

A Study of Rice Harvest Losses in China: Do Mechanization and Farming Scale Matter?

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Constrained by resources and environment, reducing food losses is receiving increasing attention in China. This study uses data from 1,106 farmers to calculate rice harvest losses and tests the impacts of mechanization and farming scale. The results are: 1) The harvest loss rate of rice averages 3.65%, and it decreases as farm scale increases. 2) The effects of mechanization on losses vary with farm scale. 3) Small- and middle-scale farmers are vulnerable to production and harvesting conditions while large-scale farmers are more affected by household and individual characteristics. Finally, policy suggestions are provided.

Key words: harvest loss of rice, farming scale, mechanization

1. Introduction

Every year about 1.3 billion tons of food are lost or wasted, accounting for about one-third of food production. Losses in less developed countries occur mainly on or near the farm (World Bank, 2010). As a country with a population of 1.4 billion, China feeds 19% of the world's population with 8% of the world's arable land, according to FAOSTAT. The importance of grain production is self-evident. Owing to a shortage of resources and a fragile environment, the opportunity to increase production is diminishing. However, reducing food loss and waste has become an alternative way of food supply.

As one of the two most important food grain products in China, rice has received a much higher priority in government policy. Because strong and young rural workers migrate to urban areas, the scale of farming has been rising, with machinery replacing labor. Do this substitution, and the increasing scale of farming increase or decrease rice harvest losses? Little research has been done into this question. A harvesting experiment conducted by Li *et al.* (1991) in Zhejiang Province and the survey of 1,400 households in 22 provinces in China by Zhan (1995) both showed that the reaping losses of rice by machinery were greater than that by manual labor. Newer studies, such as Wu *et al.* (2015), and Huang *et al.* (2018), reported the harvest loss rate in China was to be about 3%.

Research into the major causes of harvest losses shows varying results. Whereas Li *et al.* (2019) showed that combine harvesters increase the losses, Wu *et al.* (2015) found that combine harvesters would not affect the losses and that the larger

the mechanical harvesting area, the lower the loss rate. Production conditions will also affect losses. Bad weather, insect damage and a shortage of labor will increase the harvest losses (Basavaraja *et al.*, 2007; Li *et al.*, 2019). A large planting area has been found helpful in reducing losses (Begum *et al.*, 2013) but some scholars have come to the opposite conclusion (Basavaraja *et al.*, 2007). In addition, harvesting attitude, household income and other factors will also affect the losses.

Our field survey showed that farmers with different planting scales have widely different resource endowments. Large-scale farmers are mainly commercial and have a higher demand for agricultural technology (Zhang and Qian, 2008), which make them more risk-averse (Wilk *et al.*, 2013). Small-scale farmers lack access to decent inputs (Murphy, 2010), and their goal is mainly to meet their own food demand (Chen *et al.*, 2000). Different field management approaches may be adopted by large- and small-scale farmers, which makes the factors that affect harvest losses vary with farm size. Li *et al.* (2019) found that harvest methods, weather and other factors have different effects according to farm scale. But they didn't explain their reasons in detail, and studied only a few factors. This study, therefore, tests and compares the influence of different factors according to farm scale.

2. Methodology and Data

Theoretically, grain loss can be considered as the conditional negative production. *Conditional* means that the magnitude of grain harvest loss is a dependent variable. Bad weather or

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diseases will increase losses, as will insufficient or low-quality labor (including that of combine harvester operators), and low-quality seeds. In the absence of these conditions, losses can be minimized. Therefore, we specify the rice harvest loss as a function of different variables, including weather conditions and other environmental factors when analyzing the causes of loss.

1) Methodology and variables

The dependent variable is harvest loss rate (*HLR*), which refers to physical losses, rather than losses of nutrition or value. We distinguish four stages of the harvesting process: *reaping*, *threshing*, *winnowing*, and *field transportation*. 1) Reaping losses may occur when farmers cut straw, or when straw falls in the field before reaping. Such falling may be caused by the wind or other forces; 2) Threshing losses refer to grains left on straw or scattered on the threshing floor during threshing (Losses in the reaping and threshing stages are difficult to distinguish in combined harvesting.); 3) Winnowing losses refer to grains discarded with impurities (Li *et al.*, 1991); 4) Field transportation losses are caused by grain sprinkling onto the road during transportation from the farm to storage. Equation (1) shows how *HLR* is calculated. *PRO* is the rice production quantity. L_{reap} , L_{thr} , L_{win} , and L_{tra} represent the losses occurring during the four stages respectively.

