RePEAT survey is based on the survey conducted by the Smallholder Diary Project (SDP)[7] that collected data from more than 3,300 households randomly from communities

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[6] RePEAT is Research on Poverty, Environment, and Agricultural technology and survey projects in Ethiopia, Kenya, and Uganda founded by GRIPS and Foundation for Advanced Studies on International Development (FASID).

[7] The SDP is a project jointly by the Ministry of Livestock Development and Fisheries, the Kenya Agricultural Research Institute, and the International Livestock Research Institute (ILRI).

in the Central, Rift Valley, Nyanza, and Western, and Eastern provinces in Kenya (Yamano, Otsuka, and Place, 2011). In 2004, the RePEAT survey randomly selected 99 sub-locations and 10 households from each of the selected sub-locations, which results in a sample of 934 households. The second round of the RePEAT survey was conducted in 2007. Due to budget constraints, 23 sub-locations in Eastern province were dropped in 2007. The survey targeted 773 households but interviewed 718 households in 76 sub-locations (the attrition rate is 7.1%). Since 5 households were not engaged in Agriculture, the panel sample used in this study has 713 households. The RePEAT survey includes detailed household information on agricultural activities (cropping, raising livestock and growing trees), land (land tenure, land acquisition, parcel characteristics), demographics, education, assets, salary, expenditure, consumption and so on. Household and parcel level data are used for both descriptive and econometric analysis. Land parcels used for analysis are agricultural farm land grown with grains, vegetables, fruits, commercial, and all other crops. Net total income is computed as the sum of net crop income, net livestock income, wage income, net income from self-owned business and transfer income such as remittances and pensions. Each net income is computed as gross income minus costs. The household food consumption is measured by total food availability which is composed of home-produced food consumption (the difference between value of total food production and value of total sale of food production), home-produced dairy consumption (difference between value of total production and value of total sale of dairy products), and purchased food consumption (total expenditure on all food items). The food consumption is classified into total food consumption, cereal consumption, non-cereal consumption (meat, vegetables, fruits, dairy products, fish, etc.). Each category is further differentiated by sources – either from home production or from market purchase. All consumptions are measured in value term. To eliminate outlier issues in outcome variables, values were winsorized at the 99th percentile.

1.4.2 Modes of Land Transfer

Table 1.1 shows the relative importance of various means by which Kenyan households acquire additional lands in 2003 and 2006. While purchased parcels accounted for only 7 of households' operated parcels in 2003 and 2006, the number of rented parcels was 63 in 2003 and 50 in 2006, respectively. In addition, 8 parcels in 2003 and 7 parcels in 2006 were inherited or gained through other channels. This indicates that land rental markets were a much more important source of land acquisition than any other channels. The average size of purchased parcels during the two periods was 1.28 acre, larger than the average of rented parcels (0.81 acre). Overall, land rental is the most important way by which farmers access additional land for cultivation on a year-to-year basis.

Table 1.1 Frequency of households' acquisition of land parcels, by mode of acquisition

Mode of acquisition	Average	2003	2006
Purchased			
Number of parcels	7	7	7
Mean area (acres) per parcel	1.28	0.84	1.73
Rented-in			
Number of parcels	57	63	50
Mean area (acre)	0.81	0.79	0.84
Inherited or other			
Number of parcels	7.5	8	7
Mean area (acre)	1.34	0.95	1.74

1.4.3 Land Access and Household Characteristics

Table 1.2 describes household characteristics in 2007 for four groups according to their land access status: those who rented-in land, those who rented-out land, those who were autarkic and those who purchased land between 2004 and 2006. The simple tabulation reveals a number of interesting insights with regard to land access. Households who purchased land during 2004 and 2006 were most resource-endowed households among groups. They have the largest number of household size and working age household members. The percentage of households with heads having completed primary education and who owned bullocks are also the highest. And most of all, the average total value of assets of this group is the highest in all groups. And as noted before, the number of households purchasing land is very small (only 20 out of 713 households). Hence, access to land through land purchase is only used by very few wealthy households.

Table 1.2 Household characteristics by land rental market status in 2007

Rental status	**All**	Rent-in	Rent-out	Autarkic	Purchased land during 2004-06
Land owned (acres)	**4.2**	3.3	9.2	4.0	4.2
Household size (# of people)	**6.1**	6.4	6.3	6.0	6.9
Number of working age members (15-64)	**3.3**	3.5	3.4	3.2	4.3
Number of dependents*	**2.6**	2.6	2.8	2.6	2.5
Household head's age	**58**	56	56	59	47
% of female-headed HHs	**0.23**	0.16	0.31	0.25	0.05
% of heads completing primary education	**0.39**	0.50	0.27	0.35	0.80
% of HHs with bullocks	**0.20**	0.25	0.17	0.18	0.40
Total value of asset (KSh)	**83,628**	89,304	110,482	71,485	262,230
Total value of livestock (KSh)	**47,639**	59,171	43,706	44,073	52,860
Number of Observations	**713**	158	52	483	20

Table 1.2 also shows that land rental markets also tend to transfer land from households with higher land-labor ratio (on average, 2.7 acre per working age member) to those with smaller land-labor ratio (0.94 acre per working age member). Land rental markets also tend to transfer land from female-headed households to male-headed households and also from households without a bullock to those with at least one bullock. The share of heads having completed

primary educations is higher for those renting in land than those renting out land. This may suggest that, for individuals with at least a primary education, the marginal return to labor may exceed that in non-farm sectors where casual labor and low-skill jobs predominate. Farming may also be a source of income diversification for educated Kenyans.

1.4.4 Land Access, Production, Income and Food Security

Table 1.3 and 1.4 presents descriptive findings on a relationship between land access measured as operational farm size and households' agriculture income, and food security by dividing households into 4 quartiles based on land size in 2007. Table 1.3 shows a clear and consistent positive relationship between operational land size and value of crop production per capita, net crop income per capita, and net total income per capita. Net crop income is defined as the value of all crop production minus costs associated with crop production, and net total income is a summation of net crop income, net livestock income, non-farm income and transfer income such as remittance and pension. Each net income is computed as gross income minus costs. Total value of crop production and net crop income for the top quartile of households are more than double those of households in the bottom quartile. These differences in farm production are consistent with differences in net total income by farm size, even though a significant share of household income is derived from non-farm activities.

Table 1.3 Household incomes by operated farm size category in 2007

Operational farm size quartile[a]	1st (smallest)	2nd	3rd	4th (largest)	**Average**
Value of crop production (KSh/capita)	7,779	9,696	15,428	24,319	**14,275**
Net crop income (KSh/capita)[b]	7,036	8,602	13,491	20,840	**12,467**
Net total income (KSh/capita)[c]	31,547	40,195	42,361	66,170	**44,952**

[a] Operational farm size includes rented land.
[b] Net crop income is defined as the value of all crop production minus all paid costs associated with crop production.
[c] Net total income is computed as the sum of net crop income, net livestock income, wage income, net income from self-owned business and transfer.

Table 1.4 Household food security status by operated land size category in 2007

Operational farm size quartile[a]	1st (smallest)	2nd	3rd	4th (largest)	**Average**
Total food consumption(KSh/capita)[b]	14,081	14,916	16,013	20,978	**16,484**
Total cereal consumption (KSh/capita)[c]	4,103	4,478	4,764	6,383	**4,927**
Total non-cereal consumption(KSh/capita)	11,916	12,910	13,757	17,473	**14,000**
Total food consumption from own production (KSh/capita)	7,159	8,409	9,586	13,905	**9,747**
Value of food purchased (KSh/capita)	6,912	6,488	6,283	6,646	**6,588**

[a] Operational farm size includes rented land.
[b] Total food consumption includes cereal consumption and non-cereal consumption (meat, vegetables, fruits, dairy products, fish, etc.).
[c] Total cereal consumption includes maize, millet, rice, wheat, sorghum, oats, barely, and simsim.

The data also show a robust and positive relationship between land access and food consumption. As Table 1.4 shows, households who belong to the highest operational land quartile consumed the highest value of total food, cereal, non-cereal and self-produced food. Among all the food categories, the largest source of the difference is food consumption from own production. For example, food consumption from own production for the top quartile household is almost double of that at the bottom quartile. On the other hand, there is very little variation in value of purchased food across quartiles. The results suggest that the main contribution of land access to rural households' food security status is through their own farm production.

1.4.5 Land Tenure Status, Value of Crop Production, Crop Income, and Input Use Intensity

Table 1.5 compares net crop income and input use intensity between rented parcels and owned parcels using parcel level data in 2007.[8] The data indicate marked differences in value of crop production and net crop income per acre cultivated area and an amount of organic fertilizer use between the two types of parcels. Value of crop output and net crop income per acre on rented parcels is significantly lower than owned parcels by 28% for value of crop output and by 34% for net income (Kenyan Shieling (KSh) 16,551 vs KSh 23,017 and KSh 13,779 vs. KSh 20,781). Data on organic fertilizer per acre also pointed toward remarkable correlation between tenure type and incentives to apply organic fertilizer. We find that organic fertilizer use in the rented parcels is less than half the level of that in own parcels (307 kg vs. 687 kg). This is not the case for chemical fertilizer. In fact, the amount of chemical fertilizer per acre is slightly higher in rented parcels than owned parcels (21 kg vs. 18 kg). Agronomy literatures discuss an importance of organic fertilizer application as a strategy used by households to improve the long-run fertility and productivity of their soils (Chikowo et al., 2004; Tittonell and Giller, 2013). It takes a few years of continued organic fertilizer application to reap the full benefits of organic fertilizer use. In contrast, application of chemical fertilizer will reap immediate payoff. It is therefore not surprising that application of organic fertilizer is very different between owned and rented parcels, whereas application of chemical fertilizer is not, because farmers are not incentivized to

[8] The results are similar to the 2004 sample. We only report the 2007 data to make it consistent with the econometric analysis. Due to the fact several of the key parcel level characteristics were not collected in the 2004 survey, we excluded 2004 from the regression analysis.

make the long-term investment when they only use the parcels temporarily and cannot fully recoup the investment.

Table 1.5 Tenure statuses, value of output per acre, and input use intensity by parcel type in 2007

Tenure status	**All parcels**	Own parcels	Rented parcels
Value of crop production (KSh/acre)	**21,727**	23,017	16,551
Net crop income per acre (KSh/acre)[a]	**19,395**	20,781	13,779
Quantity of organic fertilizer (kg/acre)	**614**	687	307
Quantity of chemical fertilizer (kg/acre)[b]	**18**	18	21
Farm size (acre)	**1.9**	2.1	1.1
Number of parcels	**1,241**	984	221

[a] Net crop income is defined as the value of all crop production minus all paid costs associated with crop production. 0 or negative crop income dummy are included.
[b] Quantity of chemical fertilizer is measured in NPK equivalent.

While the simple tabulations presented in the descriptive analysis provide preliminary insights about the relationship between operated land size and household production and food security, and differences in input use intensity and crop income per unit land between rented and owned parcels, we will need to rely on rigorous multivariate econometric analyses to draw inferences about the causal relationships between land access and food security, etc.

1.5 Econometric Results

This section presents the main econometric results based on equations (2), (3), and (4). We find the econometric results are mostly consistent with the descriptive results presented in the previous section. For example, the econometric results confirm the positive and significant relationship between land access, crop productivity, and food security. Additionally, value of land productivity and an amount of organic fertilizer per acre are significantly lower for the rented parcels than for the owned parcels after the household fixed effect and important parcel level characteristics are controlled for. In addition, the switching regression allows us to gain additional insights about the extent to which households are able to adjust their operated land size relative to the optimal size.

1.5.1 Land Access and Food Security

Table 1.6 reports the effect of land access on food consumption that was estimated by panel fixed effect estimation using a panel household data set from 2004 and 2007. The model is in log-log specification, so the coefficients are elasticities. The results are highly consistent with the descriptive findings as the coefficient on operated land size is positive and significant at the 1% level in the case of household total food consumption, total cereal consumption, non-cereal consumption, and self-produced food consumption. The magnitudes of the coefficients on operated land size suggest that a 10% increase in operated land size would increase household total food consumption per capita, cereal consumption per capita, non-cereal consumption, and self-produced food consumption by 2.0%, 3.2%, 1.3%, and 4.1%, respectively. The negative coefficients on household size for all the consumption categories are consistent with the literature that food consumption is associated with considerable economies of scale which describes that expenditure of food consumption per capita of a household with few members is generally more than that of a household with more members (Nelson, 1988; Pradhan and Ravallion, 2000). Total value of livestock is important for total food consumption, non-cereal consumption and own produced consumption, but not for cereal consumption and food purchase, suggesting that wealthier households have more diversified and nutritious dietary patterns.

Table 1.6 Impact of and access on per capita food consumption (household fixed effect model)[a]

Explanatory variables	Log of total food consumption (KSh/capita)[b] (1)	Log of total cereal consumption (KSh/capita)[c] (2)	Log of total non-cereal consumption (KSh/capita) (3)	Log of total food consumption from own production (KSh/capita) (4)	Log of value of food purchased (KSh/capita) (5)
Log of operational farm size (acre)	0.203***	0.315***	0.129***	0.406***	0.0566
	(0.0359)	(0.0530)	(0.0387)	(0.0529)	(0.0411)
Log of HH size (residents)	-0.764***	-0.790***	-0.785***	-0.846***	-0.680***
	(0.0609)	(0.0933)	(0.0679)	(0.0680)	(0.0986)
Female-headed (=1)	0.0145	0.0239	-0.0434	-0.149	0.0893
	(0.0783)	(0.130)	(0.0916)	(0.0983)	(0.112)
Log of head's age	-0.285*	-0.368*	-0.178	-0.340*	-0.103
	(0.150)	(0.211)	(0.173)	(0.197)	(0.216)
Head completed primary education (=1)	-0.0835	0.0199	-0.105	-0.173**	0.00160
	(0.0571)	(0.0869)	(0.0667)	(0.0829)	(0.0770)
Log of value of livestock (KSh)	0.0422***	-0.00654	0.0757***	0.0862***	0.0137
	(0.0125)	(0.0185)	(0.0159)	(0.0185)	(0.0158)
Constant	11.75***	11.13***	10.91***	10.72***	10.47***
	(0.626)	(0.901)	(0.720)	(0.821)	(0.918)
Observations	1,426	1,426	1,426	1,426	1,426
R-squared	0.583	0.405	0.513	0.454	0.515
Number of HH	713	713	713	713	713

The numbers in parentheses are robust standard errors.
***, **, and * indicate significance at 1, 5, and 10%, respectively.
[a] Interaction terms between year 2007 and locations, and year 2012 dummy are included in all regressions.
[b] Total food consumption includes cereal consumption and non-cereal consumption (meat, vegetables, fruits, dairy products, fish, etc.).
[c] Total cereal consumption includes maize, millet, rice, wheat, sorghum, oats, barely, and simsim.

Table 1.7 reports the estimated effects of land access on food consumption using the IV method. The result of the first stage regression is shown in Table A1.1, which shows that inherited land size is positively and significantly related to operated land size at 1% level. The coefficients on operated land size are consistent with those of the fixed effect results, as those remains positive and statistically significant for food consumption except for food purchase. The magnitude of coefficients on operated land size suggests that a 10% increase in operated land size would increase household total food consumption, cereal consumption, non-cereal consumption, and home produced food consumption by 2.6%, 2.1%, 2.7% and 5.4%, respectively, again pointing toward the fact that land access helps improve food security through food availability.

Table 1.7 Impact of and access on per capita food consumption (household IV model)[a]

	Log of total food consumption (KSh/capita)[b]	Log of total cereal consumption (KSh/capita)[c]	Log of total non-cereal consumption (KSh/capita)	Log of total food consumption from own production (KSh/capita)	Log of value of food purchased (KSh/capita)
Explanatory variables	(1)	(2)	(3)	(4)	(5)
Log of operational farm size (acre)	0.261***	0.210***	0.267***	0.544***	0.00569
	(0.0435)	(0.0594)	(0.0537)	(0.0631)	(0.0480)
Log of HH size	-0.771***	-0.715***	-0.777***	-0.839***	-0.644***
	(0.0248)	(0.0352)	(0.0299)	(0.0371)	(0.0324)
Female-headed (=1)	-0.0685**	-0.0410	-0.0583	-0.0641	-0.0786*
	(0.0315)	(0.0434)	(0.0362)	(0.0459)	(0.0404)
Log of head's age	-0.0814	-0.124*	-0.0155	0.0960	-0.221***
	(0.0547)	(0.0724)	(0.0665)	(0.0815)	(0.0676)
Head completed primary education (=1)	0.111***	0.127***	0.118***	0.0719*	0.163***
	(0.0270)	(0.0373)	(0.0315)	(0.0387)	(0.0332)
Log of value of livestock (KSh)	0.0666***	0.0298***	0.115***	0.156***	0.00304
	(0.00841)	(0.00979)	(0.0104)	(0.0121)	(0.00912)
Constant	10.54***	9.686***	9.641***	8.013***	10.94***
	(0.271)	(0.342)	(0.318)	(0.376)	(0.306)
Observations	1,426	1,426	1,426	1,426	1,426
R-squared	0.660	0.463	0.637	0.655	0.520

The numbers in parentheses are robust standard errors.
***, **, and * indicate significance at 1, 5, and 10%, respectively.
[a] Interaction terms between year 2007 and locations, and year 2012 and no inheritance dummies are included in all regressions.
[b] Total food consumption includes cereal consumption and non-cereal consumption (meat, vegetables, fruits, dairy products, fish, etc.).
[c] Total cereal consumption includes maize, millet, rice, wheat, sorghum, oats, barely, and simsim.

Table 1.8 Impact of land access on production and agriculture income (household fixed effect and IV model)[a]

	Log of value of crop production (KSh/capita)		Log of net crop income (KSh/capita)[b]		Log of net total income (KSh/capita)[c]	
	FE	IV	FE	IV	FE	IV
Explanatory variables	(1)	(2)	(3)	(4)	(5)	(6)
Log of operational farm size (acre)	0.708***	0.829***	0.682***	0.800***	0.334***	0.442***
	(0.0639)	(0.0751)	(0.0734)	(0.0882)	(0.0567)	(0.0841)
Log of HH size	-0.870***	-0.915***	-0.889***	-0.877***	-0.796***	-0.787***
	(0.0721)	(0.0426)	(0.0921)	(0.0512)	(0.0982)	(0.0481)
Female-headed (=1)	-0.207*	-0.102*	-0.230	-0.0907	-0.249*	-0.200***
	(0.121)	(0.0536)	(0.164)	(0.0628)	(0.135)	(0.0591)
Log of head's age	-0.202	-0.0230	-0.495**	-0.0242	-0.193	-0.424***
	(0.209)	(0.0928)	(0.247)	(0.110)	(0.221)	(0.103)
Head completed primary education (=1)	-0.0651	0.0975**	-0.0105	0.0600	-0.0821	0.208***
	(0.0855)	(0.0445)	(0.106)	(0.0536)	(0.109)	(0.0508)
Log of value of livestock (KSh)	0.0179	0.0513***	0.0127	0.0448***	0.0397*	0.0887***
	(0.0183)	(0.0139)	(0.0227)	(0.0162)	(0.0205)	(0.0151)
Constant	10.34***	9.054***	11.24***	8.777***	11.48***	11.39***
	(0.873)	(0.430)	(1.021)	(0.512)	(0.902)	(0.462)
Observations	1,425	1,425	1,426	1,426	1,426	1,426
R-squared	0.464	0.651	0.595	0.658	0.364	0.498
Number of HH	713		713		713	

The numbers in parentheses are robust standard errors.
***, **, and * indicate significance at 1, 5, and 10%, respectively.
[a] Interaction terms between year 2007 and locations and year 2012 dummy are included in all regressions and no inheritance dummy is included in all IV regressions.
[b] Net crop income is defined as the value of all crop production minus all paid costs associated with crop production.
[c] Net total income is computed as the sum of net crop income, net livestock income, wage income, net income from self-owned business and transfer income.

