Land Plot Size, Machine Use and Agricultural Intensification in China*

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Abstract

Using a three-round panel data from 2001 to 2013 of 1,022 farm households in China, we examine the scale effects of mechanization and their implication for the number of cultivating seasons at the plot/parcel level in China. We control for plot quality and use household fixed effects to capture unobservables such as shadow prices of inputs and budget and knowledge constraints at the household level. We also restrict our sample to the allocated plots to address possible endogeneity issue arising from unobserved characteristics of rented land. We find that mechanization has significant economies of scale. The scale economies are more pronounced at the harvest stage than at the land preparation stage: they are also more pronounced plots located in plains than for those in hills or mountains. We also find that the plots less suitable for mechanization are cultivated less frequently over the survey period.

Keywords: Machine adoption, plot size, scale economies

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1 Introduction

China has experienced unprecedented economic achievement for more than three decades and remains one of the fastest growing economies in the world. Rapid urbanization and development of the non-farm economy have led to massive movements of labor from rural to urban areas, leaving agricultural production mostly in the hands of female and senior farmers (de Brauw et al. 2013; Mu and van de Walle 2011). Due to considerable surplus labor in rural areas, these changes did not raise concerns about agricultural production until recently, when the rural real wage experienced a sharp rise, signaling the exhaustion of this surplus rural labor (Zhang et al. 2011). Recently, China has also experienced a reduction of the self-sufficiency ratio of grains, which fell from around 95-100 percent in 2008 to 90.6 percent in 2010 (Huang et al. 2012). As the world's most populous country, This reduction in grain self-sufficiency ratio could lead to problems in food security world-wide.

In order to maintain agricultural production as labor costs continue to rise, agricultural labor input will need to be substituted with machine input (Otsuka et al. 2013). China's farming system, like that of many Asian Countries, is characterized by small landholdings, a high degree of land fragmentation, and high intensification at both the intensive and extensive margin. Although China has experienced rapid farm mechanization in recent decades thanks to the rapid development of machinery rental markets (Zhang et al. 2017), the extent to which mechanization can be realized in China's farming system remains a critical question. Small plot size poses serious constraints for mechanization because of scale economies of machine use (Foster and Rosenzweig 2011). In addition, a considerable amount of China's land is located in hills or mountains, posing further difficulties for mechanization.

In this study, we explore the extent to which small plot size deters mechanization and the implications for agricultural production, specifically the number of cultivating seasons per year. In our field trips in China, we often observed that small plots were less frequently cultivated; the farmers we interviewed attributed this reduced intensification to the difficulty of using machines on small plots, especially if these plots are in mountainous and hilly areas. Cultivating in these small plots become less worthwhile when labor costs increase.

Our data come from a three-round household survey conducted in 2001, 2009 and 2013. The survey covers 1,100 panel farm households from six provinces. In the 2013 round, we collected additional information on the use of machinery for each major farming activity (such as land preparation, fertilizer and pesticide/herbicide application, and harvesting) for each plot/parcel of land in order to examine the scale effects of machine use at different production stages.

We estimate machine use as a function of plot size, plot quality, and other plot-level variables while controlling for household fixed effects that account for socio economic factors (such as shadow prices of inputs, liquidity constraints, knowledge, and preferences). This specification thus captures the scale economies of machine use (Foster and Rosenzweig 2011). We focus our analysis on the plots allocated to households in order to avoid the possible endogeneity arising from unobservable characteristics of rented land.[1]

We find that machine use shows significant economies of scale which are more pronounced i) at the harvest stage than at land preparation, and ii) for plots located in plains than those in hills or mountains. We further find that number of planting seasons have reduced from 2000 to 2013 and such pattern is more pronounced i) for small plots than large ones and ii) for plots located in plains than those in hills or mountains. These findings are consistent with the insights we gained from farmer interviews conducted during field trips.

This paper contributes to the literature on scale economies of machine use in as least three aspects. First, we examine scale effects of machine use at the plot level, taking advantage of a unique data set collected for this purpose. Most existing literature has used household-level data, which poses identification concerns because it may be difficult to separate the scale effects from the effects of household unobservables, which are often time variant.

[1]Rural agricultural land in China is owned by village collectives instead of individuals. Farmers have land use rights on the allocated land and thus often consider "allocated land" as owned land.

Second, we examine scale effects of machine use separately at the land preparation stage and at the harvest stage, as the effects at the two stages and for different plot locations are likely to be different. Scale effects arise from multiple sources: i) larger machines can work more efficiently than smaller machines but cannot operate on small plots; ii) the fixed cost for machines to be moved to a plot results in lower average cost for larger plots; and iii) mechanization in small plots is more difficult because it requires the machine to change directions more frequently. A farmer can somehow overcome the scale effects of small plots if she/he can coordinate with neighbors to jointly operate machines; however, this may incur a coordination cost. The coordination cost tends to be lower for land preparation than for harvest. Further, two-wheel tractors are commonly used in China for land preparation; these can be used on relatively small plots, while harvesters or combiners used for harvest cannot. To our knowledge, no existing literature has studied the scale effects of machine use at different production stages at the plot level.

Third, we also examine the scale effects for plots at different locations (i.e., plains versus hills or mountains). Exploring the effects of geographic constraints on machine use is useful, given non-negligible share of China's land that is located in the hills or mountains.[2]

Our paper also contributes to the literature on the effects of plot/farm size, land fragmentation, and mechanization on agricultural production. Most related studies explore the effects of mechanization on productivity and profitability (e.g. Foster and Rosenzweig (2011); Carletto et al. (2013); Otsuka et al. (2013); Liu et al. (2016); K. Deininger K and Singh (2017)). We look at a different outcome - the number of cultivating seasons per year, and show that plots less suitable for mechanization (i.e., plots that are smaller and/or located in hilly/mountainous areas) are cultivated less frequently.

[2]These plots account for 15.2 percent of the total cultivated area in our sample.

2 Data and Descriptive Results

Our data come from a three-round panel farm household survey in rural China. The first two rounds of the survey were conducted by the Center for Chinese Agricultural Policy (CCAP) of the Chinese Academy of Sciences in April 2001 and April 2009, respectively. The first round of the survey interviewed 1,189 households in 60 villages in six provinces: Hebei, Liaoning, Shanxi, Zhejiang, Hubei, and Sichuan. Figure 1 depicts the sample villages. The second round re-interviewed 1,071 households from 58 villages from the first round. The third round survey was conducted jointly by CCAP and International Food Policy Research Institute (IFPRI) in November and December 2013. This round re-interviewed 1,067 households from the 2008 round. The survey yields a three-round panel of 1,022 households.

In each round, the survey collected information on plot characteristics (including area, tenure, irrigation status, quality, distance to main house, and location in a plain or hill/mountain) and crops planted in each crop season for all of the plots cultivated or owned by a household. The 2013 round provides further information on the adoption of machinery for each major farming activity including land preparation, fertilizer and pesticide/herbicide application, and harvesting for each plot of land.