$$HLR = \frac{L_{reap} + L_{thr} + L_{win} + L_{tra}}{(L_{reap} + L_{thr} + L_{win} + L_{tra}) + PRO} \times 100\% \quad (1)$$

There are two main kinds of harvesting methods in China: 1) *combined harvesting*: completed by combine harvesters at one time. 2) *segmented harvesting*, which includes: A) manual reaping and threshing; B) machine reaping and manual threshing; C) manual reaping and machine threshing; D) machine reaping and machine threshing, carried out in separate stages. Table 1 shows that about two-thirds of large-scale farmers use combined harvesting, while the corresponding proportion of small- and middle-scale farmers is less than half.

In China, owning machinery is far too expensive for most farmers. More commonly, therefore, farmers purchase harvest outsourcing services from machinery organizations (Machine Cooperatives) or individuals who own machines. These organizations or individuals will also carry out the harvesting operation. Table 1 shows that the proportion of large-scale farmers purchasing services is higher than that of small- and middle-scale farmers.

Our choice of variables is based on the production function framework. We specify rice harvest losses as being “produced” by different inputs (land, labor, machine, capital

etc.) together with weather and environmental conditions etc. We specify the harvest loss rate (*HLR*) as the dependent variable, with three types of explanatory variables: a) mechanical variables, *M*; b) variables of production and harvesting conditions, *P*; and c) variables of household and individual characteristics, *H*.

Equation (1) shows that the value of the dependent variable is between 0-100%, and because some samples take the value of 0%, a Tobit model is built for regression estimation. Suppose the model is:

$$HLR = \beta_0 + \beta_1(M) + \beta_2(P) + \beta_3(H) + \mu \quad (2)$$

Where β_0, \dots, β_3 are parameters to be estimated, and μ is the error term. *M* (mechanical variables) includes *Com*, *Ser*, *Win*, and *Tra*. *P* (production and harvesting condition variables) comprises *Wea*, *Pest*, *Area*, *Yield*, *Land*, *Distance*, *Attitude*, *Labor*, *Saving*, *Maturity*, and *Price*. *H* (household and individual characteristic variables) includes *Gender*, *Age*, *Edu*, *Training*, *T-inc*, and *R-inc*. Specific definitions are given in Table 1.

Based on the *Regional Layout planning of Advantageous Agricultural Products*, published by Ministry of Agricultural and Rural Affairs of China (MARA) in 2008, our sample covers three regions: the Yangtze River basin, the northeast plain, and the southeast coast. We add regional dummy variable to control for unobservable differences between regions. Stata15.0 software is used to estimate the model.

2) Data

Data was collected from the field survey conducted in collaboration with the Research Center for the Rural Economy of the MARA in 2016. The sample size of each province was based on the distribution of rice planting areas in China, and a total of 1,106 samples were investigated. In previous studies, the scale of farmers was generally defined according to their total planted area, which varied greatly between samples. In this study, all samples are sorted according to their area planted with rice. The smallest third of the samples are classified as small-scale farmers, with an average area of 0.09 ha, while the middle third and upper third are classified as middle- and large-scale farmers, with an average area of 0.22 ha and 0.66 ha, respectively.

3. Results and Discussion

1) Results

The average harvest loss rate in China is found to be 3.65% (Table 1), which is largely in agreement with previous studies. It is equivalent to nearly eight million tons of rice and required more than one million hectares of farmland to produce in

2016. The loss rate of small-scale farmers is the largest, at 4.59%, followed by middle-scale farmers, at 3.90%. The loss rate of large-scale farmers is the smallest, at 2.60%.

We tested the impacts of major factors on harvest losses, by focusing on mechanical harvesting and farming scale. Table 2 shows the Tobit regression results of different scales of farmers.