1.5.2 Land Access, Production, and Income

Table 1.8 shows the impacts of land access on crop production and household income using household level panel data in 2004 and 2007. As in the case of food consumption, the econometrics results on the impact of operated land size on crop production and income are generally consistent with the descriptive evidence. Like in Table 1.7, we report results based on both the fixed effect estimation (columns 1, 3 and 5) and on IV estimation (columns 2, 4, 6). Results from fixed effect model estimation indicate that doubling the operated land size would increase value of crop production per capita by 71%, net crop income per capita by 68 % and net total income per capita by 33%. The IV results also suggest significant and large effect of land access on crop production, net crop income and net total income; doubling the operated land size would lead to 83%, 80% and 44% increase respectively. Results on other variables are also interesting and mostly as expected. For example, female-headed households have significantly lower crop production and net total income. Total value of livestock has consistently positive and significant impact on production and net income in all IV estimations and on net total income in the fixed effect model. This is not surprising as high value of livestock may help household buy more inputs and also provide more organic fertilizer for crop production.

1.5.3 Land Rental and Value of Crop Output, Crop Income per Acre, and Input Use Intensity

Table 1.9 reports the estimation results on the impact of land rental on value of crop production and net crop income using parcel level data in 2007. The base models include only land area and dummy for a rented parcel (columns 1 and 3). The base model is expanded by including irrigation dummy, steepness dummy, and distance from home to the parcel (columns 2 and 4). The base model indicates that land productivity is 52% (in the case of the value of crop production per acre) or 50% (in the case of net crop income per acre) less for the rented parcels than for the owned parcels. Adding the parcel characteristics (irrigation, distance to home and steepness) only slightly reduced the coefficients (from 52% to 51%, and from 51% to 49%, respectively, for the case of value of crop production per acre, and for the case of net crop income). Two key explanations for lower land productivity of rented parcels compared to owned parcels. One explanation is related to tenure security. Because rental is informal and more temporary, tenants do not have incentive to invest on the rented land as compared to own land. The other explanation is that parcel quality including soil fertility may be lower for rented parcel than for owned parcels. Lower land productivity on rented parcels in our case is likely to be outcome of the two combined effects. Given the magnitude of differences in value of crop output and net crop income between own and rented parcels and the fact that the differences are only trivially affected by the addition of the observed parcel characteristics, it is suggested that the large productivity differences between the two types of parcels are unlikely to be solely caused by the unobserved quality difference of parcels.

Table 1.10 reports the fixed effect Tobit results on input use intensity (i.e., the amount of organic and chemical fertilizer use per acre). Consistent with the descriptive evidence, the coefficient on rented parcels is negative and statistically significant for organic fertilizer but insignificant for chemical fertilizer. Lower level of organic fertilizer on the rented parcels is consistent with the argument that farmers have less incentive to make investment including organic fertilizer on parcels that are less secure. If the unobserved land quality is taken into account in the investment decision, then our results on rented parcels are the lower bound estimate of disincentive effect of tenure insecurity. The negative and significant coefficient on a dummy variable for rented parcels in the organic fertilizer regression (columns 1 and 2, Table 1.10) further increases our confidence that tenure insecurity is likely to have contributed to lower land productivity of rented parcels as compared to owned parcels.

Table 1.9 Impact of land tenure on value of output per acre (household fixed effect model, parcel level data in 2007)

	Log of value of crop production (KSh/acre)		Log of net crop income (KSh/acre)[a]	
Explanatory variables	(1)	(2)	(3)	(4)
Log of operational farm size (acre)	-0.0788	-0.103	-0.175***	-0.196***
	(0.0653)	(0.0670)	(0.0483)	(0.0482)
Rented in parcel (=1)	-0.518***	-0.511***	-0.495***	-0.485***
	(0.0901)	(0.0921)	(0.0846)	(0.0842)
Steep parcel (=1)		0.00304		-0.0118
		(0.142)		(0.132)
Irrigated parcel (=1)		0.897		0.770**
		(0.552)		(0.385)
Distance to parcel (km)		-0.0258**		-0.0314***
		(0.0110)		(0.0106)
Log of paid input costs (KSh/acre)	0.0901***	0.101***		
	(0.0222)	(0.0217)		
Constant	9.055***	9.004***	9.578***	9.595***
	(0.133)	(0.134)	(0.0227)	(0.0340)
Observations	1,241	1,226	1,241	1,226
R-squared	0.103	0.139	0.625	0.636
Number of HH	713	712	713	712

The numbers in parentheses are robust standard errors.
***, **, and * indicate significance at 1, 5, and 10%, respectively.
[a] Net crop income is defined as the value of all crop production minus all paid costs associated with crop production.

Table 1.10 Impact of land tenure on fertilizer use (household fixed effect Tobit model, parcel level in 2007)[a]

	Organic fertilizer (kg/acre)		Chemical fertilizer (kg/acre)[b]	
Explanatory variables	(1)	(2)	(3)	(4)
Log of operational farm size (acre)	61.93	-71.85	-0.447	-1.022
	(107.3)	(179.4)	(0.997)	(1.129)
Rented in parcel (=1)	-2,294***	-1,990***	-0.249	-0.297
	(614.1)	(598.8)	(2.413)	(2.640)
Steep parcel (=1)		195.7		4.282
		(568.4)		(3.288)
Irrigated parcel (=1)		-1,580**		7.313
		(752.1)		(17.24)
Distance to parcel (km)		-383.0		-0.249
		(233.4)		(0.350)
Observations	1,241	1,226	1,241	1,226

The numbers in parentheses are robust standard errors.
***, **, and * indicate significance at 1, 5, and 10%, respectively.
[a] All regression is estimated by the semi-parametric trimmed LAD approach.
[b] Quantity of chemical fertilizer is measured in NPK equivalent.

Table 1.11 Determinants of net land leased-in (maximum likelihood estimates, 2007 data)

Explanatory variables	(1)	(2)
Leasing-in equation		
Area owned (acre)	-0.723***	-0.673***
	(0.115)	(0.138)
Female-headed (=1)	-0.275	-0.320
	(1.352)	(1.372)
Own bulls (=1)	6.744**	7.674*
	(3.181)	(3.971)
Log of value of assets (KSh)	-0.0961	0.102
	(0.581)	(0.625)
Number of working members (15-64 years of age)	0.317	0.483**
	(0.247)	(0.247)
Number of dependents (<15 & >64 years of age)	-0.246	-0.125
	(0.253)	(0.246)
Head completed primary education (=1)	6.530**	6.957**
	(2.860)	(2.891)
Head's age	0.0963**	0.0939**
	(0.0459)	(0.0442)
Average number of own steeped land parcels	1.763	0.775
	(1.396)	(1.368)
Average number of own irrigated land parcels	-0.505	-0.0593
	(3.088)	(3.298)
Average distance to own land parcels (km)	3.957***	2.902**
	(1.429)	(1.171)
Constant	9.291	-0.278
	(12.77)	(14.26)
Leasing-out equation		
Area owned (acre)	0.444***	0.495***
	(0.0771)	(0.107)
Female-headed (=1)	1.091	1.234
	(0.786)	(0.769)
Own bulls (=1)	-2.393***	-3.266***
	(0.890)	(0.996)
Log of value of assets (KSh)	-0.633**	-0.336
	(0.308)	(0.327)
Number of working members (15-64 years of age)	-0.314**	-0.315**
	(0.142)	(0.144)
Number of dependents (<15 & >64 years of age)	-0.175	-0.227
	(0.141)	(0.148)

Table 1.11 (cont'd)

Explanatory variables	(1)	(2)
Leasing-out equation		
Head completed primary education (=1)	-1.478**	-1.881**
	(0.727)	(0.768)
Head's age	0.0294	0.0236
	(0.0228)	(0.0245)
Average number of own steeped land parcels	0.410	0.549
	(0.621)	(0.600)
Average number of own irrigated land parcels	-2.240	-3.693**
	(1.664)	(1.679)
Average distance to own land parcels (km)	-0.00719	-0.00958
	(0.132)	(0.115)
Constant	47.84***	29.07
	(12.20)	(33.78)
District dummies included	No	Yes
Σ	7.016***	6.803***
	(1.25)	(1.18)
Log likelihood	-1003.55	-978.94
Observations	712	712

The numbers in parentheses are standard errors adjusted for clustering effect at the village level. ***, **, and * indicate significance at 1, 5, and 10%, respectively.

1.5.4 Determinants of Net Land Leasing In and Out

Table 1.11 reports the results for the switching regression of land rental (equation 5) using data from 2007 to show the extent of land rental market imperfection. The base model (column 1) only includes all the relevant household characteristics and the augmented model (column 2) includes both the household characteristics and the district dummies.

First, we look at the lease-in side. If the rental land market functions perfectly, the coefficients of land endowment will be -1 (i.e., β_{in} = -1 in equation (5)) in columns (1) and (2). However, the coefficients of area owned in renting-in equation are -0.73 for the base model and -0.67 for the augmented model and both coefficients are significantly different from -1 at the 1% significance level. This indicates that land rental markets do not perform perfectly. Tenants who rented in land only rented in 73% to 67% of the amount of land they would like to rent in in the case of no transaction costs of renting land.[9]

Next, we turn to the lease-out side. If the land rental market functions perfectly, the coefficient of land endowment would be 1 (i.e., $\beta_{out} = 1$ in equation (5)) in columns (2) and (3). However, the coefficients of area owned in lease-out equation are 0.44 for the base model and 0.48 for the augmented model and both coefficients are statistically different from 1 at 1% level of significance. In other words, households who rented out land were only able to rent out 44% to 48% of the amount of land they would want to rent out in the case of no transaction costs of renting land.[10] To put our estimates into a context, farmers in India were found to be able to rented-in (or out) 78% (or 68%) of the amount of land they would desire to rent-in (or out) if there is free of transaction costs of renting while the situation is much more dire in Ethiopia as the corresponding figures are 30% and 21% (Deininger et al., 2008). Thus, the land rental market in Kenya functions at a level that is comparable to that in India but much higher than that in Ethiopia.

The coefficients on other variables provide further insights on the performance of land rental markets in Kenya. First of all, land rental does allow land-poor households to rent in land from land-rich households as indicated by the negative coefficients of land endowment in the rent-in and positive coefficients of land endowment in the rent-out equations. Similarly, rental markets tend to transfer land from households with less labor to households with more labor, as

[9] The average land area of households who rented-in lands is 1.2 hectare. If tenants could adjust rented-in land size fully, which means if $\beta_{in} = -1$, the computed average rented-in land area would become 1.9 hectare for column (2) case.

[10] The average land area of households who rented-in lands is 8.4 hectare. If landholders could adjust rented-out land size fully, which means if $\beta_{out} = 1$, the calculated average rented-in land area would become 18.1 hectare for column (2) case.

the coefficients of number of household members whose ages are between 14 years old and 65 years old is significant and negative in the rent-out equation and positive and significant (though only in the expanded model) in the rent-in equation. Consistent with the literature, having a bullock or not is very significant in household's renting decisions, as land rental tends to transfer land from households without a bullock to households with at least one bullock. Additionally, households with heads having completed primary educations are more likely rented-in and rented-out, which is consistent with finding in the descriptive result. This may show that the marginal return to labor for individuals who completed primary education may be higher for farm sector than non-farm sector where low-skilled jobs prevail. Average distance to owned land parcels is positive and significant in the leasing-in model, suggesting households with land that is far away from their homes tend to rent-in land. The negative coefficients for the average number of own irrigated parcels (though significant only in the specification with district dummies) in the leased-out models tend to suggest that households with good quality land are less likely to rent out land.

For robustness check, I also estimated simple probit models to identify determinants of land rental market participation. Results from probit models are reported in Table A1.2. Except for the working age members in the leased-out model, results on other key variables such as area owned, own bullock dummy, and whether a head completed primary education dummy or not are largely consistent with those from the Tobit switching regression models.

1.6 Conclusions and Policy Implication

While African governments have devoted enormous efforts to promoting food security, the prevalence of malnutrition and food insecurity is still quite high. Raising farm production and productivity is a top food security strategy for rural households who remain largely dependent on agriculture for their livelihoods. Considerable evidence shows a strong correlation between operated farm size and food production in rural Africa. However, there is no rigorous empirical evidence to shed light on the linkage between land access and food security. It is quite possible that households with relatively small landholding sizes have diversified to a greater extent into non-farm activities and are able to fully offset their lower own farm production with food purchased through their non-farm incomes. We attempt to fill in these knowledge gaps by exploring the relationship between land access and food security using data from rural Kenya in this study.

Our analyses yield three salient findings. First of all, we establish a strong linkage between land access and food security. In general, households with small farms are not able to procure sufficient food through non-farm jobs to achieve comparable levels of food consumption per capita as their relatively land-abundant neighbors. Second, we find that land rental markets are the most important means available to land-constrained rural households to access additional land for cultivation. Third, regression results show that rental markets perform below their potential. The value of crop production and net crop income are significantly lower on rented parcels than on owned parcels even after parcel characteristics and household fixed effects are controlled for. Consistently, farmers also apply less organic fertilizer on rented parcels than on owned parcels. In addition, farmers are not able to use land rental markets to attain their optimal operated land size. Tenants (landlords) were only able to rent in (out) from 67 to 73% (from 44 to 48%) of the optimal amount of land they would like to rent in absence of transaction costs of renting land.

Therefore, while land rental markets currently play a positive role in promoting household food security in rural Kenya, there appears to be untapped potential for them to play a more important role than they currently do. Policy efforts to improve the functioning of land rental markets may be an under-recognized yet potentially important component of food security and nutrition strategies in rural Kenya, and most likely in other parts of the region. More detailed research on the organization and behavior of land rental markets is needed to identify the specific causes of the apparently considerable underperformance of Kenya's rural land rental markets.

APPENDIX

Table A1.1 The first stage regression of Table 1.7 and 8[a]

Explanatory variables	Log of operational farm size (acre)
Log of operational farm size (acre)	0.378***
	(0.0222)
Log of HH size	0.101***
	(0.0334)
Female-headed (=1)	-0.145***
	(0.0419)
Log of head's age	0.0784
	(0.0737)
Head completed primary education (=1)	0.113***
	(0.0365)
Log of value of livestock (KSh)	0.0811***
	(0.00886)
Constant	-0.0431
	(0.372)
Observations	1,426
R-squared	0.480

The numbers in parentheses are robust standard errors.
***, **, and * indicate significance at 1, 5, and 10%, respectively.
[a] Interaction terms between year 2007 and locations, and year 2012 and no inheritance dummies are included in the regression.

Table A1.2 Determinants of land leased-in and leased-out (probit model-marginal effect at mean, 2007 data)

	Leasing-in		Leasing-out	
	(1)	(2)	(3)	(4)
Area owned (acre)	-0.0130**	-0.0160***	0.00343***	0.00275**
	(0.00565)	(0.00568)	(0.00119)	(0.00128)
Female-headed (=1)	-0.0558	-0.0629*	0.0119	0.0123
	(0.0369)	(0.0358)	(0.0149)	(0.0143)
Own bulls (=1)	0.103**	0.156***	-0.0299**	-0.0279**
	(0.0509)	(0.0578)	(0.0142)	(0.0120)
Log of value of assets (KSh)	0.0196	0.00651	0.00292	-0.000108
	(0.0147)	(0.0158)	(0.00602)	(0.00603)
Number of working members (15-64)	0.0139**	0.0148**	-0.00241	-0.00337
	(0.00603)	(0.00611)	(0.00246)	(0.00225)
Number of dependents (<15 & >64)	0.00555	0.00855	0.00193	0.000581
	(0.00699)	(0.00737)	(0.00233)	(0.00215)
Head completed primary education (=1)	0.0855**	0.0985**	-0.0418***	-0.0383***
	(0.0395)	(0.0401)	(0.0131)	(0.0122)
Head's age	-0.00145	-0.00129	-0.00112**	-0.00104**
	(0.00124)	(0.00128)	(0.000503)	(0.000485)
Average number of own steeped land parcels	-0.0250	-0.0311	-0.0169	-0.00744
	(0.0288)	(0.0292)	(0.0128)	(0.0122)
Average number of own irrigated land parcels	0.125	0.199**	0.00741	-0.00152
	(0.0977)	(0.0986)	(0.0365)	(0.0325)
Average distance to own land parcels (km)	-0.00356	-0.00284	-0.0378***	-0.0268***
	(0.00624)	(0.00584)	(0.00979)	(0.00834)
District dummies included	No	Yes	No	Yes
Chi-squared	38.83	60.83	26.89	65.85
Pseudo R^2	0.06	0.09	0.11	0.16
Observations	711	711	711	711

The numbers in parentheses are robust standard errors.
***, **, and * indicate significance at 1, 5, and 10%, respectively.

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CHAPTER 2: THE POSSIBILITY OF A MAIZE GREEN REVOLUSION IN KENYA: AN ASSESSMENT OF AN EMERGING INTENSIVE FARMING SYSTEM

2.1 Introduction

The improvement of agricultural productivity is imperative for poverty reduction in developing countries in general, and in sub-Saharan Africa, in particular, considering its high rate of population growth, increasingly limited availability of cultivatable lands, and the rise of food prices in the international market (David and Otsuka, 1994; Otsuka, Estudillo, and Sawada, 2008; Barret, Carter and Timmer, 2010). Asia experienced a rapid rise of agricultural productivity, known as the "Green Revolution," characterized by adoption of chemical fertilizer and fertilizer-responsive high-yielding varieties in the 1970s and 1980s, along with expansion of irrigation infrastructure (Hayami and Kikuchi, 1978; David and Otsuka, 1994; Evenson and Gollin, 2003c; Hayami and Godo, 2005; Otsuka and Larson, 2013b). In contrast, Africa is the only continent experiencing the stagnation of agricultural productivity. Researchers, therefore, continue to look for ways to enhance agricultural productivity in Africa. However, it is widely believed that underdeveloped infrastructure and markets lead to high transaction costs for purchase of chemical fertilizer and seeds of high-yielding varieties and to poor access to irrigation, and, hence, it is not possible for small farmers to achieve rapid growth in agricultural productivity (Jayne et al., 2003; Kydd et al., 2004; Reardon et al., 1999; Gregory and Bumb, 2006).