After dropping the non-cultivating households (i.e., the households that rented out all of their land), the 2013 survey provides a sample of 2,860 plots cultivated by 879 households. Table 1 shows the distribution of landholdings (cultivated land) per household. The sample mean is 11.6 mu (about 0.77 ha) while the median is 4.8 mu (about 0.32 ha). About 93 percent households cultivated land less than 30 mu (2 ha) and 65 percent cultivated land less than 7.5 mu (0.5 ha).

In addition to these small landholdings, the land is often fragmented. Figure 2 depicts the histogram of number of plots cultivated by the sample households. A median household cultivated three plots. About 82 percent households cultivated more than one plot, while 22 percent cultivated five or more plots.

Among the plots cultivated by the sample households, 1,941 plots are located in plains and 893 are located in hilly or mountainous areas. The plots located in hilly or mountainous areas account for 15.4 percent of the total area of cultivated land in the sample. Figure 3 depicts the distribution of plot size by location (plain versus hill/mountain). Not surprisingly, the plots in hilly or mountainous areas are generally smaller than those in the plains.

Table 2 reports the proportion of households that adopted machinery in any plot and proportion of households that adopted machinery in all plots, by production stage. Machinery is adopted by 72 percent of households for land preparation, by 28 percent for fertilizer and/or pesticide application, and by 51 percent for harvest. Households that use machinery for fertilizer/pesticide application tend to use machinery on all plots. However, only 56 percent households used machinery for land preparation on all plots, while only 32 percent used machinery on harvest in all plots. In comparison, 72 percent and 51 percent of households used machinery on at least one the plot for land preparation and harvest, respectively.

Figure 4 depicts proportion of machine use by production stage (land preparation, fertilizer/pesticide application, and harvest) conditional on plot size. Machine use at each production stage increased monotonically in plot size, pointing to the existence of scale economies. The nonlinearity of the curves suggests the presence of critical points of scale economies related to machine use at different production stages.

We further describe machine use patterns versus plot size for plots in plains and for plots in hills or mountains. Figures 5-7 depict the proportion of machine use conditional on plot size by location at three production stages: land preparation, fertilizer/pesticide application, and harvest, respectively. Machine use increases monotonically for both types of plots. Notably, the curves for plots in hills or mountains are placed significantly lower than the curves for plots in plains at each production stage, suggesting that machine adoption is much lower in hilly/mountainous plots at each plot size. We also find that the curves for plots in hills or mountains are flatter than those for plots in plains, which suggests that the scale economies of machine use are weaker for hilly/mountainous plots. This observation motivates us to examine scale economies of machines use separately by plot location.

Machine use information at the plot level is only available in the 2013 round. However, we obtained information on the usage of tractors and harvesters at the household level in the first two rounds. In 2000, about 42 percent of households used tractors and 23 percent of households used harvesters. The shares of households that used tractors and harvesters remained relatively stable in 2008: 44 percent and 28 percent, respectively. Tractors are mostly used for land preparation; thus we use tractor use as a proxy for machine use at the land preparation stage for comparison with the 2013 round, keeping in mind that this may lead to an overestimation as tractors are also used for transportation in China. Table 2 shows that from 2008 to 2013, there was a dramatic increase in machinery use (72 percent households used machines for land preparation and 51 percent used machines for harvesting in 2013). This result is consistent with the notion that rapidly increasing labor costs (as shown in Figure **??**) reached critical levels between 2008 and 2013, inducing wide adoption of machinery in agriculture. Zhang, Yang, and Wang (2011) show that the Lewis turning point in rural China arrived in 2003. Our result suggests that within 10 years after the arrival of the Lewis turning point, widespread adoption of machinery has been observed in response to the labor shortage in rural China.

We also obtained crop planting information for each season at the plot level for each of the three rounds. Table 3 reports the number of crop planting seasons per year at the plot level by year, by plot size, and by plot location. In 2000, smaller plots were more intensively cultivated than larger plots. This is not surprising, given that plot size tends to be negatively associated with population density and that higher population pressure induces higher agricultural intensification (Boserup 1965). In 2008, the number of planting seasons per year fell for each combination of plot size and location, concurrent with the rising labor costs and stagnant machinery adoption seen from 2000 to 2008. We observe continuing decrease in farming intensification from 2008 to 2013 for plots smaller than 3.0 mu but not for those above 3.0 mu. We hypothesize that this observation results from the fact that the high adoption of machinery on plots above 3.0 mu (as shown in Figure 3) effectively relaxed the rural labor shortage.

3 Empirical Estimation

3.1 Scale Effects on Machine Use

3.1.1 Empirical Methodology

To examine the scale effects on machine use, we estimate the following equation at the plot level using the 2013 survey data:

$$y_{ij} = \beta_1(0.8 < A_{ij} < 1.5) + \beta_2(1.5 < A_{ij} < 3) + \beta_3(A_{ij} > 3) + \beta_4 X_{ij} + \beta_j + \epsilon_{ij}, \quad (1)$$

where y_{ij} is a dummy variable indicating machine use for plot i in household j at a certain production stage. A_{ij} is plot area in mu (15 mu = 1 ha), while X_{ij} is a vector of plot characteristics including irrigation status, land quality (high, median, or low), and distance to homestead. β_j is household fixed effects and ϵ_{ij} is the error term. We cluster the standard errors at the village level.

To allow for the nonlinearity of scale effects on machine adoption (as shown in Figure 4), we use a semi-parametric method and group plots into four equal categories based on their size. ($A_{ij} < 0.8$), ($0.8 < A_{ij} < 1.5$), ($1.5 < A_{ij} < 3$), and ($A_{ij} > 3$) indicate the first to fourth quartile of plot size, respectively. In equation (1), the first quartile ($A_{ij} < 0.8$) is the base group. The parameters of interest are β_1, β_2, and β_3, which estimate the scale effects of machine use. Positive scale effects imply that $\beta_3 \geq \beta_2 \geq \beta_1 \geq 0$ and that at least one sign is not an equality.

To account for the different patterns of scale effects based on plots' geographic location (as shown in Figures 5-7), we estimate equation (1) separately for the whole sample, for plots located in plains, and for plots located in hills or mountains.

Because we control for household fixed effects, we identify the scale effects based on the variation in machine adoption among plots within the same households. Table 2 shows that 28 percent of households adopted machinery for fertilizer/pesticide application; among them, 86 percent adopted machinery on all the plots they cultivated. As a result, we only have variation in a relatively small sample of households with which to identify the scale effects of machine use at the fertilizer/pesticide application stage. We therefore focus our analyses on the land preparation stage and the harvest stage in order to exploit a larger variation of our sample.

The inclusion of household fixed effects addresses the endogeneity concerns arising from the correlation between plot size and household and community unobservables such as productivity and shocks, output prices, shadow prices of inputs, and liquidity and knowledge constraints. We include variables on plot quality and irrigation status as regressors to address the endogeneity concerns arising from the correlation between plot size and productivity potential.

Rural agricultural land in China is owned by village collectives instead of individuals. Land purchase is not an option in China. The landholding structure (cultivated land) mainly results from egalitarian allocation during the period of central planned economies. This structure is, to a lesser degree, also affected by land rentals, which have become increasingly common over time (Jin and Deininger 2009). It is possible that farmers could manage rented plots differently than they manage their allocated plots and/or that rented plots could have unobserved characteristics that are not sufficiently captured by the control variables. To address these concerns, we restrict our sample to households' allocated plots. households cannot significantly affect their landholding structure of their allocated plots. Our strategy is similar to the strategy used by Foster and Rosenzweig (2011) and K. Deininger K and Singh (2017), who assume that households' inherited landholding structure is exogenous.