Table 1. Variable summary (mean) and definitions

Variables ¹⁾	Definition	All farmers	Small scale	Middle scale	Large scale
<i>HLR</i>	Harvest loss rate (%)	3.65	4.59	3.90	2.60
Mechanical variables					
<i>Com</i>	1 if combined harvesting, 0 otherwise	0.46	0.36	0.43	0.61
<i>Ser</i>	1 if buy outsourcing service at reaping and threshing, 0 otherwise	0.59	0.44	0.59	0.76
<i>Win</i>	1 if grain cleaned by machine, 0 otherwise	0.53	0.51	0.58	0.51
<i>Tra</i>	1 if transported by machine, 0 otherwise	0.60	0.37	0.60	0.83
Production and harvesting variables ²⁾					
<i>Wea</i>	1 if bad weather (strong wind/heavy rain or other), 0 if normal	0.16	0.11	0.12	0.24
<i>Pest</i>	No pest =1, slight pests =2, general or serious pests=3	1.84	1.81	1.83	1.90
<i>Area</i>	Planting area of rice (ha)	0.33	0.09	0.22	0.66
<i>Yield</i>	Yield (quintal/ ha)	80.45	82.34	79.84	81.62
<i>Land</i>	1 if the terrain is flat, 0 otherwise	0.75	0.76	0.76	0.75
<i>Distance</i>	Distance from the field to storage locations (km)	0.65	0.57	0.72	0.68
<i>Attitude</i>	1 if operators treat harvesting serious, 0 otherwise	0.23	0.26	0.19	0.24
<i>Labor</i>	1 if farmers report a lack of manpower, 0 otherwise	0.28	0.31	0.31	0.21
<i>Saving</i>	1 if farmers pick up rice after harvest, 0 otherwise	0.16	0.14	0.15	0.18
<i>Maturity</i>	1 if harvest when rice is mature, 0 otherwise	0.95	0.98	0.94	0.91
<i>Price</i> ³⁾	The price of rice (yuan/kg)	2.98	3.08	2.95	2.92
Household and individual variables					
<i>Gender</i>	Gender of household head (male=1, female=0)	0.84	0.83	0.85	0.86
<i>Age</i>	Age of household head	54.12	55.48	55.45	51.74
<i>Edu</i>	School year of household head (years)	7.01	6.91	6.89	7.25
<i>Training</i>	1 if household head obtained training, 0 otherwise	0.09	0.11	0.11	0.07
<i>T-inc</i>	Household income (ten thousand yuan)	7.07	6.05	7.18	8.04
<i>R-inc</i>	Rice income as a percentage of total income (%)	15.80	6.61	11.35	28.98
N	Number of samples	1106	374	335	382 ⁴⁾

Notes: 1) The highest correlation coefficient between independent variables is no more than 0.8 and the vif-value is less than 10, which means there is no multicollinearity.

- 2) Variables about production and harvesting are reported by farmers based on their observations during harvesting, and include factors such as weather types, pests, and the attitudes of operators.
- 3) Though in this model we use a cross-sectional data, a price variable is still included. In China, farmers plant different types of rice, which differ in price, yield, harvesting time, and nutritional contents etc.
- 4) Samples that used manual reaping and manual threshing were not included when counting large-scale farmers, as large-scale farmers are unlikely to adopt these methods.

(1) Impacts of mechanization in harvesting

The parameter of *Com* is significantly positive for middle-scale farmers, and marginally significant for large-scale farmers but with negative effect. The parameter of *Ser* is significantly positive for large-scale farmers. The coefficient of *Win* is positive for all farmers while the coefficient of *Tra* is negative for small-scale farmers.

(2) Effects of farming scale and other production or harvesting factors

In the results for small- and middle- scale farmers, most of the production and harvesting factors are statistically significant. The parameters of *Wea*, *Pest*, and *Labor* all have positive effects on losses and are statistically significant for small- and middle-

scale farmers, while *Area*, *Distance*, and *Attitude* all have significant negative effects. *Yield* and *Land* have negative effects on small-scale farmers and middle-scale farmers, respectively. Moreover, *Wea*, *Pest*, and *Attitude* have the same effects on large-scale farmers as on small- and middle-scale farmers. And the coefficient of *Price* is marginally significant with negative effect while that of *Land* is marginally significant with positive effect for large-scale farmers.

(3) Impact of household and individual characteristics

Large-scale farmers are mainly affected by household and individual characteristics. For large-scale farmers, the coefficient of *T-inc* is positive while that of *R-inc* is negative.