Yet, under these circumstances, some farmers have begun adopting a new farming system of maize production in the highlands of Kenya characterized by application of organic fertilizer, i.e., manure produced from improved dairy cattle in addition to use of hybrid seeds, chemical fertilizer, intercropping with legumes, and crop rotation (Otsuka and Yamano, 2005). A typical farmer in this system grows Napier grass, which is a common feed crop for cattle that can also repel pests, feeds it to improved cattle that are raised in stalls, collects manure from the stalls, and applies it on maize fields, where intercropping hybrid maize with nitrogen-fixing legumes is practiced. This farming system is similar not only to the Green Revolution in Asia in the 1970s and 1980s whose essence is application of high-yielding varieties and chemical fertilizer, but also to the agricultural revolution in U.K. in the 18th century, which is based on application of manure produced from stall-fed cattle as well as production of feeds on crop fields. It may not be unrealistic to assume that this new farming system, which embodies the essence of the two preceding revolutions in agricultural history, will bring about "revolutionary" changes in farm productivity in Sub-Saharan Africa.

To our knowledge, however, no study has statistically examined the determinants of adoption and productivity impacts of this emerging farming system in Sub-Saharan Africa. Therefore, this study aims to identify the determinants of adoption of this new farming system and to estimate its impact on productivity of maize, the major staple crop in Kenya, through regression analyses based on the unique parcel level panel dataset. In addition to estimating the effects of each element of the new farming system on productivity, this study attempts to measure the impact of the entire system by creating a single agriculture intensification index that captures this multidimensional input intensification. Our approach will provide insights into the effects of the new farming system on the land productivity of maize farming, which should assist policy makers in constructing new, effective strategies for agricultural productivity improvement in Sub-Saharan Africa.

The remainder of the chapter is structured as follows. Section 2.2 outlines the background of this study, while Section 2.3 describes the data collection method and provides descriptive statistics. Section 2.4 explains how the maize farming system index is constructed, Section 2.5 describes our identification strategies, and Section 2.6 presents estimation results. Finally, Section 2.7 discusses conclusions and policy implications of this study.

2.2 Background Information

In the 18th century, the agricultural revolution was realized by introduction of the turnip as a feed crop, the stall-feeding of cattle, and ample application of manure to crop fields (Timmer, 1969). This new farming system was based on crop rotation, feed production, stall-fed cattle, and application of manure, which enhanced crop yields. In contrast to cattle grazing under a three-field system which requires large areas of land but does not require intensive labor use, stall-feeding of cattle is labor intensive as it requires feed crops or feeding grass. The collection of manure from stalls and its application to crop fields is also labor intensive. In addition, stall-feeding of cattle makes it possible to fully collect manure. Therefore, a farming system based on stall-feeding of cattle is more labor-using and yield-enhancing technology than the traditional three-field farming system based on grazing. This method seems to fit with densely populated areas in Sub-Saharan Africa, which have been experiencing rapid population growth, shrinkage of cultivatable lands per capita, and declining soil fertility.

Asia has experienced rapid productivity growth mainly in rice and wheat since the late 1960s (David and Otsuka, 1994; Hayami and Godo, 2005), which is called the Green Revolution. This high growth in agricultural productivity was realized by application of chemical fertilizer, adoption of high-yielding modern rice varieties, and development of irrigation. Farmers used modern varieties and chemical fertilizer simultaneously because provision of soil nutrients is necessary to realize high yield potential of the modern varieties. Therefore, the important lesson from the Green Revolution in Asia is that both adoption of high-yielding varieties and application of chemical fertilizer are necessary to increase crop yields significantly (Hayami and Ruttan, 1985; David and Otsuka, 1994).

However, in a country where infrastructure is underdeveloped, it is difficult for poor farmers in rural area to have access to chemical fertilizer due to its high transaction costs. Moreover, unlike lowland rice farming, which is most sustainable, upland farming requires maintenance of soil fertility by applying organic fertilizer in addition to chemical fertilizer. Hence, many farmers in the highlands of Kenya apply organic fertilizer which is made from feces collected from stall-fed cows as depicted in Figure 2.1. Farmers grow feed grass such as Napier grass, which repels pests, and feed it to improved cows in the stalls. Then, farmers collect the cows' feces and create manure from it. Many of them plant a hybrid maize variety and apply both manure and chemical fertilizer on the plot. Moreover, they often intercrop maize with legumes that fix nitrogen from the atmosphere, which improves soil fertility. It is important to emphasize that this system combines technological advantages from two agricultural revolutions, one that occurred in England in the 18th century and another that was achieved in Asia in the 20th century. We hypothesize that the emerging farming system has potential to boost maize productivity significantly in Sub-Saharan Africa.

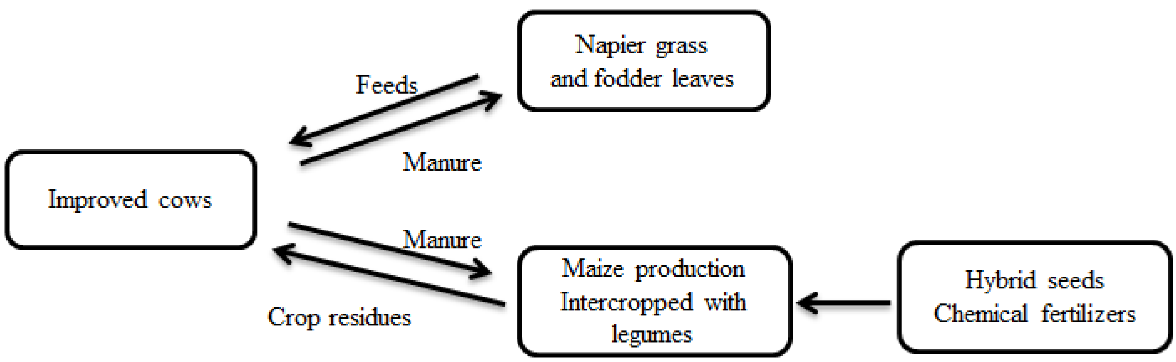

Figure 2.1 Organic green revolution in East Africa
Source: Revised figure 4. From Otsuka and Yamano, 2005

2.3 Descriptive Analysis

2.3.1 Data

In order to analyze the determinants of adoption of the new maize farming system and its impact on maize and entire crop yields, including yield of leguminous crops, and milk production, data are taken from a survey called RePEAT. This data set was jointly collected by the National Graduate Institute for Policy Studies (GRIPS), the World Agroforestry Center, and Tegemeo Institute of Agricultural Policy and Development in Kenya. The RePEAT survey is originally based on a survey conducted by the Smallholder Diary Project (SDP) that collected data from more than 3,300 households randomly selected from communities in the Central, Rift Valley, Nyanza, and Western, and Eastern provinces in Kenya by the International Livestock Research Institute, Nairobi. In 2004, the RePEAT survey randomly selected 99 sub-locations, which is the smallest administrative unit, and up to 10 households from each of the selected sub-locations, which results in a sample of 899 households. The second round of the RePEAT survey was conducted in 2012, which revisited 751 households that were interviewed in 2004. Thus, the attrition rate is 16.5%. Attrition weights are estimated and used to control for potential attrition bias in all regressions. Because our focus is maize farmers, we limit our sample to farmers who grow maize on at least 20% of their farm land in our analysis. After this eligibility rule is applied, our final panel sample is composed of 622 households in 96 sub-locations in 2004 and 2012.

The RePEAT survey includes detailed household information on agricultural activities, land use, demographics, education, assets, nonfarm income, agricultural expenditure, and consumption. In the survey area, farmers are endowed with land parcels each of which is typically subdivided into multiple plots to grow multiple crops. Each parcel has unique ID that is traceable overtime, which makes it possible to compare the maize production on the same parcel across two crop seasons within the same year or over the two survey years. However, plot numbers are given in each cropping season in a year and thus these are not traceable even across crop seasons in a given year. In our sample, 622 households had 958 parcels in 2004 and had 880 parcels in 2012. There are main and short cropping seasons in the survey area. The agricultural production data were collected for all crops in all plots for both the main and the short seasons. In 2004, 991 plots were grown with maize in the main season and 561 were grown with maize in the short seasons. In 2012, the corresponding figures are 877 plots and 479 plots, respectively. This gives us 1,552 maize plot level sample observations in 958 parcels in 2004 and 1,356 maize plot observations in 880 parcels in 2012. To address extreme values or outliers, we drop the outcome variables if their values are more than the 99th percentile of each variable.

Table 2.1 Sample household and sub-location characteristics

	2004		2012		Testing difference in means[a]
	Mean	S.D.	Mean	S.D.	
Household characteristics					
Number of households	622		622		
Female-headed households (%)	22%	(41)	29%	(46)	***
Head completed primary education (%)	35%	(48)	41%	(49)	**
Age of the head (years)	55.89	(13.9)	61.01	(14.2)	***
Value of productive asset (KSh)	49,394	(184,421)	35,050	(155,685)	
Value of asset (KSh)	80,829	(201,970)	65,933	(169,348)	
Household size	6.6	(2.9)	7.1	(3.2)	***
Household members between 15 & 64	3.6	(2.0)	4.4	(2.4)	***
Number of dependents	2.8	(1.9)	2.6	(1.7)	**
Owned land size (ha)	1.7	(2.4)	1.5	(1.8)	**
Owned land size per household members between 15 & 64 (ha)	0.6	(0.9)	0.4	(0.7)	***
Sub-locations characteristics					
Number of sub-locations	96		96		
Sub-location population density (persons/km^2)	744	(1,123)	1,101	(1,616)	***
Time to the nearest big town (min by car)	98	(48)	79	(37)	***

*** and ** indicate significance at 1 and 5%, respectively.
[a] Significance testing of the difference in means between 2004and 2012.

Table 2.1 shows socioeconomic characteristics of the sample households and sub-locations. According to this table, the proportion of female-headed households has increased from 22% to 29% and that of household's head who completed primary education raised from 35% to 41% from 2004 to 2012. The typical household head has become older by 5 years. The average values of productive assets and total non-land assets have decreased by about 14,000 Kenyan Shieling (KSh) and 15,000 KSh respectively from 2004 to 2012.[11] The average household size and the number of household working age (15-64 years) members increased by 0.5 and 0.8 respectively, and the number of dependents has decreased by 0.2 over time. The size of owned land was small already in 2004, i.e., 1.7 hectares, indicating that the population pressure was severe in Kenya. Owned land size has shrunk to 1.5 hectares over the eight-year period, which clearly leads to a decrease in the land-labor ratio over time. The sub-location population density (persons per square kilometer (km^2)) has increased from 744 to 1,101 over time. Due to the fact that the land-labor ratio has reduced and the population pressure has risen over time, it is clear that it is necessary to increase agricultural productivity to avoid food insecurity in rural Kenya. Transportation infrastructure has improved over time in Kenya as evidenced by the shortened time distance from the center of sub-location to the nearest big town by a motor vehicle by 9 minutes, which indicates that accessibility to agricultural inputs and output markets and information could have improved over time.

2.3.2 Maize and Milk Production in Kenya

Table 2.2 provides production data in Kenya based on maize plot data per cropping season in 2004 and 2012. The size of a maize plot has shrunk over time, which is consistent

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[11] Throughout this chapter, all prices are converted to the real price setting 2009 as a base year. The consumer price index for 2004 is 66.03 and that for 2012 is 103.53.

with the declining trend in the owned land size. The adoption rate of hybrid maize, however, has increased from 49% to 72%, expenditures for chemical inputs other than chemical fertilizer, which include herbicides, pesticides, and fungicides, have risen from 88 KSh per hectare to 176 KSh per hectare from 2004 and 2012, and expenditure of hired labor also has increased from 2,941 KSh per hectare to 3,973 KSh per hectare. Though the ratio of intercropping with legumes has declined by 6%, the quantity of intercropped legume seeds has been raised by 5 kg per hectare over time. Both the adoption rate of manure and the quantity of manure applied per hectare have risen significantly over time. In contrast, the adoption rate of chemical fertilizer and its applied quantity, which is converted into the total weight (in kg per hectare) of primary nutrients in terms of nitrogen (N), phosphorus (P_2O_5), and potassium (K_2O_5) contained in fertilizers (hereafter, NPK), have stagnated from 2004 to 2012. The maize yield has increased by about 40% and value of all crop production including maize and all other intercropped crops of a maize plot has increased by 21%. Similarly, sample households experienced a growth in their net crop income, defined as total value of all crop production minus all paid costs associated with crop production including costs of chemical and organic fertilizer, other chemical inputs, seed, and hired labor, by 21% over time.

Table 2.3 shows the amount of fertilizer application and land productivity by the type of maize seeds on a maize plot per cropping season. The adoption of hybrid maize seeds is associated with a higher yield and value of harvest than that of local seeds by about 63% and 68%, respectively. Consistently, the proportion of plots with chemical fertilizer application is higher for hybrid seeds than for local seeds by 37%, and the quantity of chemical fertilizer applied per hectare is also greater for the hybrid seed plots than for the local seed by 31 kg per hectare. In contrast to chemical fertilizer use, the proportion of manure used is same for local seed plots and hybrid plots. However, when we look at the quantity of manure applied per hectare, it is greater for hybrid seeds than for local seeds. This indicates that rural farmers in Kenya know the importance of applying both chemical and manure to realize the yield potential of the hybrid seeds.

Overall, it is indicated that maize farmers in the highlands of Kenya spontaneously began exerting efforts to intensify land use under the increasing population pressure on the limited land resources.

Table 2.2 Crop production of the maize plots per cropping season

	2004		2012		Testing difference in means[a]
	Mean	S.D.	Mean	S.D.	
Number of plots	1,552		1,356		
Maize plot size (ha)	0.38	(0.42)	0.34	(0.31)	***
Hybrid maize seeds (%)	49%	(50)	72%	(45)	***
Intercrop with legumes (%)	78%	(42)	72%	(45)	***
Manure applied (%)	39%	(49)	48%	(50)	***
Chemical fertilizer applied (%)	70%	(46)	71%	(45)	
Intercropped legumes seeds (kg/ha)	20	(25)	25	(25)	***
Quantity of manure (kg/ha)	970	(2,554)	1385	(2,729)	***
Quantity of chemical fertilizer (kg/ha) [b]	46	(62)	44	(50)	
Cost of other chemical inputs (KSh/ha) [c]	88	(376)	176	(506)	***
Cost of hired labor (KSh/ha)	2,941	(5,625)	3,973	(5,684)	***
Quantity of maize yield (kg/ha)	1,363	(1,452)	1,909	(1,446)	***
Value of crop production (KSh/ha)	41,733	(43,285)	50,701	(43,652)	***
Net crop income (KSh/ha) [d]	32,101	(39,441)	38,918	(39,589)	***

*** and * indicate significance at 1 and 10%, respectively.

[a] Significance testing of the difference in means between 2004and 2012.

[b] Quantity of chemical fertilizer is measured in NPK equivalent.

[c] This includes herbicides, pesticides, fungicides, and other chemical input.

[d] Net crop income is defined as the value of all crop production minus all paid costs associated with crop production.

Table 2.3 Means of yield and fertilizer application by seed type in the maize plots per cropping season in 2012

	Type of maize seeds			Testing difference in means[a]
	Local seeds	Hybrid seeds	All	
Number of maize parcels	381	975	1,356	
Maize yield (kg/ha)	1,315	2,143	1,909	***
Value of crop production (KSh/ha)	34,151	57,215	50,701	***
Manure				
Manure applied (%)	48%	48%	48%	
Quantity Applied (kg/ha)	1,070	1,509	1,385	***
Chemical fertilizer				
Chemical fertilizer applied (%)	45%	82%	71%	***
Quantity Applied (kg/ha)	22	53	44	***

*** and * indicate significance at 1 and 10%, respectively.
[a] Significance testing of the difference in means between local seeds and hybrid seeds.

It is a mistake to examine only maize fields if we are interested in the impacts of new maize-based farming system because keeping improved dairy cows is an integral part of this farming system. Table 2.4 displays the slight decline in the number of improved cows and the total number of cows from 2004 to 2012 in the RePEAT data, though these changes are not statistically significant. However, the quantity of milk produced per cow by local, improved, and both local and improved cows all increased over time. Milk production per improved dairy cow is about four times greater than that of a local cow, which demonstrates the much higher productivity of improved cows over local cows. The use of improved dairy cows is reminiscent of the White Revolution realized in India a few decades ago (Kajisa and Palanichamy, 2013).

Table 2.4 Milk production per household in a year

	2004		2012		Testing difference in means[a]
	Mean	S.D.	Mean	S.D.	
Number of households	662		662		
Number of local cows	1.3	(4.8)	1.3	(4.5)	
Number of improved cows	1.9	(2.9)	1.8	(2.5)	
Number of total cows	3.2	(5.2)	3.1	(4.8)	
HH with improved cows (%)	0.57	(0.5)	0.56	(0.5)	
Quantity of milk produced per cow for HH owning only local cows (liter/cow)	154	(222)	182	(211)	
Quantity of milk produced per cow for HH owning only improved cows (liter/cow)	695	(619)	841	(665)	***
Quantity of milk produced per cow for HH owning local & improved cows (liter/cow)	336	(307)	396	(296)	
Quantity of milk produced per cow for all HH (liter/cow)	511	(570)	624	(627)	***
Value of milk produced (KSh/cow)	29,268	(35,912)	27,683	(35,729)	
Net milk income (KSh/cow)[b]	20,922	(29,498)	22,127	(30,916)	

*** indicates significance at 1%.
[a] Significance testing of the difference in means between 2004and 2012.
[b] Net milk income is defines as the value of milk produced minus all the paid costs associated with milk production.

2.4 The Agriculture Intensification Index

It is difficult to measure the overall effect of the farming system, which consists of multiple changes in input uses and production practices, by simply looking at individual elements of the new farming system separately because their effects on agriculture production could be interactive. In fact, many changes are expected to be complementary. In such a case, if we analyze the impacts of each change on outcome variables by estimating the production function by using each input and technology separately as an explanatory variable, we could miss the interacting effects of multiple changes. Although it is theoretically possible to specify the general form of production function, such as translog, it is empirically difficult to estimate such a function due to the limited degree of freedom and high correlation among various elements of the new farming system.[12] Therefore, it will be useful to construct a

[12] Table A2.1 shows both household and plot level matrices of the pairwise correlation coefficients of input uses that consist of the new maize farming system. All the inputs are positively correlated and the correlation

single index that represents the degree of adoption of the new maize farming system. This single index should incorporate the important multiple indicators from each dimension of agriculture intensification in the system.