3.1.2 Results

The results of equation (1) are reported in Tables 4 and 5 for machine use at the land preparation stage and at the harvest stage, respectively. In both tables, columns (1)-(3) present results for all plots, for plots located in plains, and for plots located in hills or mountains, respectively.

For machine use during land preparation, we see significant scale effects between the first three quartiles of plot size; these scale effects are less pronounced once the plot size is larger than the third quartile (Column 1, Table 4). Compared with machine adoption on plots smaller than 0.8 mu, the propensity to adopt machinery on plots between 0.8-1.5 mu increases by 5.87 percentage points, while the propensity to adopt on plots between 1.5-3.0 mu increases by 12.2 percentage points. We do not find a significant difference in the probability of machinery adoption between the plots sized 1.5-3.0 mu and those larger than 3.0 mu. The finding is consistent with Figure 3, which shows that machinery adoption increases on plots of smaller size and levels off when farm size is larger.

We gain further insights by separately estimating equation (1) by plot location. We find that scale effects are more pronounced for plots located in plains than for those located in hills or mountains (Columns 2 and 3, Table 4). Compared with the base group (plot size lower than 0.8 mu), the increased probability of adoption for plots sized 0.8-1.5 mu is 7.35 percentage points if the plot is located in a plain and 5.40 percentage points if the plot is located in hilly or mountainous areas. The probability increase for plots sized 1.5-3.0 mu is 15.0 percentage points if the location is in plains versus 5.08 percentage points if the location is in hills or mountains. For plots in plains, significant scale effects exist between the first three quartiles of plot size ($<$ 0.8 mu, 0.8-1.5 mu, and 1.5-3.0 mu). We do not see scale effects between the (1.5-3.0 mu) and the ($>$ 3.0 mu) group. In contrast, the scale effects are insignificant between the last three quartiles (0.8-1.5 mu, 1.5-3.0 mu, and $>$ 3.0 mu) for plots in hills or mountains. Therefore, the results in the whole sample (Column 1, Table 4) are driven by the sample plots in plains. The aggregated results cover heterogeneity in scale effects based on plot location.

Regarding machine use at the harvest stage (Table 5), we again see larger scale effects of machine use for plots in plains than for those in hills or mountains. Compared with the base group (< 0.8 mu), for plots located in plains (Column 2, Table 5), the propensity of machinery adoption is 7.36 percentage points higher for the (0.8-1.5 mu) group, 15.6 percentage points higher for the (1.5-3.0 mu) group, and 19.0 percentage points higher for the (> 3.0 mu) group. In contrast, for plots located in hills or mountains (Column 3, Table 4), no scale effects are detected between the first three quartiles of plots (ie, the [< 0.8 mu] group, the [0.8-1.5 mu] group, and the [> 3.0 mu] group); the propensity of machine adoption increased by 8.57 percentage points, compared with the base group.

In Tables 4 and 5, we see that machinery is more commonly adopted on irrigated plots, irrespective of plot location and production stage. This result suggests the existence of complementarities between irrigation and machine use. Such complementarity is stronger for plots located in hills or mountains.

These findings, in combination with Figures 3-6, suggest that i) scale effects of machine adoption are present regardless of plot location and production stage; ii) machinery is more likely to be adopted in plots located in plains than plots in hills or mountains; and iii) scale effects are more pronounced for plots in plains than for those in mountains, especially at the harvest stage; this could be due to the fact that two-wheel tractors are usually better adapted to small plots than harvest machines. The latter two findings clearly show the geographic constraints of machine use. Such constraints exist even if plot size can be effectively enlarged. Because a considerable amount of China's land is located in hills or mountains due to the country's high level of agricultural intensification at the external margin, it is important to understand to what extent these geographic constraints of machine adoption will affect agricultural production in China.

3.2 Change in Crop Planting Seasons by Plot Size

3.2.1 Method

Our findings on scale effects of machinery adoption suggest that small plots and plots located in hills or mountains face higher costs for machine use. These higher costs, combined with sharply increased labor costs, makes planting on small plots and on plots in hills or mountains less worthwhile. We explore the changes in number of crop planting seasons per year by plot size using the following specification:

$$h_{ijt} = \alpha_1(t = 2008) + \alpha_2(t = 2013) + \alpha_3 x_{ijt} + \alpha_j + u_{ijt}, \tag{2}$$

where h_{ijt} is number of crop planting seasons of field i in household j at year t, $(t = 2008)$ and $(t = 2013)$ are year dummy variables. The base group is year 2000. α_j is household fixed effects,[3] x_{ijt} is plot level characteristics as in equation (1), and u_{ijt} is the error term.

We estimate equation (2) separately for the four groups - (< 0.8 mu), (0.8-1.5 mu), (1.5-3.0 mu), and (> 3.0 mu) - and separately for plots in plains and those in hills or mountains. Similar to equation (1), we restrict this sample to households' allocated plots and cluster standard errors at the village level. The parameters of interest are α_1 and α_2, which show the changes in number of planting seasons by year.

3.2.2 Results

Table 6 shows the estimation results of equation (2) by plot size for plots located in plains. Columns 1-4 show results for the (< 0.8 mu), the (0.8-1.5 mu), the (1.5-3.0 mu), and the (> 3.0 mu) group, respectively. For the (< 0.8 mu) group, compared with year 2000, the expected number of planting seasons falls significantly by 0.177 in 2008 and by 0.321 by 2013. We observe a similar continuing drop in farming intensification,although to a lesser degree, from 2000 to 2008 and from 2008 to 2013 for the (0.8-1.5 mu) and the (1.5-3.0 mu) group.

[3] Our data is a panel at the household level not at the plot level.

In contrast, the (> 3.0 mu) group did not see a reduction in the number of planting seasons from 2008 to 2013, after a mild reduction from 2000 to 2008 (0.064); this is consistent with our descriptive results discussed earlier. Based on the sample means reported in Table 3, we translate the estimated effects to percentage changes. From 2000 to 2013, the reduction in number of planting is 19.3 percent for the (< 0.8 mu) group, 15.9 percent for the (0.8-1.5 mu) group, 11.2 percent for the (1.5-3 mu) group, and 3.7 percent for the (> 3.0 mu) group.

Table 7 present the results for plots located in hills or mountains. We see continuing reductions in the number of crop planting seasons in 2000-2008 and 2008-2013 for each size group. The percentage reduction from 2000 to 2013 is 26.7 percent for the (< 0.8 mu) group, 22.6 percent for the (0.8-1.5 mu) group, 24.7 percent for the (1.5-3 mu) group, and 15.7 percent for the (> 3.0 mu) group. These percentage reductions are higher than the percentage reduction for the corresponding size group in plots located in plains, which is consistent with the earlier finding that machine adoption is easier in the plains than in the hills or mountains.