Table 2. Tobit regression results for different scales

	Small scale		Middle scale		Large scale	
Mechanical variables						
<i>Com</i>	0.424	(0.70)	1.081**	(2.09)	-0.757*	(-1.74)
<i>Ser</i>	0.076	(0.12)	0.178	(0.27)	1.080**	(2.05)
<i>Win</i>	1.556***	(3.76)	1.357***	(3.52)	0.600*	(1.76)
<i>Tra</i>	-1.290***	(-3.12)	-0.603	(-1.36)	-0.509	(-1.15)
Production and harvesting variables						
<i>Wea</i>	1.876***	(2.68)	2.023**	(2.47)	1.235*	(1.91)
<i>Pest=2</i>	0.916**	(2.10)	1.174**	(2.54)	1.037***	(3.36)
<i>Pest=3</i>	3.403***	(5.68)	3.331***	(5.59)	1.352***	(3.23)
<i>Area</i>	-19.785***	(-3.13)	-12.346***	(-2.90)	-0.574	(-1.47)
<i>Yield</i>	-0.024**	(-2.43)	-0.008	(-0.98)	-0.006	(-1.00)
<i>Land</i>	-0.356	(-0.72)	-1.657***	(-3.24)	0.676*	(1.68)
<i>Distance</i>	-0.635*	(-1.87)	-0.500*	(-1.96)	0.014	(0.10)
<i>Attitude</i>	-2.292***	(-4.72)	-1.056*	(-1.95)	-0.810*	(-1.95)
<i>Labor</i>	1.030**	(2.42)	0.805*	(1.92)	0.153	(0.50)
<i>Saving</i>	0.746	(1.41)	0.073	(0.12)	0.448	(1.37)
<i>Maturity</i>	-0.850	(-0.71)	-0.768	(-1.00)	-0.285	(-0.60)
<i>Price</i>	-0.235	(-0.38)	0.500	(0.61)	-1.993*	(-1.93)
Household and individual variables						
<i>Gender</i>	0.489	(1.08)	-0.052	(-0.09)	0.083	(0.24)
<i>Age</i>	0.016	(0.83)	0.031	(1.55)	0.006	(0.33)
<i>Edu</i>	0.048	(0.65)	0.076	(0.75)	-0.078	(-1.19)
<i>Training</i>	0.181	(0.31)	0.664	(0.91)	-0.244	(-0.52)
<i>T-inc</i>	-0.003	(-0.10)	0.047	(1.37)	0.078**	(2.37)
<i>R-inc</i>	0.044	(1.33)	0.007	(0.42)	-0.019**	(-2.23)
<i>The northeast plain</i>	1.998**	(2.50)	-0.930	(-1.25)	-2.234***	(-4.03)
<i>The southeast coast</i>	2.491**	(2.58)	-0.504	(-0.68)	-2.816***	(-4.90)
<i>Cons</i>	4.899*	(1.67)	3.562	(1.04)	9.693***	(2.92)
McFadden's Pseudo R-square	0.080		0.060		0.052	

Notes: 1) ***, **, and * indicate 1%, 5%, and 10% significance levels, respectively.

2) The t-statistics computed based on the robust standard errors are in parentheses.

2) Discussion

(1) Does mechanization in harvesting reduce field losses?

The impact of machinery on losses varies not only with farming scale, but also with different harvest stages. Combined harvesting increases the losses of middle-scale farmers, while it reduces the losses of large-scale farmers. Combine harvesters are usually too large to operate efficiently on small areas of farmland, which adds to losses. On small farms, operating machinery is more difficult: it requires slower speed and more care. The attitude of harvester operators is more diligent for small-scale farmers (0.26) than for middle-scale farmers (0.19) (Table 1) and a diligent attitude can reduce losses (Table 2). These may account for the impact of *Com* not being significant for small-scale farmers, although still positive. On large-scale farms, combine harvesters can finish the harvest quickly, avoiding losses caused by bad weather or labor shortages.

Large-scale farmers' purchase of outsourcing services will increase losses. Farmers purchase work that was originally

done by family members on the market: this creates a principal-agent relationship between farmers and service providers (Yang, 2007; Ren *et al.*, 2001; Cai and Liu, 2019). The goals of farmers and service providers are not identical. The farmers' goal is to harvest as much of their rice as possible, which requires service providers to adjust the speed and equipment of the machine to suit the farmland and rice crop. On the other hand, the service providers' goal is to maximize profits, and their income is directly proportional to the area of the land on which they operate, which may prompt them to speed up their machines or be less diligent in their work. Such different goals may lead to moral hazard (Cai and Liu, 2019). Because they are specialized and know more about their machinery, service providers may speed up their operations, in an effort to maximize their income—but this can increase harvest losses. However, the impact of moral hazard has not been reflected in small- and middle-scale farmers. A possible explanation is that even if service providers want to speed up machines, they will be limited by small areas.