This study uses principal component analysis (PCA) to construct an index of agricultural intensification. PCA is a variable reduction procedure which decomposes variations in the variables included in the analysis into components (Darnell, 1994). A component is a linear combination of weighted explanatory variables, in such a way that the component accounts for a maximal amount of variance in the explanatory variables (Cavatassi, Davis, and Lipper, 2004). Since the first component captures the greatest proportion of total variation, it will be used as an agricultural intensification index in our analysis. The component is constructed based on the factor scores which are used as weights for each explanatory variable to calculate an index which represents the degree of agricultural intensification.

For this study, we generate two agricultural intensification indices, one at the household level and the other at the plot level. The household level agricultural intensification index is computed by the following formula (Filmer and Prichett, 1998):

$$HI_{it} = \sum_{i=1}^{N} F_k \left[\frac{(x_{ik} - X_k)}{S_k}\right], \quad (1)$$

where HI_i is the household level agricultural intensification index for household i which follows a normal distribution with a mean of zero, F_k is the factor score for the variables k in the PCA model, x_{ik} is the variable k of household $i,$ and X_k and S_k are the mean and standard deviation of the variable k. The PCA model includes a dummy variable for hybrid maize seed adoption, quantity of intercropped legume seeds with maize, quantity of manure per hectare, quantity of chemical fertilizer converted in NPK per hectare, and number of improved cows

coefficients are mostly statistically significant.

per hectare, as these input variables represent household level agricultural intensification of the new maize farming system.

Table 2.5 Factor loading for maize production intensification index in maize plots

	Pooled years	2004	2012
Household level			
Individual elements		**Factor loadings**	
Hybrid maize seeds (=1)	0.46	0.48	0.41
Quantity of intercropped legume seed (kg/ha)	0.09	0.03	0.10
Quantity of manure (kg/ha)	0.41	0.38	0.45
Quantity of chemical fertilizer (kg/ha)[a]	0.59	0.60	0.59
Number of improved cows (numbers/ha)	0.51	0.51	0.52
KMO	0.60	0.59	0.57
Proportion variation explained	0.31	0.32	0.29
Mean of agriculture intensification index generated from pooled data	0.00	-0.126	0.124
SD of agriculture intensification index	1.24	1.32	1.14
Plot level			
Individual elements		**Factor loadings**	
Hybrid maize seeds (=1)	0.56	0.56	0.57
Quantity of intercropped legume seed (kg/ha)	0.43	0.38	0.45
Quantity of manure (kg/ha)	0.34	0.27	0.36
Quantity of chemical fertilizer (kg/ha) [a]	0.62	0.69	0.59
KMO	0.56	0.49	0.57
Proportion variation explained	0.35	0.34	0.36
Mean of agriculture intensification index generated from pooled data	0.00	-0.181	0.204
SD of agriculture intensification index	1.19	1.22	1.12

[a] Quantity of chemical fertilizer is measured in NPK equivalence.

Similarly, the plot level agricultural intensification index is constructed as follows:

$$PI_{ips} = \sum_{ips=1}^{N} G_l \left[\frac{(z_{ipsl} - Z_l)}{T_l}\right], \quad (2)$$

where PI_{ip} is the plot level agricultural intensification index of household i on maize plot p in the cropping season s, G_l is the factor score for the variables l in this model, z_{ipsl} is the variable l of household i on maize plot p in cropping season s, and Z_l and T_l are the mean and standard deviation of the variable l. This PCA model includes the same variables as in the household level intensification index with exception of the number of improved cows per hectare, since though the number of improved cows per hectare is one of the key variables of the new maize farming system, this variable is only observable in the household level data. As both HI_i and PI_{ips} becomes greater, farming is supposed to be more intensified. Since the data used for the analysis consist of two rounds of panel data, it is necessary to create indices which can be compared over time. Therefore, the pooled data from two rounds of panel data are used to estimate both intensification indices.

Table 2.5 shows the factor loadings of the individual elements accounting for both household and plot level agricultural intensification indices. The principal components explain 31% of the variance in the 5 variables for the household level model and 35% of that in the 4 variables for the plot level model. Factor loading, which provides direction and weight for each variable, shows that the quantity of chemical fertilizer applied and number of improved cows account for a large part of the agricultural intensification in the household level model and hybrid seed adoption and the quantity of chemical fertilizer applied contribute greatly to the agricultural intensification in the plot level model. The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy takes a value between 0 and 1, and higher KMO values indicate that the correlation between pairs of the explanatory variables could be explained by the other explanatory variable (Kaiser, 1974). The KMO of the household level index is 0.60 and that of the plot level index is 0.56, and it is usually considered that PCA is acceptable if a value of KMO is more than 0.5. The factor loadings for both indices obtained from the pooled samples of the 2004 and 2012 surveys display similar patterns, which indicates that it is acceptable to use indices created from pooled data. The result shows that agricultural intensification indices have increased from -0.126 to 0.124 from 2004 to 2012 at the household level and from -0.181 to 0.204 at the plot level, indicating that agricultural intensification has advanced even in the short period of 8 years.

Table 2.6 Mean of crop production by quartile of the agriculture intensification index in maize plots in 2012

	Quartile of agriculture intensification index			
	1st	2nd	3rd	4th
Hybrid maize seeds (%)	11%	85%	95%	96%
Intercrop with legumes (%)	50%	66%	79%	91%
Manure applied (%)	39%	44%	46%	60%
Chemical fertilizer applied (%)	32%	69%	87%	96%
Intercropped legumes seeds (kg/ha)	11	17	26	45
Quantity of manure (kg/ha)	528	762	1042	3134
Quantity of chemical fertilizer (kg/ha) [a]	9	23	49	94
Cost of other chemical inputs (KSh/ha) [b]	54	118	189	334
Cost of hired labor (KSh/ha)	2,083	3,458	4,709	5,213
Quantity of maize yield (kg/ha)	1,247	1,664	2,064	2,606
Value of crop production (KSh/ha)	27,503	40,384	52,122	79,475
Net crop income (KSh/ha) [c]	23,901	32,076	38,142	58,648
Maize plot size (ha)	0.32	0.38	0.37	0.28

[a] Quantity of chemical fertilizer is measured in NPK equivalence.
[b] This includes herbicides, pesticides, fungicides, and other chemical inputs.
[c] Net crop income is defined as crop production minus all paid costs associated with crop production.

Table 2.6 provides evidence that the agricultural intensification index captures the degree of intensification of each input quite well by looking at crop production on maize plots per cropping season by the quartile of the plot level index in 2012. As shown in the table, there are upward trends in all individual input uses, as the quartile of the agricultural index goes up. Consistently, outcome variables such as maize yields, value of production from all crops, and net crop income increase as the degree of agricultural intensification deepens. These findings indicate that the farmers' effort of agricultural intensification is likely to pay off in rural Kenya. Furthermore, it is interesting to note that households that belong to the greatest quartile of the index have the smallest operated maize plot size, which is consistent with the negative correlation between farm size and agricultural intensification widely observed in Sub-Saharan Africa in recent years (Larson et al., 2014).

2.5 Estimation Strategy

2.5.1 Determinants of the New Maize Farming System Adoption

Following the literature on agricultural intensification, this study focuses on population pressure as the driving force that accelerates agricultural intensification. Boserup (1965) argues that a rise in population density will change the relative prices of land and labor, which increases the demand for new inputs such as fertilizer, irrigation water, improved seeds, and herbicide in order to intensify land use. This leads to an increase in input use per unit of area, which is regarded as agricultural intensification. In this way, population pressure accelerates intensive use of labor and other non-land inputs, which facilitates a shift of farming system from extensive, such as slash and burn farming, to intensive, such as sedentary multi-cropping farming with higher agricultural productivity (Otsuka and Place, 2001). Similarly, Hayami and Ruttan (1985) argue that changes in relative input scarcities would bring about changes in farmers' behaviors and institutions to adapt to new conditions, which is called the "induced innovation hypothesis." In their hypothesis, it is hypothesized, as in the Boserupian view, that population pressure decreases a wage rate relative to a land price, which increases the demand for labor and non-land input use, thereby enhancing land productivity. Empirical evidence shows that population pressure is associated with smaller land size and higher agricultural intensification (Josephson, Ricker-Gillbert, and Florax, 2014; Muyanga and Jayne, 2014; Ricker-Gillbert, Jumbe, and Chamberlin, 2014). Following the existing literature, this study employs the community level population density and the ratio of a household's own land to family labor as proxies for population pressure on land in order to explore its impact on agriculture intensification.

To assess the effects of the population pressure and other variables to explain agricultural intensification, we consider estimation of the following reduced form equation based on seasonal maize plot level data:

$$I_{iphvdst} = \alpha_0 + \alpha_1 Pop_{vdt} + \alpha_2 LL_{hvdt} + \alpha_3 PL_{iphvdst} + \alpha_4 Pr_{vdt} + \alpha_5 X_{hvdt} + \alpha_6 Dist_{vdt} + \alpha_7 Div_d + \alpha_8 D_t + \alpha_9 Div_d * D_t + SS_s + \beta_{phvd} + \varepsilon_{iphvdst}, \quad (3)$$

where $I_{iphvdst}$ is the agricultural intensification index or one of the four agriculture input or practice variables of interest, i.e., the amount of manure applied per hectare, amount of chemical fertilizer converted into the NPK applied per hectare, adoption of hybrid maize seed, and amount of intercropping legume seed planted. All variables pertain to maize plot *i* in parcel p of household h in sub-location v in division d in cropping season s in year t.[13] Pop_{vdt} is a sub-location level population density (persons per km^2). LL_{hvdt} is a ratio of household's own land size to a number of working age (15-64) household members. $PL_{iphvdst}$ is plot land size. Pr_{vdt} is a vector of sub-location level output and input prices including a maize price, a diammonium phosphate (DAP) price, which is the price of most popular chemical fertilizer in the survey area, an average hybrid maize seed price, and a wage rate of hired labor in agriculture. X_{hvdt} is a vector of household control variables including a number of working age (15-64) household members, a dummy variable for female head, household head's age, a dummy variable for head with primary education, value of livestock, and a soil carbon content of the main maize plot which represents soil fertility of household's farm land. Some soil samples were lost or spoiled in the laboratory and thus a dummy variable for no soil information is created and included in the regressors in order to avoid the loss of the observations without soil sample information. $Dist_{vdt}$ is a travel time from the center of sub-location to the nearest big town by a motor vehicle. Div_d and D_t are division and time dummies. Division and time interaction terms are also added to control for the impact of time specific localized shocks that could affect both agricultural intensification and

[13] Both division and sub-location are types of administrative regions in Kenya. There are 43 divisions, which divided into 96 sub-locations in our sample data.

population pressure. SS_s is a short season dummy. β_{phvd} is a household-parcel fixed effect that intends to capture time-invariant parcel characteristics such as soil type and land quality and time-invariant household level factors such as farmer management ability, household risk preferences, and unmeasured household wealth, which could be correlated with population density and the land-labor ratio and input use simultaneously. The existence of β_{phvd} would cause OLS estimates to be biased and inconsistent. Because of the availability of plot level production data for the same parcels in different seasons and different years, we can purge β_{phvd} by estimating equation (3) using a household-parcel level fixed effects estimation approach. Our main interest is the estimated parameters of α_1 and α_2.

2.5.2 Impact of the New Maize Farming System on Agricultural Production

To examine the impact of the new maize farming system on agricultural productivity, the impact of each individual element of the new farming system is estimated separately. Additionally, in order to measure the impact of the entire farming system, the effect of the agricultural intensification index is also estimated. The following model is used to examine individual and overall effects:

$$Q_{iphvdst} = \delta_0 + \delta_1 I_{iphvdst} + \delta_2 PL_{iphvdst} + \delta_3 X_{hvdt} + \delta_4 Dist_{vdt} + \delta_5 Div_d + \delta_6 D_t + \delta_7 Div_d * D_t + SS_s + \theta_{phvd} + \mu_{phvdt} + \varepsilon_{iphvdst}, \qquad (4)$$

where $Q_{iphvdst}$ is one of the three output variables of interest, which are the physical maize yield per hectare, value of all crop production, and net crop income which is defined as value of all crop production minus all paid costs. As in the determinants of intensification regression models, the existence of the time-invariant unobservable factor (θ_{phvd}) would cause the OLS estimates to be biased and inconsistent. To deal with this, we first estimate equation (4) using household-parcel fixed effects model approach. However, even after the time-invariant household-parcel characteristics are controlled for, there are still concerns that the time-variant household and parcel level factors, μ_{phvdt} could affect both intensification and agricultural outputs simultaneously. To deal with this problem, we take advantage of a subsample of parcels for which the production data is available for at least one plot from both seasons or more than one plot in any one cropping season in a given year. Such subsamples of parcels allow us to estimate δ_1 from within household-parcel-year variation.

Outputs from a new maize farming system accrue not only from crop production but also from milk production. Therefore, the following models are also employed in order to capture the effect of the maize-based farming system on total value of crop and milk production and net income from the crop and milk production:

$$Y_{hvdt} = \pi_0 + \pi_1 HI_{hvdt} + \pi_2 L_{hvdt} + \pi_3 X_{hvdt} + \pi_4 Dist_{vdt} + \pi_5 Div_d + \pi_6 D_t + \pi_6 Div_d * D_t + \rho_{hvd} + \varepsilon_{hvdt}, \quad (5)$$

where Y_{lkjt} is alternately the value of crop and milk production per hectare or net income per hectare defined as value of crop and milk production minus all paid costs associated with crop and milk production. HI_{hvdt} is the household level intensification index. L_{hvdt} is household's land endowment. As indicated above, the unobservable fixed effects, ρ_{hvd}, would result in inconsistent estimates. Hence, the household fixed effects model is estimated for equations (5).

Even though the intensification appears to increase land productivity and profitability, it is not clear whether agricultural intensification also contribute to overall household income. Though intensification increases crop income, household income could reduce in total if intensification requires large amount of family labor and a household reduces labor allocation to non-farm activity. Therefore, we also conduct household fixed effects estimation to examine the effect of maize farming intensification on household net non-farm income and net total income, which is a sum of net crop income, net livestock income, wage income, net income from self-owned business and transfer income such as remittances and pensions, by using same specification of equation (5). The dependent variables are household net non-farm per capita and net total income per capita.

2.6 Estimation Results

2.6.1 Determinants of Adoption of the New Maize Farming System

Table 2.7 shows the estimation results of the new maize-based farming system adoption model. In columns (1) to (5), the specifications explaining quantity of manure per hectare, quantity of NPK equivalent chemical fertilizer use per hectare, adoption of hybrid maize seed dummy, quantity of intercropped legume seeds planted per hectare, and the agriculture intensification index on a maize plot per cropping season are estimated by the household-parcel level fixed effects model.

The econometric results confirm that population pressure is indeed the driving force for the emergence of the new farming system. For example, sub-location level population density has a positive and significant impact on hybrid seeds adoption and the agriculture intensification index. Additionally, the land-labor ratio has a negative and significant effect on chemical fertilizer use and the agriculture intensification index. These estimation results support our hypothesis that population pressure encourages input use intensification. It is observed that plot size has consistent negative and significant impacts on all technology adoption except hybrid maize seed, which also indicates that a constraint on farm size facilitates intensification.

Table 2.7 Estimation results of the determinants of input intensification per cropping season (parcel fixed effects model, plot level data)[a]

	Organic fertilizer (t/ha)	Chemical fertilizer (10kg/ha)[b]	Hybrid maize seeds (=1)	Intercropping legume seeds (kg/ha)	Intensification index
Explanatory variables	(1)	(2)	(3)	(4)	(5)
Log of sub-location population density (ppl/km^2)	0.470	0.340	0.152*	5.227	0.328*
	(0.722)	(0.907)	(0.0782)	(4.364)	(0.194)
Log of owned land size per working adult (ha)	0.0688	-0.370**	-0.00952	-1.056	-0.0681*
	(0.118)	(0.177)	(0.0167)	(0.973)	(0.0387)
Log of cultivated plot size (ha)	-0.544***	-0.985***	0.0172	-4.513***	-0.231***
	(0.104)	(0.198)	(0.0159)	(0.923)	(0.0425)
Log of maize price (KSh/kg)	0.205	0.0141	0.0421*	-0.397	0.0570
	(0.209)	(0.290)	(0.0221)	(1.491)	(0.0605)
Log of DAP price (KSh/kg)	1.087*	-2.450**	-0.0203	1.971	-0.150
	(0.604)	(1.032)	(0.104)	(5.492)	(0.232)
Log of hybrid maize seed price (KSh/kg)	0.0197	0.550	-0.0834	-1.316	-0.0460
	(0.466)	(0.940)	(0.103)	(4.556)	(0.213)
Log of farm wage rate (KSh/day)	-0.0932	-1.785	-0.0497	2.083	-0.201
	(0.466)	(1.193)	(0.0853)	(5.167)	(0.216)
Log of HH size	0.277	0.610*	0.0391	-0.144	0.137
	(0.269)	(0.328)	(0.0426)	(2.025)	(0.0847)
Female-headed (=1)	-0.333	0.0621	0.0318	1.893	0.0349
	(0.250)	(0.532)	(0.0525)	(2.340)	(0.113)
Head's age	-0.00688	0.0139	-0.00182	0.135	0.00229
	(0.00895)	(0.0226)	(0.00166)	(0.0827)	(0.00447)
Head completed primary education (=1)	-0.104	0.679	-0.00915	-1.420	0.0275
	(0.237)	(0.550)	(0.0388)	(2.309)	(0.101)
Log of value of productive assets (KSh)	0.138**	0.0964	0.0105	-0.147	0.0391
	(0.0688)	(0.124)	(0.0106)	(0.642)	(0.0252)
Log of carbon in the soil	-0.145	1.090	0.0119	1.401	0.104
	(0.491)	(0.842)	(0.0738)	(4.539)	(0.176)
Log of time to big town (min by car)	-1.846	-4.778*	-0.0979	-2.723	-0.711
	(1.812)	(2.505)	(0.278)	(18.52)	(0.640)
Constant	0.147	30.34**	0.487	-19.76	1.011
	(8.946)	(12.02)	(1.344)	(85.02)	(3.022)
Observations	2,879	2,884	2,908	2,883	2,831
R-squared	0.068	0.164	0.189	0.106	0.155
Number of parcels	1,118	1,119	1,122	1,120	1,113

The numbers in parentheses are robust standard errors.
***, **, and * indicate significance at 1, 5, and 10%, respectively.
[a] Interaction terms between year 2012 and divisions, and year 2012, short season, and no carbon information dummies are included in all regressions.
[b] Quantity of chemical fertilizer is measured in NPK equivalence.

As expected, the chemical fertilizer use is negatively and statistically significantly affected by DAP price (price of the most popular chemical fertilizer in the survey area). It also appears that the chemical fertilizer and organic fertilizer substitute each other, as supported by the fact that the coefficient of DAP price in the model of quantity of manure is positive and significant at 10% level. While the hybrid seed price has the expected negative sign in the coefficient of adoption of hybrid seed, it is statistically insignificant, suggesting seed price is not a substantial factor affecting farmers' decision on whether to adopt hybrid seed varieties or not. On the other hand, farmers' adoption decisions are positively and significantly influenced by maize price, which is not surprising if farmers are profit maximizers and hybrid seed varieties have yield advantages over the conventional varieties.