3.3 Discussion

Our descriptive and empirical analyses yield two main findings. First, machine use shows significant economies of scale, which are more pronounced i) at the harvest stage than at land preparation and ii) for plots located in plains than for those in hills or mountains. This finding can be explained by machinery technologies. In China and other Asian countries, tractors have been adapted to small plot sizes. Thus, farmers cultivating small plots can also benefit from mechanization at the land preparation stage. Harvesters/combiners are larger than two-wheel tractors and thus show higher complementarities with plot size. It makes sense that machines are not technically suitable to operation in mountainous and hilly areas. This finding can also be attributed to farmers' coordination on farming activities among neighboring plots. If a farmer can coordinate with farmers who cultivate adjacent plots to operate machines at the same time, small plot size will not be a constraint. It is easier for farmers to coordinate at the land preparation stage than at the harvest stage because i) the timing of harvest is more affected by other factors (such as management, crop varieties, etc.) than land preparation timing and ii) harvest methods may differ by crop type. Farmers' coordination tends to be less effective in mountainous and hilly areas because plots in these areas are less likely to be adjacent than those in plains.

The second finding is that land was cultivated less intensively (measured by number of planting seasons per year) from 2000 to 2013; this pattern is more pronounced i) for small plots than for large ones and ii) for plots located in plains than for those in hills or mountains. This finding is consistent with our observations, as well as what we learned from interviews with farmers in our field trips. Mechanization is more difficult on small plots and plots located in hilly or mountainous areas (as shown in the earlier results). Higher labor costs and constraints of mechanization make it less profitable to intensively cultivate these plots.

Our results on the significant scale economies of mechanization are consistent with recent studies in India on scale economies of mechanization (Foster and Rosenzweig 2011, 2017). We further show the usefulness of looking at mechanization at different production stages and in plots at different geographic locations.

Our study also relates to the large literature on farm size and productivity. A recent strand of this literature has shown that small farmers' advantages in productivity and profitability in Asia have been diminishing as a result of increasing labor costs and the existence of scale economies of machine use (Foster and Rosenzweig 2011; Otsuka et al. 2013; Liu et al. 2016; K. Deininger K and Singh 2017). Our finding complements this literature by showing that the plots less suitable for mechanization are cultivated less frequently.

Finally, our study also relates to the literature on the cost of land fragmentation (Wan and Cheng 2001; Rahman and Rahman 2008; Hung et al. 2007). This literature suggests that land fragmentation is related to low productivity at the household level. Our study provides an explanation of this result.

4 Conclusion

Using a three-round farm household panel data from 2001 to 2013, we examine scale effects of mechanization and their implication on the number of cultivating seasons at the plot/parcel level in China. We control for plot quality and use household fixed effects to capture unobservables, such as shadow prices of inputs and budget and knowledge constraints at the household level. We also restrict our sample to household-allocated plots to address possible endogeneity issues stemming from unobserved characteristics of hired land.

We find significant economies of scale of mechanization. The scale economies are more pronounced at the harvest stage than at the land preparation stage and for plots located in plains than for those in hills or mountains. We also find that the plots less suitable for mechanization were cultivated less frequently over the survey period.

Our findings have important policy implications. The Government of China has taken a number of measures to encourage the growth of larger farms, as well as a more consolidated landholding structure. These measures include the provision of more secure land titles, the facilitation of land rental transactions, the provision of subsidized loans to large farms, etc. Our results suggest that these measures will likely be more effective for plots located in plains than for those located in hilly or mountainous areas; however, the latter account for a non-negligible share of China's total agricultural land. With continuing increases in labor costs, we would expect these hilly/mountainous plots to be less cultivated. Our findings also suggest that mechanization will likely increase rental prices for plots in the plains and reduce those for plots in the hills and mountains.

Will the expected increases in land productivity sufficiently make up for the loss of output from the reduced intensification of marginalized plots? How will increased rental prices in the plains affect the well-being of the farmers cultivating the marginalized plots? These questions warrant further investigation.

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Figure 1: Map of Sample Villages

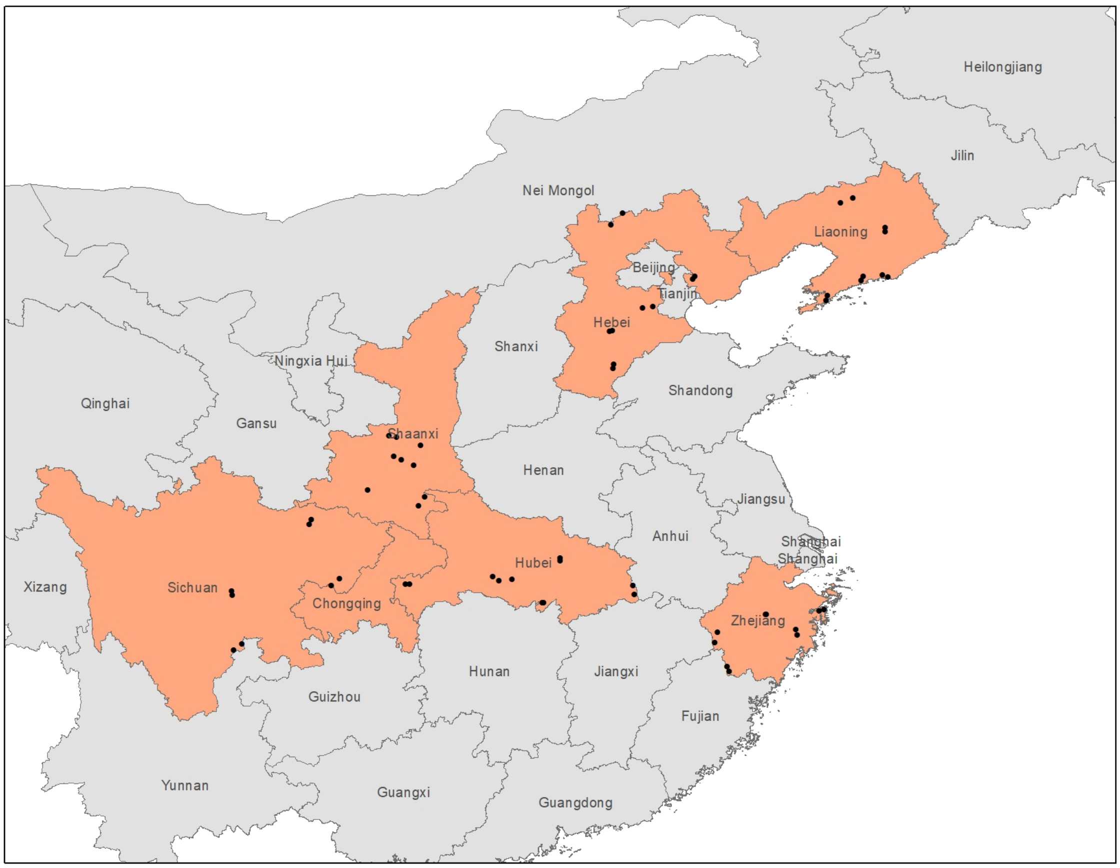

Figure 2: Distribution of number of plots cultivated by the sample households in 2013