Mechanical winnowing was found to increase losses. If the winnowing device is incorrectly adjusted, grains as well as impurities can be blown away. Transporting by mechanized vehicle reduces losses by shortening the time taken for transportation.

(2) Does larger-scale farming help to control harvesting losses?

Small- and middle-scale farmers are vulnerable to production and harvesting conditions, while large-scale farmers reduce their dependence on environmental conditions and labor by using modern agricultural technology and taking advantage of their large scale (Zhang and Qian, 2008).

Bad weather and pests increase losses of all farmers. Overall, the impact of weather and pests on large-scale farmers is relatively small (Wilk *et al.*, 2013). Labor shortages increase the losses of small- and middle-scale farmers: small- and middle-scale farmers allocate more of their labor to the non-farm sector, while large-scale farmers tend to focus on agricultural production and are more willing to adopt mechanized operation (Liu, 2006; Zhang and Qian, 2008). Large-scale farmland is of greater interest to outsourcing service providers (Zhou, 2017a, b), which allows large-scale farmers easier access to mechanical services than small- and middle-scale farmers. Table 1 shows that the proportion of small- and middle-scale farmers lacking labor during the harvest is higher than that of large-scale farmers. Combined harvesting is used by less than 50% of small- and middle-scale farmers, meaning that they rely more on labor. For small- and middle-scale farmers, a large planting area and flat land are convenient for harvesting—especially for mechanical operation. But for large-scale farmers, the flatter the land, the greater the loss. Because the flat land provides favorable conditions for service providers to speed up machines. This may coincide with the moral hazard in the outsourcing services analyzed above. The further away the farmland is from the storage facility, the better packaging and transportation equipment the farmer is likely to use, which reduces losses during transportation. For large-scale farmers, these production conditions are generally good, which makes them less sensitive to these factors.

Rising prices could reduce harvest losses of large-scale farmers. Large-scale farmers grow rice for profit, while small- and middle-scale farmers are more interested in family consumption (Chen *et al.*, 2000). Therefore, an increase of rice price will encourage large-scale farmers to carry out field

management more effectively, while small- and middle-scale farmers lack such motivation.

(3) Taking more measures to control field harvest losses

The losses of large-scale farmers are affected by household and individual characteristics. Some wealthier farmers may not be too concerned about losses. The higher the proportion of rice income, the lower the loss rate. Table 1 shows that the proportion of rice income of large-scale farmers is far more than that of small- and middle-scale farmers. Therefore, with more of their income coming from rice production, large-scale farmers are more motivated to reduce losses.

4. Conclusions

Through a survey of 1,106 farmers, this study calculated rice losses in China and analyzed the influencing factors by focusing on the degree of mechanization and farming scale. Our conclusions are as follow. First, the average rice harvest loss rate in China is 3.65% with losses decreasing as scale increases. Second, the impact of machinery on losses depends on farming scale and on which stages of the harvest machinery is used. A larger scale helps reduce losses, while combine harvesters increase the loss rate of middle-scale farmers and reduce that of large-scale farmers. Because of moral hazard, purchasing outsourcing services increases losses for large-scale farmers. Third, small- and middle-scale farmers are vulnerable to production and harvesting conditions, such as pests and labor shortages. Large-scale farmers are more affected by household and individual characteristics: a high household income increases losses while a high proportion of rice income reduces losses.

For these reasons, it would be more effective to adopt different loss reduction measures according to farming scale. Strengthening weather and pest management is important for all farmers. For small- and middle-scale farmers with poor production conditions and less enthusiasm for market production, it is necessary to improve their access to outsourcing services, such as pest management and mechanical services, to guide them onto the track of modern agriculture and reduce their dependence on environmental conditions and labor. For large-scale farmers, to ensure the quality of mechanical services and avoid moral hazard, appropriate intermediary organizations should be established (Yang and Guo, 2004) to regulate the market for outsourcing services, and to clarify the rights and obligations of both parties. Moreover, improving their income from rice farming will effectively reduce their losses.

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