2.6.2 Impact of the New Maize Farming System on Agricultural Production

Table 2.8 shows the impact of individual input use and intercropping on land productivity alternatively measured by maize yield per hectare, value of all crop production per hectare, and net crop income per hectare on a maize plot per cropping season. The equation (4) is estimated in two ways. We first present the household-parcel fixed effects results for each of three measures of land productivity (columns 1, 3, and 5) and then the household-parcel-year fixed effects results (columns 2, 4, and 6).

The household-parcel fixed effects model shows that adoption of hybrid maize is found to contribute to 12% and 13% increases in maize yield and value of all crop production. Additionally, the household-parcel-year fixed effects estimation indicates that the adoption of hybrid maize would increase net crop income by 16% respectively. Quantity of intercropped legume seeds is shown to have an almost zero impact on maize yield. This is unsurprising because by intercropping maize with legume, the area of maize planted is smaller in an intercropped field than a pure-stand field. Thus, it is not surprising that intercropping with legume has no effect on maize yield. However, farmers could obtain compensation from revenue from legume harvest in addition to revenue from maize and thus total crop revenue from an intercropped field could be more than a pure-stand field. In fact, an increase in intercropped legume seeds by 10 kg raises value of crop production by from 3 to 4% and net crop income by about 4%. Hence, although intercropping with legumes on a maize plot does not increase maize yield, farmers can obtain higher revenue and income from the intercropped production of legumes. In addition, as legumes enhance soil nutrients by fixing nitrogen from the atmosphere, intercropping with legumes could contribute to a gain in total crop revenue in the longer run. Both household-parcel fixed effects and household-parcel-year fixed effects estimations show that the additional application of manure by one ton per hectare is expected to increase maize yield, value of all crop production, and net income from all crops by about 2-3%, 3%, and 3%, respectively. Similarly, additional application of chemical fertilizer by 10 kg per hectare is expected to increase maize yield and value of all crop production by about 2-3% and 2%, respectively. However this positive impact disappears in net crop income, implying that chemical fertilizer application increases yields but not net income dues to its high costs. There are consistent negative effects of farm size on all outcome variables, which demonstrates the inverse relationship between farm size and agricultural productivity.[14]

[14] In order to check if there are interacted effects of adoption of hybrid maize seeds and other input use, Table A2.2 shows the estimation results of the effects of input intensification including interaction terms between adoption of hybrid maize seeds with intercropping with legume, manure application, and chemical fertilizer application. Though individual effects of each input still remains mostly positive and significant, most effects of the interaction terms are insignificant. This seems to contradict with the descriptive finding in which many farmers use hybrid seeds and fertilizers at the same time and they achieve higher yields than those who don't. One possible explanation is that there are mainly two types of farmers, who use inputs all together and achieve high yields and who don't. Thus, interaction effects might be difficult to observe in the interaction terms.

Table 2.8 Estimation results of the effects of input intensification on crop production per cropping season (parcel and parcel-year fixed effects models, plot level data)[a]

	Log of maize yield (kg/ha)		Log of value of crop production (KSh/ha)		Log of net crop income (KSh/ha)[c]	
Type of fixed effects model	Parcel	Parcel -year	Parcel	Parcel -year	Parcel	Parcel -year
Explanatory variables	(1)	(2)	(3)	(4)	(5)	(6)
Hybrid maize seeds (=1)	0.124**	0.0792	0.125**	0.0806	0.0835	0.156*
	(0.0526)	(0.0646)	(0.0582)	(0.0848)	(0.0672)	(0.0924)
Intercropping legume seeds (kg/ha)	0.000314	-0.00100	0.0039***	0.00290**	0.0041***	0.00429***
	(0.0009)	(0.00114)	(0.00100)	(0.00135)	(0.00112)	(0.00149)
Manure (t/ha)	0.0275***	0.0176*	0.0321***	0.0313***	0.0324***	0.0194
	(0.00843)	(0.00949)	(0.00903)	(0.0116)	(0.0107)	(0.0120)
Chemical fertilizer[b] (10kg/ha)	0.0290***	0.0180***	0.0215***	0.0103	0.00533	-0.00974
	(0.00522)	(0.00631)	(0.00614)	(0.00915)	(0.00633)	(0.00868)
Log of cultivated plot size (ha)	-0.457***	-0.530***	-0.387***	-0.450***	-0.333***	-0.435***
	(0.0406)	(0.0447)	(0.0470)	(0.0555)	(0.0434)	(0.0646)
Log of household size	0.128		0.116		0.0784	
	(0.0964)		(0.0904)		(0.0822)	
Female-headed (=1)	-0.0960		-0.0858		-0.0510	
	(0.114)		(0.110)		(0.103)	
Age of head	0.00154		0.00130		-0.000914	
	(0.00416)		(0.00407)		(0.00366)	
Head completed primary education (=1)	0.0907		0.0197		0.188*	
	(0.101)		(0.0873)		(0.103)	
Log of value of productive assets (KSh)	0.00802		-0.0387		-0.00229	
	(0.0247)		(0.0250)		(0.0269)	
Log of carbon	0.0499		-0.0789		0.250	
	(0.172)		(0.153)		(0.199)	
Log of time to big town (min by car)	-0.692		-0.691		-0.256	
	(0.496)		(0.467)		(0.549)	
Constant	8.721***	6.266***	12.89***	9.680***	10.18***	9.405***
	(2.232)	(0.0777)	(2.129)	(0.0973)	(2.506)	(0.113)
Observations	2,810	2,810	2,810	2,810	2,809	2,809
R-squared	0.732	0.737	0.522	0.532	0.810	0.782
Number of fixed-effects	1,110	1,803	1,113	1,805	1,113	1,805

The numbers in parentheses are robust standard errors.
***, **, and * indicate significance at 1, 5, and 10%, respectively.
[a] Short season dummy is included in all regression. Interaction terms between year 2012 and divisions, and year 2012, and no carbon information dummies are included in regression of (2), (4) and (6).
[b] Quantity of chemical fertilizer is measured in NPK equivalence.
[c] Net crop income is defined as crop production minus all paid costs associated with crop production.

Table 2.9 Estimation results of the effects of the intensification index on crop production per cropping season (parcel and parcel-year fixed effects models, plot level data)[a]

	Log of maize yield (kg/ha)		Log of value of crop production (KSh/ha)		Log of net crop income (KSh/ha)[b]	
Type of fixed effects model	Parcel	Parcel -year	Parcel	Parcel -year	Parcel	Parcel -year
Explanatory variables	(1)	(2)	(3)	(4)	(5)	(6)
Intensification index	0.155***	0.0817***	0.185***	0.126***	0.129***	0.0864**
	(0.0214)	(0.0261)	(0.0248)	(0.0360)	(0.0263)	(0.0366)
Log of cultivated plot size (ha)	-0.463***	-0.534***	-0.397***	-0.457***	-0.342***	-0.430***
	(0.0399)	(0.0441)	(0.0459)	(0.0546)	(0.0426)	(0.0638)
Log of household size	0.137	-	0.115		0.0748	
	(0.0960)		(0.0900)		(0.0826)	
Female-headed (=1)	-0.103		-0.0892		-0.0521	
	(0.113)		(0.109)		(0.102)	
Age of head	0.00138		0.00148		-0.000736	
	(0.00411)		(0.00405)		(0.00370)	
Head completed primary education (=1)	0.102		0.0202		0.180*	
	(0.102)		(0.0868)		(0.102)	
Log of value of productive assets (KSh)	0.0104		-0.0384		-0.00188	
	(0.0245)		(0.0249)		(0.0269)	
Log of carbon	0.0574		-0.0771		0.245	
	(0.171)		(0.153)		(0.200)	
Log of time to big town (min by car)	-0.747		-0.704		-0.219	
	(0.504)		(0.470)		(0.543)	
Constant	9.192***	6.386***	13.23***	9.864***	10.20***	9.580***
	(2.268)	(0.0605)	(2.138)	(0.0755)	(2.476)	(0.0897)
Observations	2,810	2,810	2,810	2,810	2,809	2,809
R-squared	0.730	0.736	0.521	0.530	0.810	0.780
Number of fixed effects	1,110	1,803	1,113	1,805	1,113	1,805

The numbers in parentheses are robust standard errors.
***, **, and * indicate significance at 1, 5, and 10%, respectively.
[a] Short season dummy is included in all regression. Interaction terms between year 2012 and divisions, and year 2012, and no carbon information dummies are included in regression of (2), (4) and (6).
[b] Quantity of chemical fertilizer is measured in NPK equivalence.
[c] Net crop income is defined as crop production minus all paid costs associated with crop production.

It may not be possible to capture the whole impact of the new maize farming system only by estimating the impact of an individual practice on agriculture production. In order to examine the effect of the entire new maize farming system, we re-estimated equation (4) by replacing all the individual intensification practices by the single agricultural intensification index on the right hand side of the equation. The estimation results using both the household-parcel fixed effect and household-parcel-year fixed effect panel estimation methods are reported in Table 2.9. Estimation results are generally consistent for both fixed effects models but estimated coefficients in parcel-year fixed effect models are smaller than those of parcel fixed effect models, suggesting possible positive bias in parcel fixed effect models which fail to control time variant household and parcel level unobservables. The results show significant and positive effects of the agricultural intensification index on all outcome variables for both models. An increase in the intensification index by one standard deviation would raise maize yield per hectare by 18% and 10%, value of all crop production per hectare by 22% and 15%, and net crop income per hectare by 15% and 10% in the parcel fixed effects model and in the parcel-year fixed effect model respectively. Consistent with the results in Table 2.8, we observe the negative impacts of the farm size on outcome variables, which confirms the inverse farm size-productivity relationship.

Since the new maize farming system aims to increase output not only from crop production but also from milk production, Table 2.10 illustrates the impacts of agricultural intensification on the total value of crop and milk production per hectare (column 1) and the sum of crop and milk net income per hectare (column 2) estimated from household level panel data. Consistent with the findings in Table 2.9, the effects of agriculture intensification are positive and significant on both outcome variables. A rise in the intensification index by one standard deviation would increase the value of crop and milk production per hectare by 36% and net crop income per hectare by 34%. The estimation results also indicate that the household head's age is negatively related to both crop and milk production and net income, indicating that a household with a younger head tends to have higher agricultural productivity.

Table 2.10 Estimation results of the effects of the intensification index on agriculture production per year (household fixed effects model, household level data)[a]

	Log of value of crop & milk production (KSh/ha)	Log of net crop & milk income (KSh/ha)[b]
Explanatory variables	(1)	(2)
Intensification index	0.293***	0.277***
	(0.0302)	(0.0382)
Log of owned land size (ha)	-0.0354	-0.0146
	(0.0446)	(0.0655)
Log of household size	0.0274	-0.0430
	(0.0791)	(0.105)
Female-headed (=1)	-0.0284	-0.161
	(0.0986)	(0.107)
Head's age	-0.00477*	-0.00897***
	(0.00282)	(0.00344)
Head completed primary education (=1)	-0.00583	-0.0262
	(0.0701)	(0.0919)
Log of value of productive assets (KSh)	0.00929	-0.0125
	(0.0218)	(0.0289)
Log of carbon	-0.104	-0.189
	(0.158)	(0.225)
Log of time to big town (min by car)	-0.337	-0.541
	(0.451)	(0.552)
Constant	12.65***	13.89***
	(2.038)	(2.447)
Observations	1,195	1,195
R-squared	0.389	0.524
Number of households	619	619

The numbers in parentheses are robust standard errors.
***, **, and * indicate significance at 1, 5, and 10%, respectively.
[a] Interaction terms between year 2012 and divisions, and year 2012, short season, and no carbon information dummies are included in all regressions.
[b] Net crop and milk income is defined as the value of crop and milk production minus all paid costs associated with crop and production.

Table 2.11 Estimation results of the effects of the intensification index on non-farm and total household income per year (household fixed effects model, household level data)[a]

	Log of net non-farm income per capita (KSh)	Log of net total income per capita (KSh)[b]
Explanatory variables	(1)	(2)
Intensification index	0.0787	0.168***
	(0.0820)	(0.0386)
Log of owned land size (ha)	0.231*	0.172***
	(0.118)	(0.0447)
Log of household size	-0.295	-0.545***
	(0.199)	(0.0889)
Female-headed (=1)	-0.496*	-0.305***
	(0.266)	(0.117)
Head's age	-0.0128	-0.00703*
	(0.00873)	(0.00374)
Head completed primary education (=1)	-0.251	-0.117
	(0.223)	(0.0921)
Log of value of productive assets (KSh)	0.0931*	0.0631**
	(0.0538)	(0.0250)
Log of carbon	-0.181	-0.176
	(0.402)	(0.218)
Log of time to big town (min by car)	1.003	-0.490
	(1.132)	(0.640)
Constant	-0.964	-0.730**
	(0.656)	(0.312)
Observations	5.095	13.25***
R-squared	(5.120)	(2.886)
Number of households	1,192	1,192

The numbers in parentheses are robust standard errors.
***, **, and * indicate significance at 1, 5, and 10%, respectively.
[a] Interaction terms between year 2012 and divisions, and year 2012, short season, and no carbon information dummies are included in all regressions.
[b] Net total income is computed as the sum of net crop income, net livestock income, wage income, net income from self-owned business and transfer income.

Furthermore, Table 2.11 shows the estimation results of the effect of maize farming intensification on the net non-farm income per capita (column 1) and the net total household income per capita (column 2) based on household level panel data. There is a potential concern that the positive effect of increase in agricultural intensification on crop income could be offset by a reduction of non-farm income if intensification requires large amount of family labor and a household reduces its labor allocation to non-farm activities. The positive and insignificant coefficient on intensification index in the off-farm equation allays such concern (column 1). Finally, intensification has significant and positive effect on total income as supported by the positive and statistically significant coefficient of intensification index on the total income equation (column 2). In terms of the magnitude of effect, one standard deviation increase in the intensification index causes net total income to increase by 21%. The results on other variables are also mostly consistent with expectation. For example, land access is significantly and positively related to both non-farm income and total income. Female-headed households are worse off than male-headed households, as they earn 50% and 31% less non-farm income and total income than male-headed households holding other factors constant. The value of productive assets is positively associated with non-farm income and total income.

2.6.3 Impact of the New Maize Farming System on Profit

One limitation of the data is that it did not collect information on family labor use on crop production and thus we could not estimate an impact of the new farming system on economic profits for which family labor cost is deducted. This may cause bias in the estimated effect of the input intensification on outcome variables.[15] If intensification requires households to use more family labor which is not captured in data, an impact of intensification on agricultural production or income would be overestimated. Though the survey team did not collect family labor use data from all plots, they collected it from the largest pure stand maize plot in the main cropping season. If a household does not have a

[15] The concern is mainly related to the quantification of the net effects on agricultural productivity and agricultural income, the results on off-farm income and total income are not affected as the labor use is internalized in the measurement of off-farm income and total income.

pure-stand maize plot, family labor use information on the largest intercropped maize plot in main season was collected. Based on this additional information in the dataset, we could compute a profit, which is defined as value of crop production minus all the costs associated with production including family labor on the largest maize plot. This enables us to check if the impact of agricultural intensification differs between net crop income and profit at least for the largest plot.

Table 2.12 Crop production of the largest pure-stand maize plot or the largest intercropped maize plot in the main cropping season

	2004		2012		Testing difference in means[a]
	Mean	S.D.	Mean	S.D.	
Number of plots	426		426		
Maize plot size (ha)	0.48	(0.45)	0.41	(0.34)	***
Hybrid maize seeds (%)	52%	(50)	76%	(43)	***
Manure applied (%)	44%	(50)	60%	(49)	***
Chemical fertilizer applied (%)	71%	(46)	75%	(43)	
Quantity of manure (kg/ha)	942	(2,567)	1525	(2,464)	***
Quantity of chemical fertilizer (kg/ha)[b]	53	(66)	43	(42)	***
Family labor (hours/ha)	891	(763)	686	(708)	***
Hired labor (hours/ha)	237	(398)	84	(207)	***
Total labor (hours/ha)	1,180	(876)	778	(736)	***
Cost of other chemical inputs (KSh/ha)[c]	106	(411)	184	(407)	***
Cost of hired labor (KSh/ha)	4,088	(6,429)	4,859	(6,029)	*
Quantity of maize yield (kg/ha)	1,661	(1,330)	2,071	(1,404)	***
Value of crop production (KSh/ha)	47,541	(40,774)	58,546	(44,362)	***
Net crop income from all crops (KSh/ha)[d]	36,920	(39,759)	45,246	(39,623)	***
Crop profit from all crops (KSh/ha)[e]	34,225	(38,841)	42,992	(39,542)	***

*** and * indicate significance at 1 and 10%, respectively.

[a] Significance testing of the difference between columns (b) and (c)

[b] Quantity of chemical fertilizer is measured in NPK equivalent.

[c] This includes herbicides, pesticides, fungicides, and other chemical input.

[d] Net crop income is defined as the value of all crop production minus all paid costs associated with crop production.

[e] Net crop income is defined as the value of all crop production minus all costs associated with crop production including family labor costs.

Table 2.13 Estimation results of the effects of the intensification index on crop production in the main cropping season (parcel fixed effects models, the largest maize plot level data)[a]

	Log of net crop income (KSh/ha)[b]	Log of crop profit (KSh/ha)[c]
Explanatory variables	(1)	(2)
Intensification index	0.0789*	0.101*
	(0.0468)	(0.0539)
Log of cultivated plot size (ha)	-0.441***	-0.433***
	(0.0922)	(0.0988)
Log of household size	0.170	0.107
	(0.107)	(0.115)
Female-headed (=1)	-0.0492	-0.0726
	(0.158)	(0.176)
Age of head	-0.00187	-0.00613
	(0.0256)	(0.0275)
Squared age of head	-0.0000145	0.0000156
	(0.000216)	(0.000230)
Head completed primary education (=1)	0.223	0.347*
	(0.155)	(0.179)
Log of value of productive assets (KSh)	-0.0224	-0.00587
	(0.0386)	(0.0389)
Log of carbon	0.0583	0.00378
	(0.193)	(0.209)
Log of time to big town (min by car)	-0.415	-0.461
	(0.446)	(0.501)
Constant	-0.0109	-0.142
	(0.240)	(0.259)
Observations	0.0328	0.0379
R-squared	(0.124)	(0.141)
Number of fixed effects	11.50***	11.75***

The numbers in parentheses are robust standard errors.
***, **, and * indicate significance at 1, 5, and 10%, respectively.
[a] Year 2012 and no carbon information dummies are included in all regressions.
[b] Net crop income is defines as the value of crop production minus all paid costs associated with crop production.
[e] Crop profit is defined as the value of all crop production minus all costs associated with crop production including family labor costs.