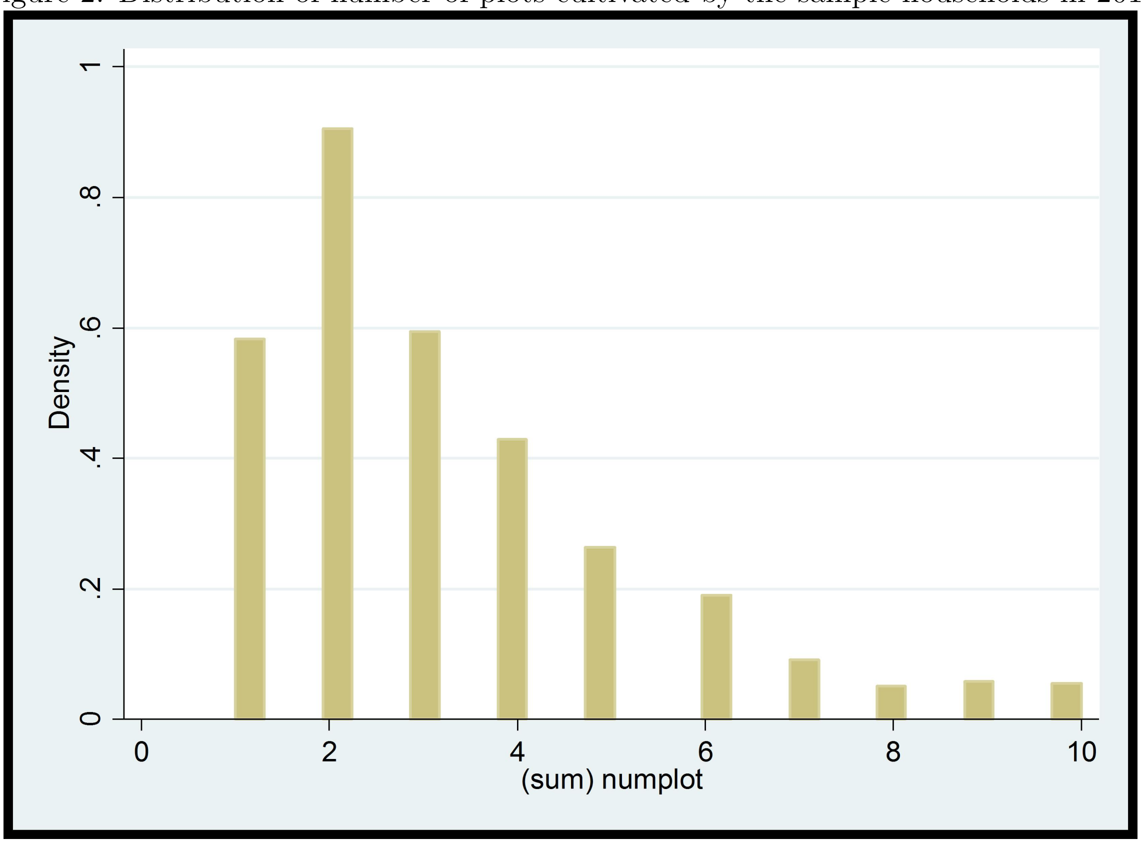

Figure 3: Distribution of plot size, plain versus hill/mountain, 2013

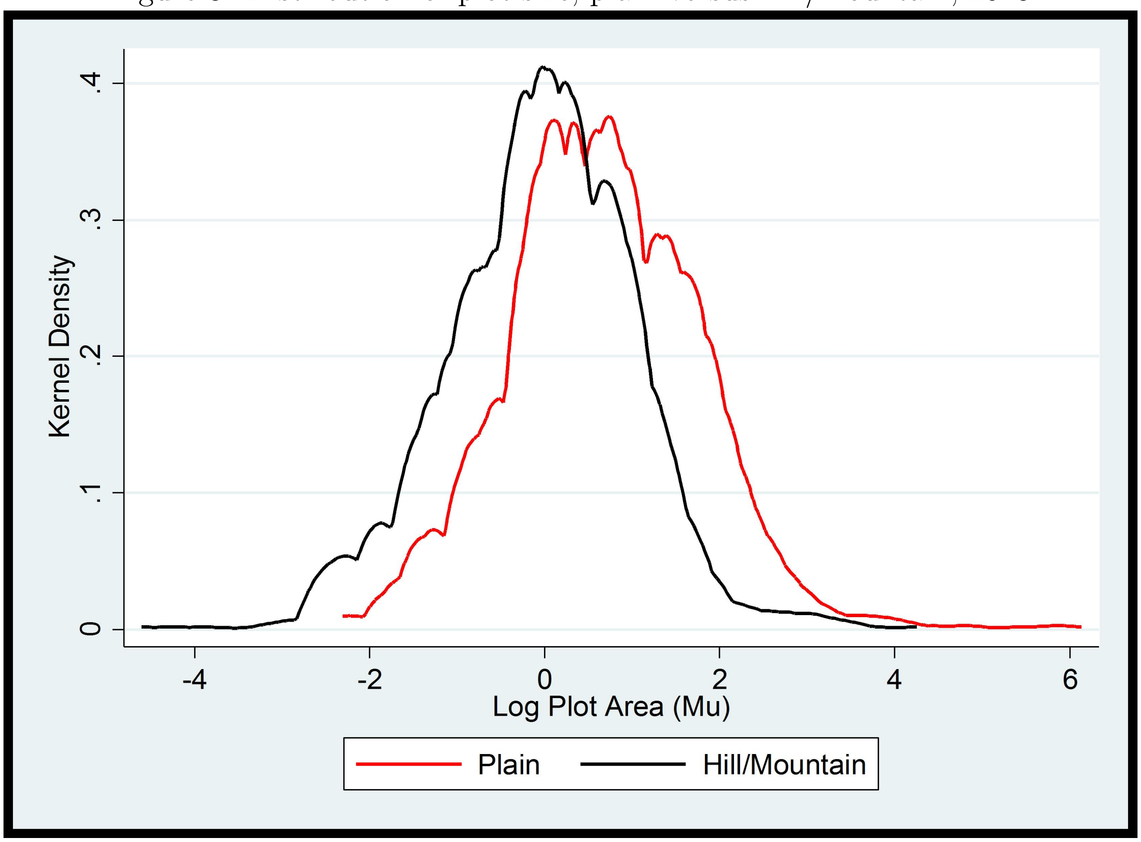

Figure 4: Proportion of machine use by production stage conditional on plot size, 2013

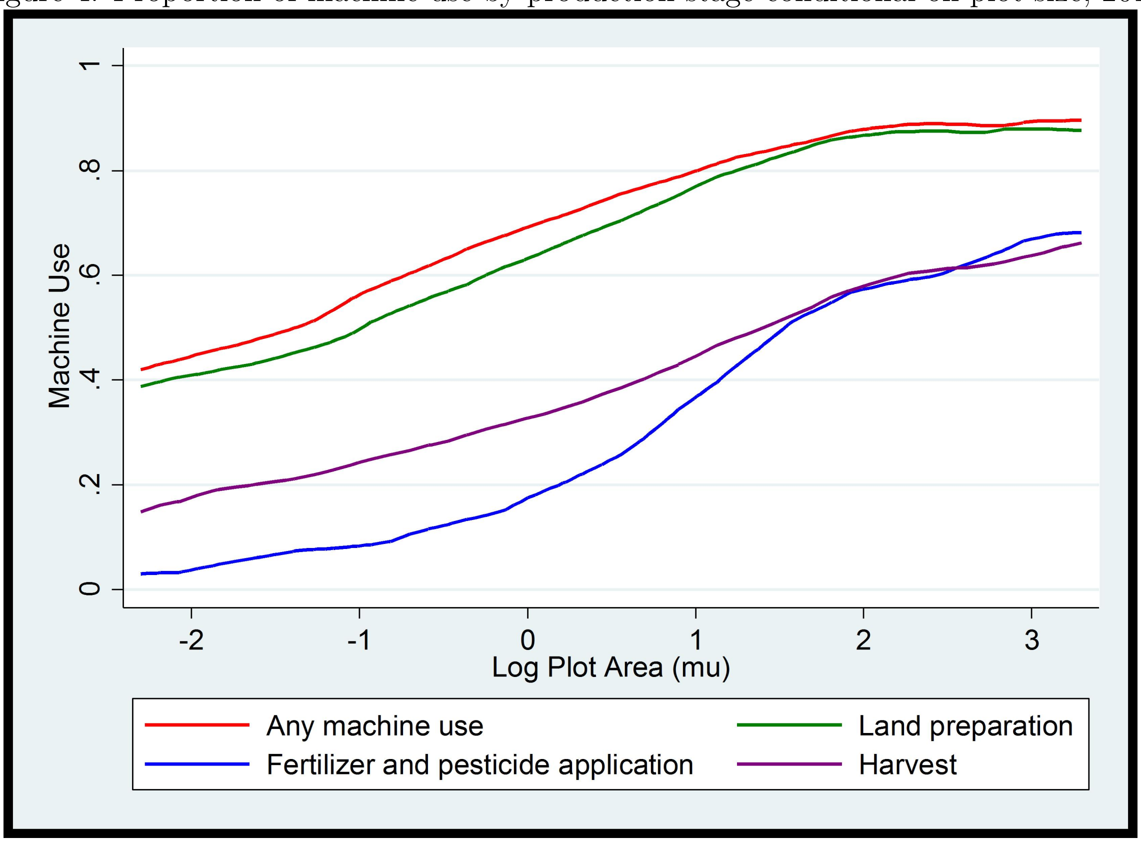

Figure 5: Proportion of machine use in land preparation conditional on plot size, by geographic location (plain or hill/mountain), 2013

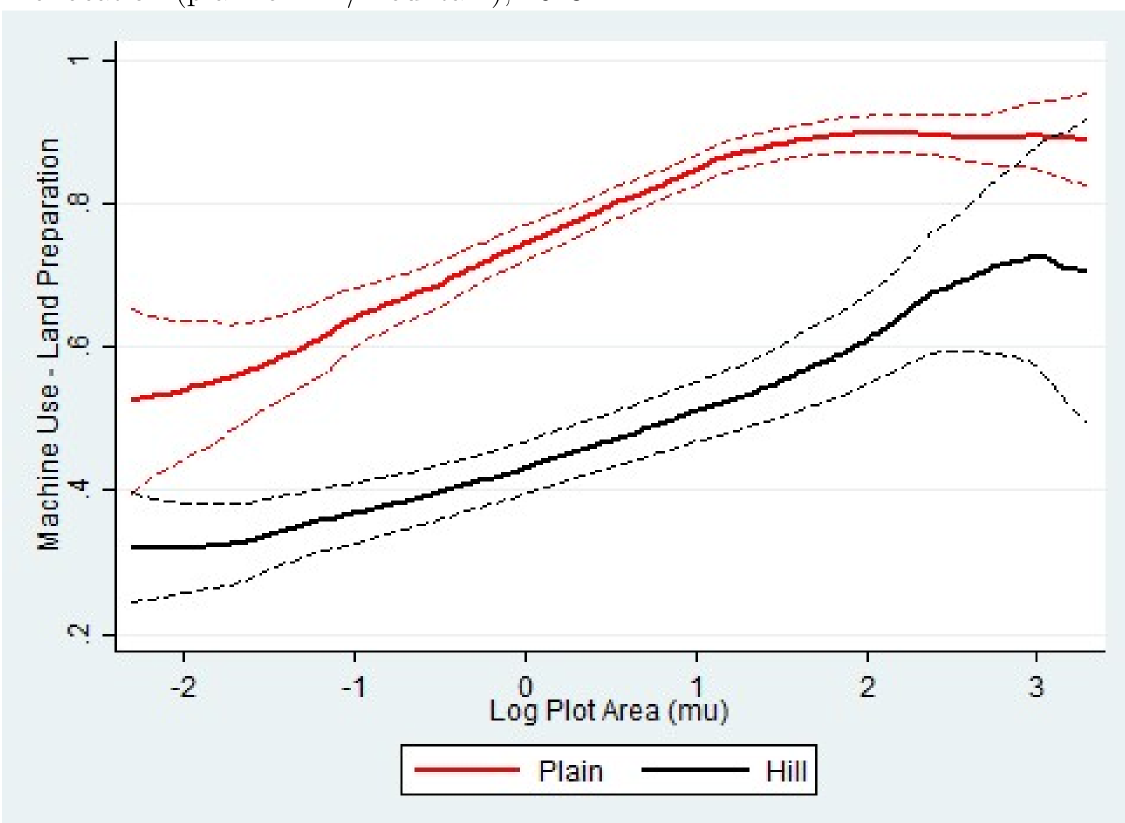

Figure 6: Proportion of machine use in fertilizer/pesticide application conditional on plot size, by geographic location, 2013