Table 2.12 displays crop production data on the largest pure-stand maize plot or the largest intercropped maize plots in the main cropping season. The means of most inputs and outputs have the same trend as in Table 2.2; crop yield and revenues increased with the level of intensification over time. Additionally, crop profit has increased by 26% over time. In contrast to other input use, family labor use, hired labor use, and total labor use have decreased significantly over time. Though hired labor use measured in working hours has decreased, costs of hired labor have increased, which indicates that the wage rate of hired labor in agricultural sector has risen over time. This means that intensification occurs in a rather unexpected manner. It could be that the intensification system intensifies the use of capital inputs to save the high cost of labor through input substitution.

Table 2.13 compares the effect of the new farming system on net crop income, which is defined as value of crop production minus all paid costs, and crop profits, which is defined as value of crop production minus all costs including family labor cost, using the same subsample of plots. The results indicate that one standard deviation increase in the intensification index would raise net crop income by about 9% and crop profit by 12%, suggesting that the potential biases of the estimated effects of the intensification system based on the large sample without accounting for family labor are likely to be small.

2.7 Conclusion and Policy Implication

As population pressure grows rapidly in Kenya, rural farmers have started to intensify a farming system by adopting new inputs and production practices, including adoption of high-yielding maize varieties, application of manure produced by improved dairy cows, and intercropping especially of maize with legumes that could fix nitrogen. Though the phenomenon of the new farming system has started to be paid attention among researchers, the empirical research that assesses the driving forces and impacts of this system is limited. Hence, this study aims to quantify the determinants of the new maize farming system and its impact on agricultural productivity. To gauge the impact of the new farming system, this study examines the impacts of individual inputs as well as the impact of the new maize farming system by using an agricultural intensification index constructed by PCA.

Our estimation results show that an increase in sub-location level population density raise the rate of hybrid maize seed adoption and the extent of agricultural intensification, meanwhile a decrease in the land-labor ratio increases chemical fertilizer application and the degree of agricultural intensification. These findings indicate that population pressure accelerates farming intensification, consistent with the Boserupian and induced innovation hypotheses. Furthermore, it is found that the adoption of hybrid maize seed, intercropping legumes with maize, manure application, and chemical fertilizer application have positive and significant impacts on land productivity. These impacts are confirmed and reinforced by the consistent and statistically significantly positive impacts of the agriculture intensification index not only on land productivity in terms of value of production and net income per hectare but also on the household total income per capita.

Therefore, we conclude that the new farming system has already improved the productivity of small-scale farmers in the highlands of Kenya. Therefore, effort for exploring the “optimum” farming system in agricultural research center is encouraged. It can be expected that much more significant increase in the productivity of farming could be achieved if appropriate research is carried out and appropriate technical support and extension services regarding this new maize farming system are provided for small-scale maize farmers in Kenya.

APPENDIX

Table A2.1 Pairwise correlation coefficients matrix of input use

		(1)	(2)	(3)	(4)	(5)
Household level						
(1)	Hybrid maize seeds (=1)	1				
(2)	Quantity of intercropped legume seed (kg/ha)	0.0044	1			
(3)	Quantity of manure (kg/ha)	0.0899***	0.0598**	1		
(4)	Quantity of chemical fertilizer (kg/ha)[a]	0.2571***	0.0041	0.1428***	1	
(5)	Number of improved cows (numbers/ha)	0.1115***	0.0286	0.163***	0.2439***	1
Plot level						
(1)	Hybrid maize seeds (=1)	1				
(2)	Quantity of intercropped legume seed (kg/ha)	0.0716***	1			
(3)	Quantity of manure (kg/ha)	0.0739***	0.0826***	1		
(4)	Quantity of chemical fertilizer (kg/ha)[a]	0.2695***	0.1653***	0.0828***	1	

***, **, and * indicate significance at 1, 5, and 10%, respectively.
[a] Quantity of chemical fertilizer is measured in NPK equivalence.

Table A2.2 Estimation results of the effects of input intensification on crop production per cropping season (parcel and parcel-year fixed effects models, plot level data)[a]

	Log of maize yield (kg/ha)		Log of value of crop production (KSh/ha)		Log of crop net income (KSh/ha)[c]	
Type of fixed effect model	Parcel	Parcel -year	Parcel	Parcel -year	Parcel	Parcel -year
Explanatory variables	(1)	(2)	(3)	(4)	(5)	(6)
Hybrid maize seeds (=1)	0.234***	0.157*	0.167**	0.0943	0.0751	0.0939
	(0.0703)	(0.0860)	(0.0770)	(0.106)	(0.0902)	(0.116)
Intercropping legume seeds (kg/ha)	0.00153	-0.000797	0.00403**	0.00179	0.00393**	0.00240
	(0.00139)	(0.00171)	(0.00168)	(0.00225)	(0.00187)	(0.00235)
Manure (t/ha)	0.0314**	0.0313*	0.0288*	0.0400*	0.0210	0.0167
	(0.0136)	(0.0169)	(0.0158)	(0.0207)	(0.0180)	(0.0210)
Chemical fertilizer (10kg/ha)[b]	0.0407***	0.0279***	0.0298***	0.0178	0.00890	-0.00841
	(0.00853)	(0.00936)	(0.00888)	(0.0135)	(0.0108)	(0.0137)
Hybrid seed * intercropping legume seeds (kg/ha)	-0.0159*	-0.0129	-0.0114	-0.0106	-0.00492	-0.00273
	(0.00896)	(0.0101)	(0.0100)	(0.0143)	(0.0119)	(0.0150)
Hybrid seed * manure (t/ha)	-0.00581	-0.0212	0.00474	-0.0134	0.0163	0.00497
	(0.0171)	(0.0199)	(0.0186)	(0.0248)	(0.0214)	(0.0250)
Hybrid seed * chemical fertilizer (10kg/ha)	-0.00203	-0.000432	-0.000261	0.00192	0.000365	0.00331
	(0.00167)	(0.00212)	(0.00186)	(0.00252)	(0.00229)	(0.00291)
Log of cultivated plot size (ha)	-0.454***	-0.526***	-0.386***	-0.449***	-0.334***	-0.437***
	(0.0407)	(0.0447)	(0.0471)	(0.0558)	(0.0436)	(0.0653)
Log of household size	0.128		0.115		0.0777	
	(0.0963)		(0.0901)		(0.0820)	
Female-headed (=1)	-0.0931		-0.0813		-0.0472	
	(0.114)		(0.110)		(0.103)	
Age of head	0.00192		0.00154		-0.000806	
	(0.00416)		(0.00407)		(0.00368)	
Head completed primary education (=1)	0.0887		0.0174		0.187*	
	(0.102)		(0.0873)		(0.103)	
Log of value of productive assets (KSh)	0.00876		-0.0386		-0.00272	
	(0.0247)		(0.0250)		(0.0268)	
Log of carbon	0.0490		-0.0789		0.252	
	(0.173)		(0.153)		(0.198)	
Log of time to big town (min by car)	-0.696		-0.677		-0.230	
	(0.498)		(0.469)		(0.548)	
Constant	8.776***	6.227***	12.80***	9.674***	10.06***	9.436***
	(2.243)	(0.0831)	(2.135)	(0.106)	(2.496)	(0.119)
Observations	2,810	2,810	2,810	2,810	2,809	2,809
R-squared	0.733	0.738	0.523	0.532	0.811	0.783
Number of fixed effects	1,110	1,803	1,113	1,805	1,113	1,805

The numbers in parentheses are robust standard errors.
***, **, and * indicate significance at 1, 5, and 10%, respectively.
[a] Short season dummy is included in all regression. Interaction terms between year 2012 and divisions, and year 2012, and no carbon information dummies are included in regression of (2), (4) and (6).
[b] Quantity of chemical fertilizer is measured in NPK equivalence.
[c] Net crop income is defined as crop production minus all paid costs associated with crop production.

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CHAPTER 3: THE EFFECT OF LAND DISTRIBUTION ON INCOME AND POVERTY REDUCTION: EVIDENCE FROM KENYA

3.1 Introduction

Land is a primal productive asset for rural farmers in Sub-Saharan Africa. Therefore, access to land has non-negligible impact on agricultural production and income for rural households (Gunning et al., 2000; Nargis and Hossain, 2006). However, past studies have shown that land distribution in Sub-Saharan Africa is highly skewed and land is highly concentrated (Griffin et al., 2002; Jayne et al., 2003; Barret et al., 2005; Holden et al., 2009). This is a worrisome situation for rural households in Sub-Saharan Africa because unequal land distribution is often found to be detrimental to income growth (Deininger and Squire, 1998; Vollrath, 2007). Since most of households in rural areas in Sub-Saharan Africa depends on agriculture for their livelihoods (Quan, 2000), land distribution and land access could have far-reaching implications on rural household's welfare in Sub-Saharan Africa.

There are several potential channels through which land inequality may affect household's income and poverty. First, land inequality can affect rural household's income and poverty through its possible effect on credit. For instance, the landless and land constrained households face challenges to access credit to invest in productive and human capital due to lack of valuable collateral (Stiglitz, 1969; Loury, 1981; Galor and Zeira, 1993; Binswanger et al., 1995; Benabou, 1996; Aghion and Bolton, 1997; Aghion et al., 1999). Second, land inequality creates unequal factor ratios across households that would persist in the presence of market imperfections (Feder, 1985; Bardhan and Udry, 1999). The persistent imbalance in the factor ratios is likely to be translated into persistent low productivity and inefficiency. Third, land distribution could affect income and poverty through its effect on provision of public goods and services, as well as social and political cohesion within a community. For example, a constraint on wealth could limit households' ability to express their concerns in politics (Bourguignon and Verdier, 2000). High inequality could hinder local communities to provide growth enhancing public goods and services that benefit all residents (Cardenas, 2003). Additionally, high unequal wealth distribution could induce public 'bads' such as social unrest and strife between inhabitants in a community which could undermine economic growth (Conning and Robinson, 2007). Fourth, the inverse relationship between farm size and agricultural productivity suggests that skewed land distribution among farmers is associated with lower land productivity in a region (Schultz, 1964; Bardhan, 1973; Feder, 1985; Hayami and Otsuka, 1993; Binswanger et al., 1995; Vollrath, 2007; Hazell, 2011). In this regard, policy makes are increasingly aware of the important implication of relationship between asset distribution and economic growth (Bardhan et al., 2000; World Bank, 2005).

Though quite a few studies have explored the relationship between asset distribution and agricultural productivity, income growth, or poverty, most of them are based on country level data. While informative, cross-country studies are likely to suffer from a number of data or methodological concerns. One concern about cross-country studies is related to data comparability. The way in which data are aggregated to the national level and the definitions of certain variables could be very different across countries. Additionally, findings based on cross-country analysis have limited policy use for policies targeted at the community and/or at the household level. From a policy perspective, it is important to understand how asset inequality affects households from different economic or social backgrounds. Cross-country studies are unable to provide an answer to this type of question.

Therefore, our study aims to contribute to the debate on the relationship between land inequality and income and poverty based on micro level panel household survey data. Specifically, we will assess the impact of land distribution on agricultural productivity, income and poverty of rural households in Kenya based on household level panel data from 5 rounds of repeated household survey from 1997 to 2010. The long panel data allow us to estimate a panel regression to control for time-invariant unobservable that could be associated with community level land inequality and household economic outcomes. The heterogeneous effects of land inequality for different groups of households are also explored. Finally, village level panel data are used to identify the determinants of village level land distribution.

The estimation results reveal several interesting findings. First, population density is negatively related to land distribution in a village. As village population density increases by 100 persons per square kilometer (km^2), the Gini coefficient of own land size would reduce by 0.004 - 0.005. Second, agricultural land inequality has consistent and negative effects on agricultural land productivity, as an increase in the Gini coefficient of own agricultural land by 0.1 would reduce the value of crop production per acre and net crop income per acre by 4.3% and 5.1%. Third, unequal distribution of agricultural land has negative effects on household per capita income and household poverty status. An increase in the Gini coefficient by 0.1 would decrease the net crop income per capita, net livestock income per capita, net non-farm income per capita, net total income per capita, and the probability of being out of poverty 4.1%, 6.6%, 5.0%, 3.8% and 2.8% respectively. Last but not least, the negative income and poverty effects of land inequality are much more significant and larger in magnitude for poor and land-constrained households. High level education, however, does not seem to mitigate the negative effects of land inequality.

The rest of this essay consists of 5 sections. Section 3.2 describes how unequal land distribution affects economic growth and poverty and land distribution in Kenya. Section 3.3 explains the estimation strategy to pursue the purpose of this paper. Section 3.4 describes data which is used for this study and shows sample characteristics. Section 3.5 presents the estimation result. Finally, Section 3.6 summarizes the major findings and discusses the policy implications.

3.2 Background

3.2.1 Why Does Land Inequality Affect Economic Growth and Poverty?

Land inequality could affect income growth in a community through multiple channels including credit access, efficiency loss due to imbalance in factor ratios across households, political and social cohesion, and loss of productivity because the existence of inverse size-productivity relationship.

First, unequal land distribution could affect income growth through its effect on credit. If households wish to raise their productivity but their human and physical capital is constrained, they need financing for investment. However, if information asymmetry between lenders and borrowers prevails, credit rationing will arise (Stiglitz and Weiss, 1981). In this environment, borrowers could access credit if they use their own assets such as lands as collateral. Hence, it would be difficult for land-constrained or landless households to access credit to invest in human and physical capital if credit market failure prevails. Additionally, limitation of access to credit not only influences accumulation of productive capital by limiting investment, but also inhibits formulation of the spill-over effects of growth enhancing technologies (Galor and Zeira, 1993). Therefore, higher land inequality could lead to lower aggregate income growth in a region. If credit markets function perfectly, the relationship between land inequality and income growth breaks down, as the distribution of resources no longer determines household income growth. The credit market imperfection in the developing world has long been documented (Binswanger et al., 1995; Benabou, 1996; Aghion and Bolton, 1997; Aghion et al., 1999).

Second, inequality in land distribution hinders aggregate productivity through the inefficiency effect of imbalance in factor ratios across households within a community. If all markets function perfectly and agricultural production function technology exhibits constant return to scale, the ratio of land and other production factors among all households in a region would be equalized by market equilibration and thus the initial endowment of land would not matter for production efficiency (Feder, 1985; Bardhan and Udry, 1999). Even though there is no land market, the efficient outcome could be achieved if other factor markets function perfectly. Therefore, if land markets or other factor markets function well, the initial distribution of land would not matter for the economic growth. However, past studies point out the fact that imperfection of rural factor markets prevails in developing areas (Binswanger and Rosenzweig, 1986; De Janvry, Fafchamps, and Sadoulet, 1991). Hence, imbalance in the factor ratios inherited from the skewed land distribution persists, leading to a long-term inefficiency and low productivity.

Third, land inequality is hypothesized to have negative effect on community's political and social cohesion and public good provisions. Limitation of wealth could make it difficult for individuals to lobby and to express their concerns in politics (Bourguignon and Verdier, 2000;

Deininger et al., 2009). Additionally, it may be easier for more equal society to reach a consensus of provision of public goods and services that could benefits all residents than more unequal society (Durlauf, 1996; Cardenas, 2003; Benjamine et al., 2011). Unequal asset distribution not only could hinder from provision of growth enhancing public goods, but also could generate public 'bads' such as social strife and unrest which could pose huge social costs and undermine economic growth (Conning and Robinson, 2007, Deininger et al., 2009). In fact, unequal land distribution since post-colonial time became one of the main causes of violence which was triggered by the president election in 2007 in Kenya (Kimenyi and Ndung'u, 2005).

Fourth, the inverse relationship between farm size and productivity is another possible reason why land inequality lowers aggregate productivity. The hypothesis of inverse relationship between land size and land productivity simply explains that small farmers are more productive than large farms because of monitoring costs of hired labor (Schultz, 1964; Hayami and Otsuka, 1993; Binswanger et al., 1995) or for some other reasons (Benjamin, 1995). While large farms usually require hired labor for agricultural production and landholders need to pay costs for monitoring, small farms, which could be cultivated only by family labor, generally do not require monitoring costs. Under this setting, land productivity of small farms would be higher than that of large farms (Bardhan, 1973; Feder, 1985; Vollrath, 2007). Highly unequal land distribution could mean that few landholders have a large share of land and many others have small pieces of land. If small landholders could not access more land up to the amount at which they maximize land productivity given their endowment, and large landholders are not productive as much as small landholders due to the high monitoring costs, then aggregate agriculture productivity could be enhanced simply by redistributing some land from large farmers to small landholders and the landless.

The limited number of previous studies on land inequality and economic growth, productivity and poverty are mostly based on aggregate data. For example, Deininger and Squire (1998) showed the negative relationship between initial land distribution and economic growth and Vollrath (2007) confirmed the negative effects of land distribution on agricultural productivity, based on county level data. Additionally, Ravallion and Datt (2002) found that the high initial proportion of landless households in a state inhibits economic growth of non-farm sector and poverty reduction based on state level panel data in India. We are not aware of any study that explores the relationship between land inequality and household's income and poverty status using household panel data. We aim to fill in this knowledge gap here.

3.2.2 Land Distribution in Kenya

Before colonization, land was allocated to households in a community and managed collectively by a community in Kenya. Though there were no official land certificates, the user rights were recognized and protected by a community (Muyanga, 2013). However, during the colonial time, the Crown Land legislation was enacted, which established "scheduled" land for white settlers and "reserves" for natives (Okoth-Ogendo, 1991; Syagga, 2010). The scheduled areas were fertile land in highland but the reserves were generally marginal and unfertile land. The colonial government took 2.8 million hectare of fertile land, which was about a half of high agriculturally potential land, from communities and allocated to the white settlers (Okoth-Ogendo, 1991; Mamdani, 1996; Kimenyi and Ndung'u, 2005, Kanyinga, 2009). As a result, the reserves became congested as population grew, which led to overuse and overgrazing of land

(Kanyinga, 2009; Muyanga, 2013).

Few years before independence, the British government and the World Bank launched the Million-Acre Settlement Scheme, which aimed at transferring white settler's farms to Kenyan. The land-transferring program was based on market-based "willing-seller/willing buyer" system. This resulted in the fact that most of land was purchased by the wealthy ethnic majority group, such as Kikuyu (Leo, 1989). Additionally, distribution of state owned land was used as a political tool to favor the patrons of rulers by providing public land to the economic and political elites (Muyanga, 2013). This resulted in skewed agricultural land distribution in Kenya, where a small number of wealthy elites had large underutilized farmland, while the large number of famers experienced reduction of per capita farm sizes. This fostered long-lasting animosities among the ethnic groups, which became one of the causes of social unrest that happened at the time of the presidential election in 2007 (Kimenyi and Ndung'u, 2005).