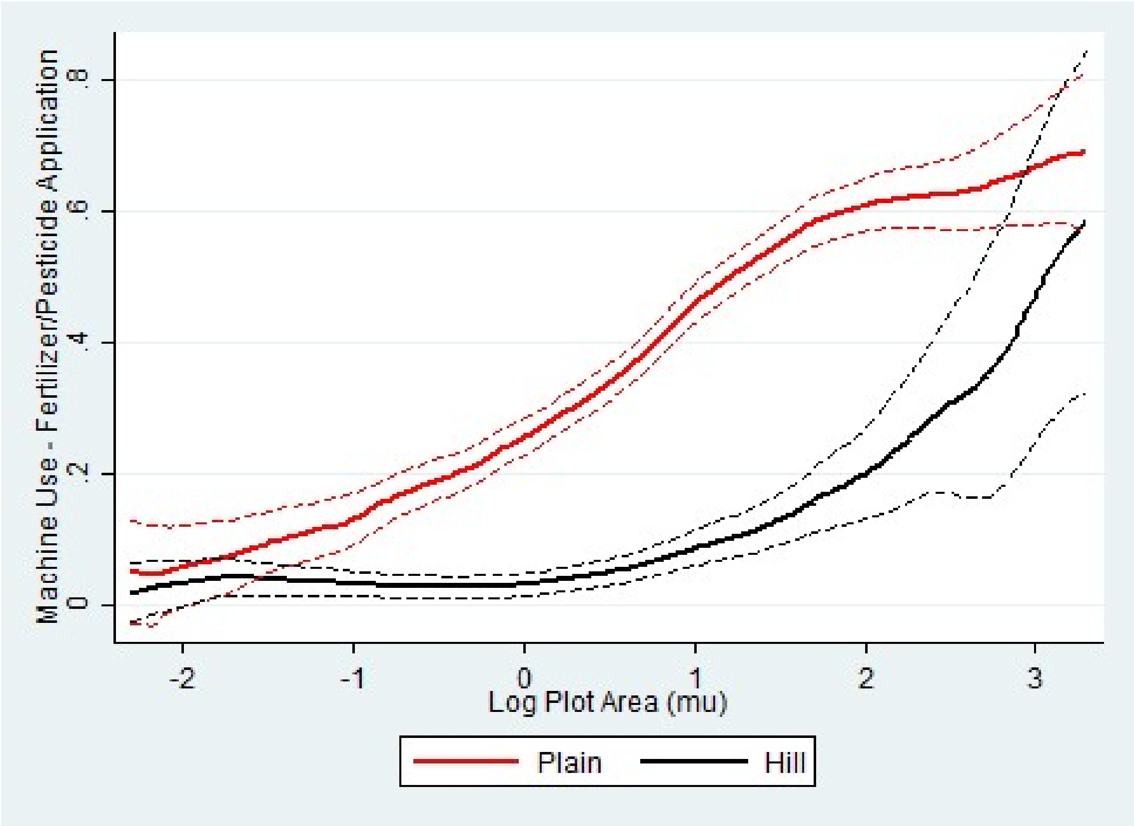

Figure 7: Proportion of machine use in harvest conditional on plot size, by geographic location, 2013

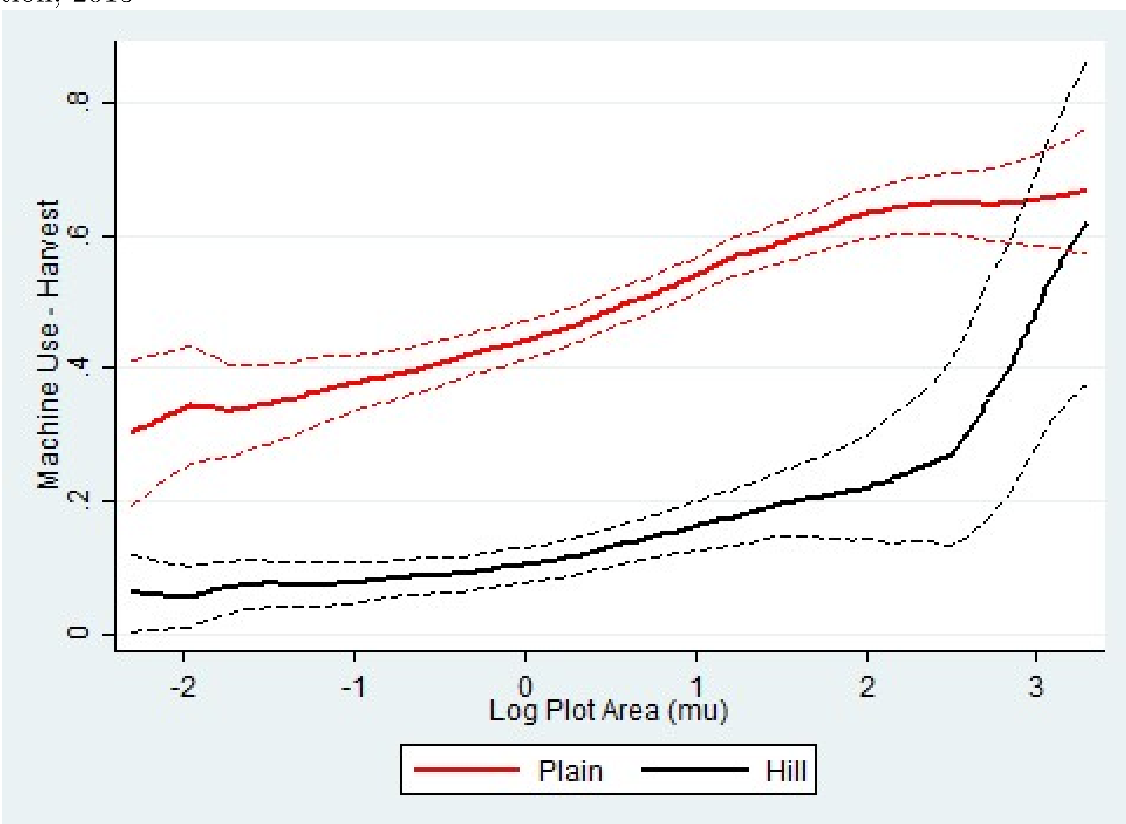

Figure 8: Proportion of machine use in harvest conditional on plot size, by geographic location, 2013

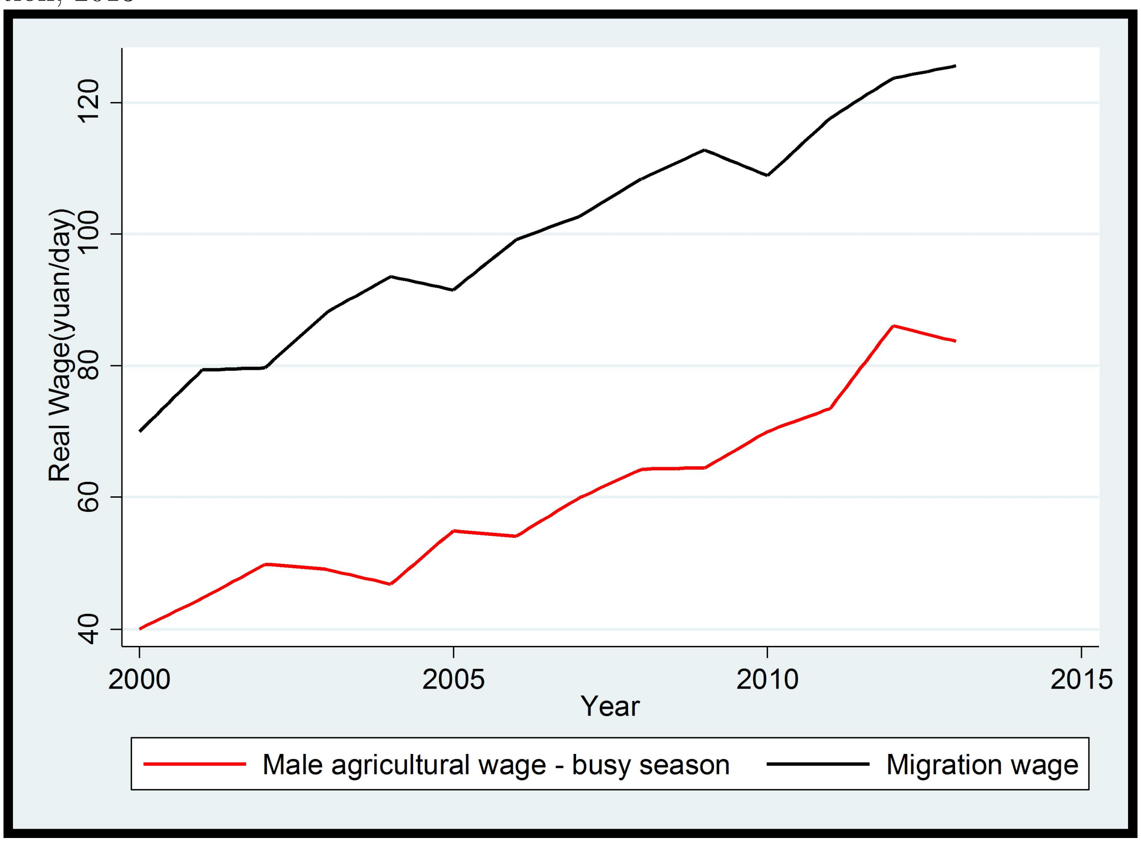

Table 1: Distribution of landholdings (cultivated land) in 2013

Percentiles	Mu
1%	0.3
5%	1.0
10%	1.5
25%	2.4
50%	4.8
75%	10.0
90%	20.3
95%	36.6
99%	131.6

Table 2: Machine adoption by production stage at the household level

Variable	Proportion of households using machines	Households using machine for all plots
Any production stage	0.76	0.59
Land preparation	0.72	0.56
Fertilizer/pesticide application	0.28	0.24
Harvest	0.51	0.32
Observations	878	878

Table 3 Mean number of crop planting seasons, by year, plot size, and location

Year	<0.8 mu	0.8-1.5 mu	1.5-3 mu	>3 mu
Plots in plains				
2000	1.667	1.546	1.450	1.287
2008	1.536	1.342	1.245	1.135
2013	1.331	1.209	1.251	1.135
Plots in hills or Mountains				
2000	1.513	1.498	1.438	1.324
2008	1.455	1.413	1.343	1.259
2013	1.205	1.297	1.285	1.277

Table 4: Estimation results of plot size on machine use for land preparation, for whole sample, plots in plains, and plots in hills/mountains

	(1) Whole Sample	(2) Plain	(3) Hill
0.8-1.5 mu (beta1)	0.0587***	0.0735***	0.0540**
	(3.32)	(3.35)	(2.07)
1.5-3.0 mu (beta2)	0.122***	0.150***	0.0508*
	(6.38)	(6.50)	(1.69)
>3.0 mu (beta3)	0.103***	0.132***	0.0826**
	(4.98)	(5.37)	(2.28)
If own land	-0.000204	0.0288	-0.0509*
	(-0.01)	(1.31)	(-1.69)
If irrigated	0.143***	0.110***	0.189***
	(5.69)	(3.57)	(3.79)
If high quality	-0.0161	-0.0651**	0.0726
	(-0.62)	(-2.12)	(1.46)
If median quality	-0.0521**	-0.0837***	-0.0500
	(-2.17)	(-2.77)	(-1.30)
Distance to home	0.000730	0.00230	-0.0410***
	(0.26)	(0.82)	(-3.07)
Household fixed effects	Yes	Yes	Yes
P value of F test of (beta1=beta2)	0.0002	0.0001	0.9086
P value of F test of (beta2=beta3)	0.2979	0.3412	0.3429
Observations	2713	1890	823

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 5: Estimation results of plot size on machine use for harvest, for whole sample, plots in plains, and plots in hills/mountains

	(1) Whole Sample	(2) Plain	(3) Hill
0.8-1.5 mu (beta1)	0.0596***	0.0736***	-0.00437
	(3.17)	(2.89)	(-0.19)
1.5-3.0 mu (beta2)	0.129***	0.156***	0.0167
	(6.37)	(5.84)	(0.63)
>3.0 mu (beta3)	0.173***	0.190***	0.0857***
	(7.81)	(6.66)	(2.68)
If own land	-0.00668	0.0290	-0.0547**
	(-0.33)	(1.13)	(-2.05)
If irrigated	0.265***	0.190***	0.585***
	(9.87)	(5.33)	(13.31)
If high quality	0.0766***	0.0261	0.0785*
	(2.76)	(0.73)	(1.79)
If median quality	0.0300	-0.0213	0.0625*
	(1.17)	(-0.61)	(1.84)
Distance to home	0.00160	0.00177	0.00999
	(0.53)	(0.55)	(0.85)
Household fixed effects	Yes	Yes	Yes
P value of F test of (beta1=beta2)	0.0001	0.0003	0.3872
P value of F test of (beta2=beta3)	0.0196	0.1404	0.0201
Observations	2713	1890	823

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 6: Results of changes in number of planting seasons, for plots located in *plains* using household panel of 2000, 2008 and 2013

	(1) <0.8 mu	(2) 0.8-1.5 mu	(3) 1.5-3 mu	(4) >3 mu
Year 2008 (alpha1)	-0.177***	-0.127***	-0.0994***	-0.0639***
	(-4.23)	(-3.12)	(-3.22)	(-2.88)
Year 2013 (alpha2)	-0.321***	-0.246***	-0.162***	-0.0470**
	(-5.88)	(-5.60)	(-4.60)	(-2.00)
If own land	-0.0581	0.0131	-0.142**	0.0117
	(-0.84)	(0.22)	(-2.52)	(0.34)
If irrigated	0.150***	0.0426	0.116***	0.0667**
	(2.60)	(0.70)	(2.60)	(2.22)
If high quality	0.0868	0.0742	0.108**	0.0279
	(1.35)	(1.22)	(2.21)	(0.91)
If median quality	-0.000638	-0.0417	0.0158	-0.0150
	(-0.01)	(-0.74)	(0.33)	(-0.52)
Distance to home	0.0425	0.00132	-0.0272	-0.000942
	(0.90)	(0.04)	(-1.31)	(-0.27)
Household fixed effects	Yes	Yes	Yes	Yes
P value of F test of (alpha1=alpha2)	0.0061	0.0083	0.0626	0.4619
Observations	1387	1385	1488	1799

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 7: Results of changes in number of planting seasons, for plots located in *hills or mountains* using household panel of 2000, 2008 and 2013

	(1) <0.8 mu	(2) 0.8-1.5 mu	(3) 1.5-3 mu	(4) >3 mu
Year 2008 (alpha1)	-0.197***	-0.164***	-0.194***	-0.146***
	(-6.49)	(-3.69)	(-3.66)	(-2.75)
Year 2013 (alpha2)	-0.404***	-0.338***	-0.355***	-0.211**
	(-7.76)	(-5.41)	(-4.75)	(-2.30)
If own land	0.0305	0.130	0.141	0.0344
	(0.48)	(1.50)	(1.30)	(0.36)
If irrigated	-0.0944**	-0.0218	0.0430	0.105
	(-2.41)	(-0.39)	(0.65)	(1.29)
If high quality	0.157***	0.148**	0.210**	0.00458
	(3.04)	(2.04)	(2.53)	(0.05)
If median quality	0.00374	0.0101	0.175**	0.0192
	(0.10)	(0.17)	(2.40)	(0.27)
Distance to home	-0.118***	-0.00657	0.00486	-0.0127
	(-5.35)	(-0.22)	(0.30)	(-0.42)
Household fixed effects	1.778***	1.396***	1.183***	1.231***
P value of F test of (alpha1=alpha2)	0.0001	0.0058	0.0286	0.4853
Observations	2714	1314	956	610

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$