Currently the primary mode of land acquisition for smallholders is via inheritance and land market transactions in Kenya. The Kenyan government supports market transactions of land by the National Land Policy (NLP), which is the framework for land access and administration. NLP provides and ensures land rights, makes regulation of the markets, and invests in infrastructure (Republic of Kenya, 2009).

3.3 Estimation Strategy

Before quantifying the effects of land distribution on productivity, income and poverty, we first explore the determinants of land distribution. Bardhan et al. (2014) showed how population growth can affect land inequality. Population growth in a community could be explained in two ways, by exceeding the birth rate over the death rate, and by exceeding the number of immigrants over out-migrants. When a household divides land for inheritance to more than one child, a household would have smaller land than before. Land inequality tends to fall if a household with large landholding divides their land at a faster rate than a household with small landholding and vice versa. Immigrants usually access land by land sale or land rental markets. If a large piece of land is divided and sold to new residents, the land inequality within a community could fall. However, if a large number of poor landless immigrants settled in a community, land inequality of that community could rise. Bardhan et al. (2014) empirically showed that land reform reduced land inequality by household divisions and market transactions, but the effect was offset by an increase in the number of landless immigrants in a state in India. This study employs the population density to measure the effects of population pressure to land on land distribution.

The model to identify determinants of land distribution based on village level data can be expressed as following:

$$Gini_{vt} = \alpha_0 + \alpha_1 Pop_{vt} + \alpha_2 Z_{vt} + \alpha_3 D_t + \beta_v + \varepsilon_{vt} \tag{1}$$

where $Gini_{vt}$ is the Gini coefficient of owned agricultural land in village *v* in year *t* measuring the degree of land inequality in a community, Pop_{vt} is population density (persons per km^2), Z_{vt} is a vector of village characteristics including the average size of land owned by an average household, average household size, average distance from a residence to the tarmac road, average distance from a residence to the extension service in a village, the proportion of households participating in the rental market, the proportion of households receiving credit, and the amount of total annual rainfall, and D_t is a vector of year dummies that capture time trends.

The existence of β_v, village level time-invariant unobserved factors that are correlated with $Gini_{vt}$ and Pop_{vt} (or Z_{vt}) causes OLS estimator of equation (1) biased and inconsistent. To eliminate β_v and obtain a consistent estimator, we estimate the first differenced version of equation (1) as

$$\Delta Gini_{vt} = \alpha_1 \Delta Pop_{vt} + \alpha_2 \Delta Z_{vt} + \alpha_3 \Delta D_t + \Delta \varepsilon_{vt} \tag{2}$$

The coefficient of interest is α_1 in this model.

To estimate the effects of land inequality on agricultural production, income, and poverty, we specify the reduced form equation as

$$y_{ivzt} = \gamma_0 + \gamma_1 Gini_{vzt} + \gamma_2 X_{ivzt} + \gamma_3 AEZ_{zt} + \gamma_4 D_t + \gamma_5 AEZ_{zt} * D_t + \delta_{ivz} + \epsilon_{ivzt} \tag{3}$$

where y_{ivzt} is alternately the value of total crop production per acre or per capita, net crop income which is the difference between the value of crop production and input costs per acre or per capita, net livestock income which is the difference between the value of livestock production and input costs per capita, net non-farm income which is net revenue from non-farm sectors per capita, net total income which is a sum of net crop, livestock and non-farm income per capita, or poverty status (= 1 if income per capita is above the national poverty line, = 0 otherwise). The subscripts, i, v, z, t stand for household, village, agro-ecological zone and year. X_{ivzt} is a vector of household characteristics including endowment of agricultural land, a dummy for female-headed household, a dummy for head with primary education, a dummy for households receiving credit, head's age, the value of total asset, distance from homestead to the tarmac road, and distance from homestead to extension service. AEZ_{zt} is a vector of agro-ecological dummy variables, which is expected to capture common shocks at the level of agro-ecological zone. Interaction terms between agro-ecological zone dummies and year dummies are also included to control for the time specific localized shocks at each agro-ecological zone. δ_{ivz}

includes village time-invariant unobserved factors (e.g., unmeasured weather, technology, productivity, land quality and so on) and household level factors (e.g., household head' innate ability, risk preference and so on). Estimation of (3) by OLS generates biased and inconsistent estimates because δ_{ivz} could affect y_{ivzt} and $Gini_{vzt}$ simultaneously. Hence, we take the first difference of the equation (3) to eliminate δ_{ivz} as:

$$\Delta y_{ivzt} = \gamma_1 \Delta Gini_{vzt} + \gamma_2 \Delta X_{ivzt} + \gamma_3 \Delta AEZ_{zt} + \gamma_4 \Delta D_t + \gamma_5 \Delta \mathrm{AEZ}_{zt} * D_t + \Delta \varepsilon_{ivzt}. \qquad (4)$$

The coefficient of interest in this estimation is γ_1.

We also explore the heterogeneous effects of land inequality on income and poverty across households of different socio-economic backgrounds. First, we added to equation (4) an interaction term between the Gini coefficient and a dummy for households with value of total assets in the lowest quartile in a village. Doing so allows us to assess whether land inequality affects poor and rich households differently. Second, we added to equation (4) an interaction terms between the Gini coefficient and a dummy for households whose agricultural land ownership is in the lowest quartile in a village to assess whether the effects of land inequality are different across households with different land endowments. Finally, to assess whether land inequality affects households with different levels of education, we add to equation (4) an interaction term between the Gini coefficient and a dummy for heads who have completed secondary education.

3.4 Data and Sample Characteristics

Our study relies on the panel household data from a repeated nationwide household survey in rural Kenya conducted by Tegemeo Institute of Egerton University in Kenya. The survey started in 1997 and the sampling frame was designed in consultant with the Kenya National Bureau of Statistics. In the sampling frame, 24 administrative districts were chosen to represent all major agro-ecological zones in Kenya. Then, proportionally to population in agro-ecological zones, one or more administrative divisions were picked from a selected district. After that, villages and households were randomly drawn from a selected division. Eventually, the survey interviewed 1540 households from 111 villages in 39 divisions in 24 districts and in 8 agro-ecological zones in 1997. The subsequent surveys were conducted in 2000, 2004, 2007, and 2010. The attrition rate between two consecutive surveys is about 5%. A test of the existence of systematic attrition in the data was conducted and the F-ratio test indicates no evidence of systematic attrition.

This household survey includes information on household characteristics, assets, geographical information, agriculture production and different income sources as well as community characteristics. The relatively long panel household data allow us to identify the impacts of land inequality on agricultural productivity, income, and poverty by the panel estimation methods. The village level Gini coefficient of agricultural land is used as a measure of land inequality in a community. To ensure the Gini coefficient is a reliable measure of land inequality, we excluded all the villages with sample size less than 10 households in our analysis. To deal with outlier issues, we further drop the observation with the value of production and all income in the top 99% of the sample.

The data used to estimate the determinants of land Gini is from multiple sources. While the Gini coefficient and many of the right hand side variables in equation (2) are calculated from the above-mentioned household panel data, we only rely on other data sources to calculate one of the key right hand side variables – population density of each village. Specifically, the population density is based on the Global Rural Urban Mapping Project dataset (GRUMP), and the global land cover dataset (GlobCover2009) assembled by Chamberlin (2012). The village level population density is computed as the ratio of total population by total arable land area in a village.

Table 3.1 Household characteristics

	1997	2010	2010			
	National	National	Eastern & Western Lowlands Zone	Western Traditional & Western Highlands Zone	High Potential Maize Zone	Central Highland Zone
Female-headed HH (%)	14%	27%	34%	25%	25%	23%
Head completed primary education (%)	54%	60%	56%	58%	60%	65%
Age of the head (years)	50.3	60.4	60.3	59.1	60.0	63.0
Household size	6.6	5.5	6.2	5.7	6.0	3.8
Owned farm size (acres)	3.2	2.9	2.5	2.3	4.8	1.8
Value of total asset (KSh)	238,030	312,636	242,368	142,216	432,179	434,680
Rented-in lands (%)	18%	17%	12%	22%	24%	10%
Received credit (%)	40%	54%	50%	55%	43%	86%
Distance to tarmac road (km)	8.2	7.1	8.6	6.5	6.4	5.0
Distance to extension service (km)	5.4	5.4	6.6	4.7	6.1	3.7
Value of crop production (KSh/acre)	45,171	40,869	25,302	38,999	29,242	87,707
Net crop income (KSh/acre)[a]	38,164	37,309	23,780	35,142	25,261	81,528
Net crop income (KSh/capita)[a]	20,924	21,403	12,800	18,416	18,581	44,406
Net livestock income (KSh/capita)[b]	30,941	14,432	5,512	9,700	23,549	21,341
Net non-farm income (KSh/capita)[c]	8,546	18,525	19,970	11,077	18,260	24,338
Net total income (KSh/capita)[d]	59,632	57,636	41,002	40,655	62,317	98,324
Headcount poverty ratio (%)	44%	38%	50%	49%	37%	7%

[a] Net crop income is defined as the value of crop production minus input costs.
[b] Net livestock income is defined as the value of livestock production minus costs.
[c] Net non-farm income is defined as the revenue from non-farm sector minus costs.
[d] Net total income is summation of net crop income, net livestock income, and net non-farm income.

3.4.1 Household Characteristics

Table 3.1 describes characteristics of households from 1997 to 2010. Following Jin and Jayne (2013), we divide the total sample into four main zones based on the agro-ecological conditions and agricultural productivity potential. They are respectively Eastern and Western Lowlands, Western Traditional and Western Highlands, High Potential Maize, and Central Highlands. The agricultural productivity potential is relatively low in lowlands and high in highlands.

There are notable intertemporal and interzonal differences in household characteristics in many aspects. The average proportion of female-headed households increased from 14% to 27% from 1997 to 2010. This varies from 23% in Central Highland Zone to 34% Eastern and Western Lowlands Zone in 2010. The completion rate of primary education of a household head increased from 54% to 60% over time ranging from 56% in Eastern and Western Lowlands Zone to 65% in Central Highland Zone. The average household head aged by about 10 years, which is not surprising as the panel data tracks same households for 13 years. The mean sizes of household and own farmland shrank by 1.1 and 0.3 acres respectively over time. While Central Highland Zone has the smallest mean household size (3.8) and own farmland (1.8 acres), Eastern and Western Lowlands Zone has the largest household size (6.2) and High Potential Maize Zone has the biggest own farm (4.8 acres). The average total value of assets has increased by 31% over time. The value of total assets in Central Highland Zone (434,680 Kenyan Shieling (KSh)[16]) is about three times as large as that in Western Traditional and Western Highlands (142,216 KSh). The change in proportion of households who rented-in land over time is negligible. The land

[16] Throughout this chapter, all prices are converted to the real price setting 2010 as a base year. The consumer price index for 1997, 2000, 2004 and 2007 are 28.62, 29.77, 36.78, 47.9, and 64.86 respectively.

rental is most active in High potential Maize Zone and least active in Central Highland Zone. The access to credit has improved over time as the proportion of households who received credit increased by 14% from 1997 to 2010. The credit access is most active in Central Highland Zone (86%) and least in High potential Maize Zone (43%). The transportation infrastructure seems improved in Kenya, as the average distance from homestead to the tarmac road shortened by 1.1 km overtime. However, the average distance from home to the extension service stays same over time. While Central Highland Zone has best infrastructure, as the distances to the tarmac road and to extension service are the shortest, Eastern and Western Lowlands has poorest infrastructure as these distances are farthest.

This study uses the value of all crop production per acre and net crop income per acre, which is the difference between the value of crop production and input costs, to measure agricultural land productivity. Though the average value of crop production per acre has declined by 4,300 KSh over time, the net crop income per acre stayed almost the same from 1997 to 2010. There are huge disparities of the value of crop production per acre and net crop income per acre across zones in 2010, as the value of crop production and net crop income in Central Highland Zone are more than 3 times higher than those in Eastern and Western Lowlands Zone.

Household net total income is the summation of net crop income, net livestock income, and net non-farm income. Each net income is computed as gross income minus costs. The change in the average net crop income per capita is negligible over time. The net livestock income per capita significantly dropped from 1997 to 2010, which is probably due to an outbreak of Rift Valley fever, a viral disease communicable to animals such as cows, sheep, and goats, in 2006 and 2007. It is highest in High Potential Maize Zone and lowest in Eastern and Western

Lowlands Zone. The net non-farm income per capita has increased more than doubly over time. The net non-farm income per capita of households in Central Highland Zone is more than double in Western Traditional and Western Highlands. The net total income per capita has declined slightly over time. There are also great disparities of net total income per capita among zones. The net total income per capita of households in Central Highland Zone is two times as great as that in Eastern and Western Lowlands Zone. The headcount poverty ratio reduced by 6% over time. The poverty ratio is significantly lower for households in Central Highland Zone with an average ratio at 7%.

Based on the household level descriptive statistics, it is evidenced that there are huge gaps in economic conditions across zones in Kenya. Though Central Highland Zone has the smallest household size and own farm size, the agricultural intensification seems to be most advanced, as the agricultural land productivity is much higher than other areas. Additionally, Central Highland Zone has most active non-farm sector economy. As a result, Central Highland Zone has the highest income level and lowest poverty ratio in Kenya.

3.4.2 Population Density and Land Distribution in Kenya

Table 3.2 describes village level population density and agricultural land distribution over time and across zones. The average village level population density in Kenya grew from 619 people per km^2 to 893 people per km^2 from 1997 to 2010. On the other hand, the average village level Gini coefficient of own agricultural land dropped by 0.11 (from 0.47 to 0.36), suggested that agricultural land became more equally distributed over time. The more equalized land distribution over time is also evidenced in the Lorentz curves in figure 3.1. Interestingly, Central

Highland Zone which has the highest village level population density (5 times greater than that in High Potential Maize Zone) also has the lowest village level Gini coefficient.

Table 3.2 Village characteristics

	1997	2010	2010			
	National	National	Eastern & Western Lowlands Zone	Western Traditional & Western Highlands Zone	High Potential Maize Zone	Central Highland Zone
Population density (persons/km^2)	619	893	925	749	368	1,912
Gini coefficient of own farm size	0.47	0.36	0.36	0.33	0.44	0.31

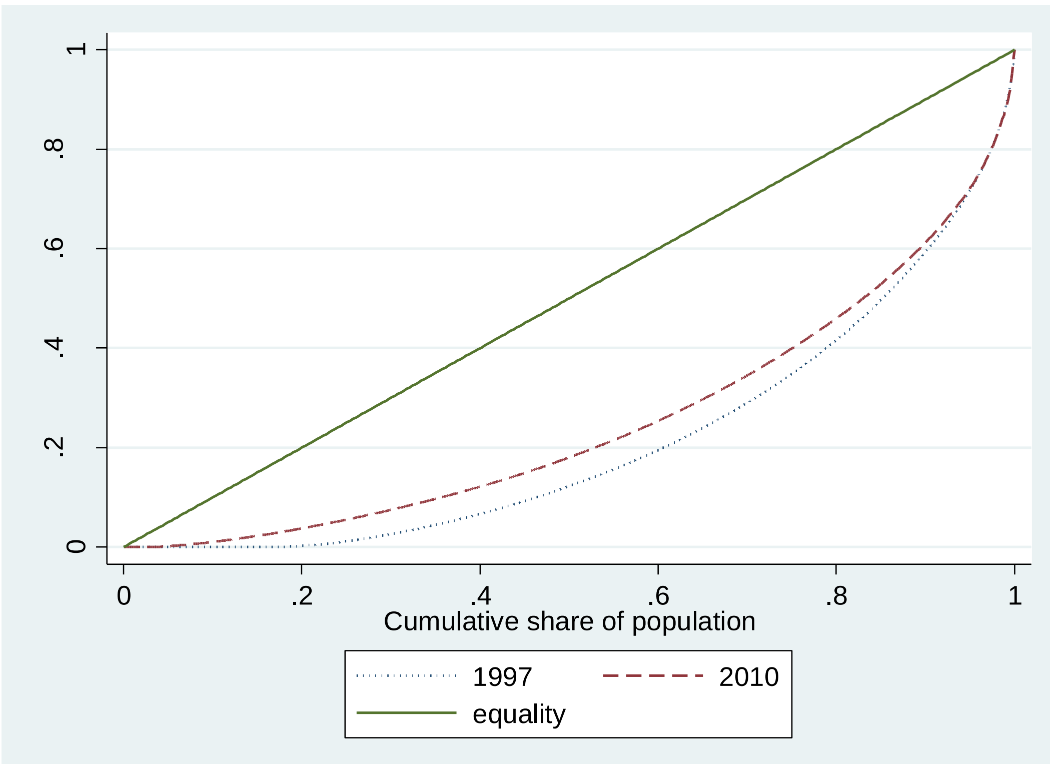

Figure 3.1 Lorenz curve of national own agricultural landholding distribution over time (1997-2010)

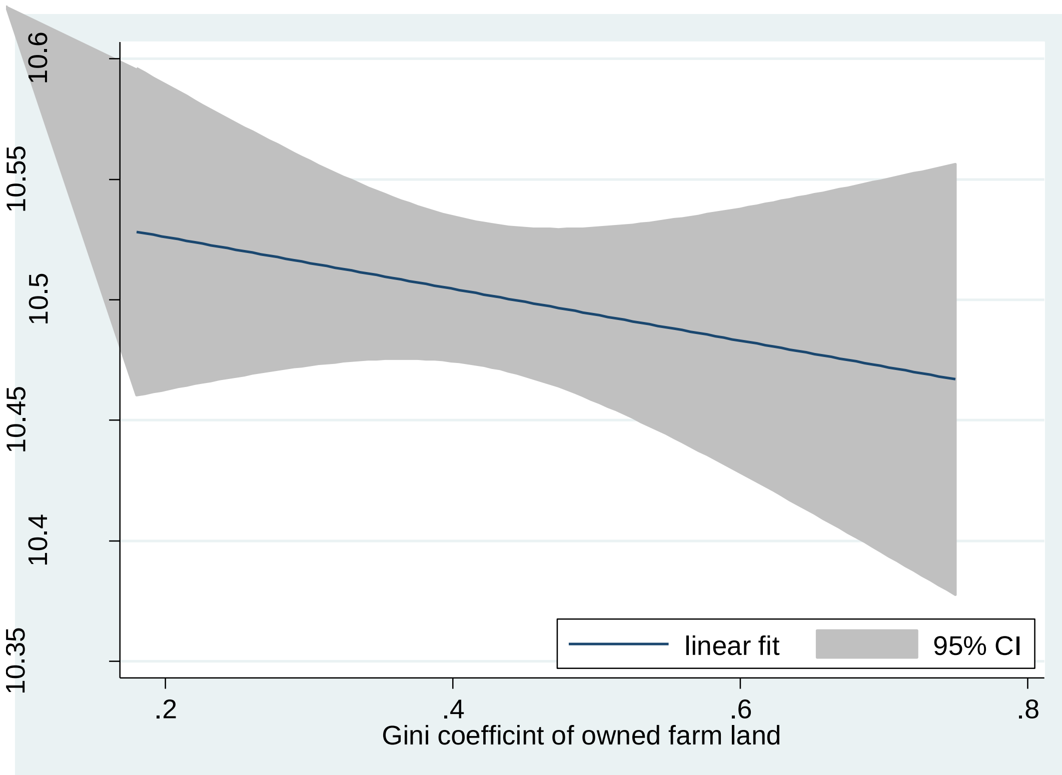

Figure 3.2 Correlation between log of income per capita and the Gini coefficient of own farm land
Note: The fitted line is regression line of log of household net total income per capita (KSh) on the village level Gini coefficient of owned farm land based on pooled household data. The regression coefficient and the standard error are -.107 and 0.13. The gray area is 95% confidence interval.

Figure 3.2 shows the negative correlation between the household net total income and the village level Gini coefficient of own farm. In the next section, this relationship is further assessed by panel regression analysis that controls for time, regional, and household characteristics.

Table 3.3 Determinants of the Gini coefficient of owned farm lands (village first-differencing and fixed effects model, village level data)

	Gini coefficient	
	FD	FE
Explanatory variables	(1)	(2)
Population density (100 persons/km^2)	-0.00511**	-0.00401*
	(0.00212)	(0.00202)
Log of average household's owned land size (acre)	-0.0271	-0.0390
	(0.0282)	(0.0323)
Log of average household size	0.0346	-0.00422
	(0.0394)	(0.0457)
% of households who rented-in lands	0.0508	0.0332
	(0.0367)	(0.0392)
% of households who received credit	-0.0115	-0.0290
	(0.0234)	(0.0297)
Log of average distance to tarmac road (km)	-0.0153	-0.00145
	(0.0137)	(0.0167)
Log of average distance to extension advice (km)	0.00345	-0.00278
	(0.00930)	(0.0103)
Log of quantity of annual rainfall (mm)	-0.00357	0.0342
	(0.0268)	(0.0313)
year 2000 dummy		0.00444
		(0.00443)
year 2004 dummy	-0.0562***	-0.0551***
	(0.0151)	(0.0143)
year 2007 dummy	-0.0493***	-0.106***
	(0.0107)	(0.0161)
year 2010 dummy	-0.00295	-0.104***
	(0.0137)	(0.0185)
Constant	0.00569*	0.238
	(0.00323)	(0.315)
Observations	355	459
Number of village		100
R-squared	0.103	0.370

The numbers in parentheses are robust standard errors.
***, **, and * indicate significance at 1, 5, and 10%, respectively.

Table 3.4 Effect of the village Gini coefficient of owned farm land on agricultural land productivity (household first differenced model, household level data)[a]

	Log of value of crop production (KSh/acre)	Log of net crop income (KSh/acre)[b]
VARIABLES	(1)	(2)
Gini coefficient of owned farmland	-0.425**	-0.514***
	(0.166)	(0.181)
Log of owned farm size	-0.0245***	-0.0223***
	(0.00676)	(0.00747)
Log of household size	0.0212	0.00980
	(0.0360)	(0.0402)
Head's age	-0.000530	-0.00140
	(0.00237)	(0.00256)
Female-headed (=1)	-0.00442	-0.0810
	(0.0642)	(0.0689)
Head completed primary education (=1)	0.000531	-0.0265
	(0.0416)	(0.0464)
Received credit (=1)	0.0121	-0.0185
	(0.0263)	(0.0279)
Log of value of total assets (KSh)	0.0277*	0.0365**
	(0.0146)	(0.0153)
Log of average distance to tarmac road (km)	-0.000505	0.00779
	(0.0184)	(0.0204)
Log of average distance to extension service	-0.0134	-0.0129
(km)	(0.0114)	(0.0128)
Log of rainfall in the main cropping season	0.0541	0.0699*
(mm)	(0.0377)	(0.0381)
Constant	0.565***	0.814***
	(0.151)	(0.181)
Observations	4,505	4,506
R-squared	0.207	0.602

The numbers in parentheses are robust standard errors.
***, **, and * indicate significance at 1, 5, and 10%, respectively.
[a] Interaction terms between year 2012 and agro-ecological zone, agro-ecological zone and year dummies are included in all regressions.
[b] Net crop income is defined as the value of crop production minus input costs.

3.5 Estimation Results

3.5.1 Determinants of Land Distribution

The regression results for the determinants of village land distribution are reported in Table 3.3. For robustness check, both first differenced (column 1) and fixed effect (column 2) estimation results are reported. Population density has significant and negative impact on inequality of household's own agricultural land within a village. An increase in population density of 100 persons per km^2 would lead to a reduction in the Gini coefficient by 0.005 in the first differenced model and by 0.004 in the fixed effect model. This could indicate that population pressure to land accelerates fragmentation of large land and distributed land to smallholders. Both the first differenced model and the fixed effect model show a declining trend of the Gini coefficient after 2000, which is consistent with the evidence in the descriptive analysis.

3.5.2 Effects of Land Distribution on Agricultural Land Productivity

Table 3.4 presents the results on the effects of land inequality on land productivity which are measured by log of the value of all crop production per acre (column 1) or by log of net crop income per acre (column 2). As expected, land inequality has significant and negative effects on agricultural productivity. An increase in the Gini coefficient by 0.1 would lead to a reduction of the value of crop production and net crop income by 4.3% and by 5.2% respectively. The results also show statistically significant inverse relationship between land size and productivity, a phenomenon that has long been observed and studied (Schultz, 1964; Bardhan, 1973; Feder, 1985; Hayami and Otsuka, 1993; Binswanger et al., 1995; Vollrath, 2007; Hazell, 2011). An increase in own farm size by 1 acre would lead to a decline in the value of crop production per acre by 2.5% and net crop income per acre by 2.2%. The presence of inverse farm-size and productivity relationship implies that redistributing land from large farmers to land constrained smallholders in the same community would be productivity enhancing. The positive and significant coefficient on the value of total assets is also consistent with expectation. In the presence of credit and other market imperfection, wealthy households have better ability to afford more and better inputs and to own and use agricultural machinery and bullocks. Majority of the other variables also have expected sign though mostly insignificant. For example, rainfall has positive effect on productivity (though only significant in the case of the net crop income), but female headship has negative effect on crop productivity.

3.5.3 Effects of Land Distribution on Income and Poverty

Table 3.5 exhibits the estimation results of the effects of land distribution on household income and poverty. Net household income is classified into 4 categories: net crop income (column 1), net livestock income (column 2), net non-farm income (column 3), and net total income which is the summation of net crop income, net livestock income, and net non-farm income (column 4). The poverty status is measured by a dummy variable ("non-poor"), which equals one if the net income per capita is above the national poverty line and zero otherwise (column 5).

Table 3.5 Effect of village Gini coefficient of owned farm land on income and poverty (household first differenced model, household level data)[a]

	Log of net crop income (KSh/capita) [b]	Log of net livestock income (KSh/capita) [c]	Log of net non-farm income (KSh/capita) [d]	Log of net total income (KSh/capita) [e]	Non-poor dummy[f]
VARIABLES	(1)	(2)	(3)	(4)	(5)
Gini coefficient of owned farm land	-0.410**	-0.656**	-0.500*	-0.383**	-0.276***
	(0.195)	(0.307)	(0.269)	(0.171)	(0.0943)
Log of owned farm size	0.0542***	-0.00379	0.0151	0.0322***	0.0135***
	(0.00775)	(0.0119)	(0.0103)	(0.00652)	(0.00373)
Log of household size	-0.842***	-0.620***	-0.439***	-0.746***	-0.248***
	(0.0445)	(0.0606)	(0.0547)	(0.0396)	(0.0194)
Head's age	0.00470	0.00213	-0.00240	0.00309	0.000357
	(0.00290)	(0.00397)	(0.00376)	(0.00230)	(0.00128)
Female-headed (=1)	-0.0682	0.0733	-0.328***	-0.109	-0.145***
	(0.0771)	(0.112)	(0.0975)	(0.0668)	(0.0356)
Head completed primary education (=1)	0.0351	0.0545	0.256***	0.162***	0.0522**
	(0.0498)	(0.0747)	(0.0637)	(0.0403)	(0.0229)
Received credit (=1)	0.0326	0.0383	0.0558	0.0581**	0.0301**
	(0.0296)	(0.0441)	(0.0380)	(0.0254)	(0.0139)
Log of value of total assets (KSh)	0.144***	0.300***	0.0978***	0.153***	0.0573***
	(0.0172)	(0.0264)	(0.0207)	(0.0162)	(0.00742)
Log of average distance to tarmac road (km)	0.00386	0.0198	-0.0403	0.00314	-0.00349
	(0.0213)	(0.0314)	(0.0284)	(0.0193)	(0.00993)
Log of average distance from extension service (km)	-0.00400	0.0237	-0.00620	0.000150	0.00954
	(0.0139)	(0.0196)	(0.0174)	(0.0111)	(0.00628)
Log of rainfall in the main cropping season (mm)	0.0322	0.180***	-0.0779	-0.0118	0.0311
	(0.0395)	(0.0629)	(0.0528)	(0.0337)	(0.0191)
Constant	0.707***	-1.097***	0.282	-0.0467	0.142*
	(0.174)	(0.207)	(0.186)	(0.126)	(0.0767)
Observations	4,508	4,516	4,528	4,523	4,589
R-squared	0.637	0.847	0.798	0.453	0.098

The numbers in parentheses are robust standard errors.
***, **, and * indicate significance at 1, 5, and 10%, respectively.
[a] Interaction terms between year 2012 and agro-ecological zone, agro-ecological zone and year dummies are included in all regressions.
[b] Net crop income is defined as the value of crop production minus input costs.
[c] Net livestock income is defined as the value of livestock production minus costs.
[d] Net non-farm income is defined as the revenue from non-farm sector minus costs.
[e] Net total income is summation of net crop income, net livestock income, and net non-farm income.
[f] Non-poor dummy is equal to one if income per capita is above national poverty line.

Like in the case of productivity, the coefficient on land inequality is consistently negative and statistically significant for all models. An increase in the Gini coefficient by 0.1 would reduce the net crop income per capita, net livestock income per capita, net non-farm income per capita and net total income per capita by 4.1%, 6.6%, 5.0%, and 3.8%, respectively. A same change in the Gini coefficient would also decrease the chance of an average household to fall into poverty by 2.8%. Additionally, access to own agricultural land has a positive and significant impact on the net crop income, net total income and poverty status. An increase in own farm size of 1 acre raises the net crop income by 5.4%, net total income by 3.2%, and the chance of getting out of poverty by 1.4%.

The effects of other household' characteristics on income and poverty have mostly expected signs. For example, a female-headed household would earn lower non-farm income (by 33%) and is more likely to fall into poverty (15%) than a male-headed household holding other factors constant. Head's education has significant and positive effects on non-farm income per capita, total income per capita and poverty status, and positive but insignificant effects on crop income and livestock income. Specifically, a household with its head who completed primary school education or higher would earn 26% higher non-farm income and 16% higher total income than other households, and reduce the probability of the household to fall below poverty line by 5%. Another highly consistent result is the positive and significant coefficients on the value of total assets in all models. Doubling the value of total assets would increase the net crop income, net livestock income, net non-farm income, and net total income by 14%, 30%, 10%, and 15 % respectively, and would reduce the likelihood of a household to fall into poverty by 6%.

Table 3.6 Heterogeneous effect of village Gini coefficient of owned farm land on income and poverty (household first differenced model, household level data)[a]

Explanatory variables	Log of net crop income (KSh/acre)[b]	Log of net livestock income (KSh/capita)[c]	Log of net non-farm income (KSh/capita)[d]	Log of net total income (KSh/capita)[e]	Non-poor dummy[f]
For those whose value of total assets are lowest quartile in a village					
Gini coefficient of owned farm land (α)	-0.536***	-0.539*	-0.443	-0.326*	-0.251***
	(0.181)	(0.309)	(0.272)	(0.172)	(0.0944)
Gini coefficient * lowest 25% group of value of assets in village (β)	0.0808	-0.414***	-0.197*	-0.202**	-0.0914**
	(0.0901)	(0.132)	(0.115)	(0.0804)	(0.0434)
Log of value of total assets (KSh)	0.0444**	0.260***	0.0786***	0.133***	0.0485***
	(0.0174)	(0.0285)	(0.0232)	(0.0183)	(0.00814)
Test α+β=0 (p-value)	0.0201	0.0026	0.0228	0.0039	0.0007
For those whose owned farm sizes are lowest quartile in a village					
Gini coefficient of owned farm land (α)	-0.548***	-0.629**	-0.492*	-0.338**	-0.260***
	(0.180)	(0.307)	(0.269)	(0.171)	(0.0944)
Gini coefficient * lowest 25% group of owed farms in village (β)	0.369***	-0.299*	-0.0863	-0.497***	-0.183***
	(0.0977)	(0.158)	(0.134)	(0.0917)	(0.0526)
Log of owned farm land (acre)	-0.00187	-0.0202	0.0104	0.00497	0.00343
	(0.00953)	(0.0148)	(0.0127)	(0.00803)	(0.00468)
Test α+β=0 (p-value)	0.3859	0.0058	0.0508	0	0
For those whose head completed secondary education					
Gini coefficient of owned farm land (α)	-0.455**	-0.463	-0.563*	-0.311*	-0.252**
	(0.195)	(0.329)	(0.295)	(0.187)	(0.101)
Gini coefficient * head completed secondary education dummy (β)	-0.142	-1.080**	0.169	-0.273	-0.0645
	(0.306)	(0.480)	(0.403)	(0.253)	(0.156)
Head completed secondary education dummy	0.0644	0.373*	0.123	0.154	0.0249
	(0.141)	(0.216)	(0.191)	(0.115)	(0.0722)
Test α+β=0 (p-value)	0.0434	0.0012	0.3155	0.0183	0.0386

The numbers in parentheses are robust standard errors.
***, **, and * indicate significance at 1, 5, and 10%, respectively.
[a] Interaction terms between year 2012 and agro-ecological zone, agro-ecological zone and year dummies are included in all regressions.
[b] Net crop income is defined as the value of crop production minus input costs.
[c] Net livestock income is defined as the value of livestock production minus costs.
[d] Net non-farm income is defined as the revenue from non-farm sector minus costs.
[e] Net total income is summation of net crop income, net livestock income, and net non-farm income.
[f] Non-poor dummy is equal to one if income per capita is above national poverty line.

3.5.4 Heterogeneous Effects of Land Distribution on Income and Poverty

The estimation results so far show negative effects of unequal land distribution on land productivity, household income and poverty. It is also important to understand how these effects vary across households with different socio-economic backgrounds. Table 3.6 displays the results of models to explore the heterogeneous effects of land inequality across households along three dimensions: non-land asset ownership (top panel), land endowment (middle panel), and head's education (bottom panel).

The results show considerable heterogeneous effects of land inequality across households in different groups. The heterogeneous effects are especially strong between households with different levels of asset ownership (non-land asset or land alike). For an average household in the lowest asset quartile, an increase in the Gini coefficient of 0.1 would reduce the net livestock income per capita, net non-farm income per capita, net total income per capita, and probability of being a non-poor household by an additional 4.1%, 2.0%, 2.0% and 1% respectively (top panel). This indicates that relatively poor households in a village are more likely to be negatively affected by unequal land distribution than others. Similarly, a constraint on land access would exacerbate the negative effects of land inequality; for households in the lowest land quartile, an increase in the Gini coefficient would decrease the net livestock income per capita, net total income per capita, and probability of being a non-poor household by an additional 3.0%, 5.0%, and 1.8% (middle panel). On the other hand, the coefficient of the interaction term between the Gini coefficient and a lowest quartile farmland dummy in the model of net crop income per acre is positive and significant, which could be due to the inverse land size and productivity relationship. The heterogeneous effects along the dimension of head's education is more mixed (bottom panel). While land inequality has significant and negative effect on non-farm income for the households whose heads did not complete secondary education, the effect is not significant any more for those with heads having completed secondary education or higher. But on the other hand, land inequality has even greater negative effect on household's livestock income for a household with a more educated head. Overall, the effects of land inequality on household total income and poverty status are not significantly different between households with heads of different levels of education.

3.6 Conclusion and Policy Recommendation

Though the relationship between unequal asset distribution and economic growth has long been discussed among researchers, most of the empirical studies on this topic were based on country level data and the empirical studies based on micro-level data are surprisingly few. Therefore, this study attempts to contribute to this important topic by assessing the effects of land distribution on agricultural productivity, income and poverty using a long household panel data in Kenya.

Our findings are generally consistent with the large theoretical literature on the relationship between asset distribution and economic growth. First, we find that the village level land inequality has significant and negative effects on land productivity. Increasing village level Gini coefficient of agricultural land by 0.1 would cause a reduction of the value of crop production per acre and net crop income per acre by 4.3% and 5.1% each. Second, unequal agricultural land distribution is negatively related to household income and poverty status. If the village level Gini coefficient of own farmland increases by 0.1, the net crop income per capita, net livestock income per capita, net non-farm income per capita, net total income per capita, and chance of being out of poverty would decrease by 4.1%, 6.6%, 5.0%, 3.8% and 2.8% respectively. Third, we find that the effects of land inequality vary with households of different socio-economic backgrounds. In particular, the negative effects of land inequality are significantly larger for households that are poorer and endowed with smaller amount of agricultural land. Improving land distribution would lead to disproportionate benefits for the households in the bottom of the poverty bracket.

The implication of our findings is clear. A more equalized land distribution is productivity and welfare enhancing for rural farmers in Kenya in particular and in Sub-Saharan Africa countries in general. The question that remains unanswered is how to reduce land inequality. There are several ways to promote equal land distribution including, land reform, promotion of land sales and rental markets, land taxes, and so on. Empirical studies find that effects of these policies are mixing. For example, Yamano et al. (2009) argue that both land sales and land rental markets improve equity and efficiency among rural farmers in Kenya. Additionally, Jin and Jayne (2013) find that land rental market transfers land from large landholders to small ones. However, others argue that the land reform based on market-based “willing-seller/willing buyer” system implemented in South Africa has resulted in large-scale commercial farming by the black elite at the expense of the poor smallholders (Lahiff and Cousins, 2005). Bardhan et al. (2014) reveals that land distribution program in West Bengal lowered land inequality but this effect was canceled out by by the rising inequality caused by inequality rising effects of population growth. Assuncao (2008) find that the land reform implemented in Brazil during 1992 and 2003 raised land inequality among households. Therefore, more research is needed in order to find effective policies to lower land inequality.

Additionally, in order to identify the causes for land distribution, we need to have data from a large number of communities with more complete and accurate information on historical as well as current social, cultural, economic, political and institutional conditions. Based on the limited information, we find population pressure is helping equalize land distribution but the magnitude of effect is extremely small, which implies that land inequality is likely to be related to many other factors for which we do not have information. Therefore, further studies about the determinants of land distribution based on more detailed community level data are required in order to formulate the effective policies to improve land distribution.

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