The Relationship between Farm Size and Productivity in Agriculture: Evidence from Maize Production in Northern China

Yu Sheng, Jiping Ding, and Jikun Huang

The relationship between farm size and productivity has long been a topic of debate in development economics. Using farm-level panel data from 2003 to 2013, we investigate the relationship between maize yield and farm size in Northern China. After controlling for farm-specific characteristics, we restore a mild U-shaped relationship between maize yield and cropping area from the apparent inverse U-shaped curve. This suggests that an inverse farm size–productivity relationship persists for most small-sized farms. Further analyses demonstrate that farmer input choice between labor and capital is likely to smooth the non-linear farm size–productivity relationship, with capital use being more likely to affect the farm size–productivity relationship at a larger scale. The findings imply that subsidizing farmers to rent land without helping them become better-equipped could result in resource misallocation towards larger farms using less-efficient labor-intensive technologies.

Key words: Farm size, land productivity, inverse relationship, Northeast and Northern China.

JEL Codes: D2, Q1.

The relationship between farm size and productivity has long been discussed amongst productivity economists, yet no consensus has emerged from an empirical perspective. An inversed farm size–productivity relationship is widely observed in developing Asian countries (Bardhan 1973; Sen 1975; Heltberg 1998; Lipton 2009; Hayami 2001, 2009), following the notion of "small is beautiful" initially observed by Chayanov (first published in Russia 1925, see Chaîanov 1986). This phenomenon is also found in Sub-Saharan Africa (Barrett, Bellemare, and Hou 2010; Carletto, Savastano, and Zezza 2013; Larson et al. 2014; Desiere and Jolliffe 2018). However, other studies show that in some developing countries, large farms could be more efficient than their small counterparts (e.g., Jha and Rhodes 1999; Jha, Chitkara, and Gupta 2000; Foster and Rosenzweig 2010; Otsuka, Liu, and Yamauchi 2013). How then, can the conflict in the empirical findings on the farm size–productivity relationship be explained?

Theoretically, when product and factor markets are perfectly competitive and functioning effectively, there will be no significant difference in productivity between farms of different sizes. This is because a competitive market will spontaneously reallocate resources from less efficient to more efficient farms, and eliminate the efficiency gap between farms of different sizes. However, mismeasurement issues and the inability to control for unobserved factors (i.e., soil quality) may contaminate the empirical farm size–productivity relationship, leading to the phenomenon that observed farm productivity declines with size (e.g., Lamb 2003; Barrett, Bellemare, and Hou 2010; Carletto, Savastano, and Zezza 2013; Carletto et al. 2016; Bevis and Barrett 2017; Desiere and

Yu Sheng is an associate professor at the China Center for Agricultural Policy, School of Advanced Agricultural Sciences, Peking University, Beijing, China. Jiping Ding is a lecturer in the College of Economics and Management, Northwest Agriculture and Forest University, Shaanxi, China. Jikung Huang is a professor at the China Center for Agricultural Policy, School of Advanced Agricultural Sciences, Peking University, Beijing, China. The authors acknowledge financial support from the National Natural Sciences Foundation of China (Ref. 71333013 and Ref. 71873005) and the Chinese Academy of Sciences (Y02015004 and KSZD-EW-Z-021–1). Correspondence to be sent to: jkhuang.ccap@pku.edu.cn.

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Jolliffe 2018). The inverse farm size–productivity relationship can also be attributed to input market imperfection and resource misallocation between differently-sized farms (Feder 1985; Eswaran and Kotwal 1986; Deininger et al. 2014; Otsuka, Liu, and Yamauchi 2016).[1]

Many studies have used these two arguments to explain the inverse relationship between farm size and productivity in China. For example, Benjamin and Brandt (2002) and Chen, Huffman, and Rozelle (2005, 2011) found that the rigid Chinese land allocation system contributed to the inverse farm size–productivity relationship. Yet, the land market distortion argument is unconvincing for recent years, as a rapid development of land rental markets since the 1990s did not trigger significant land consolidation until the late 2000s. Nor can land quality difference between farms of different sizes explain the apparent inverse relationship between crop yield and farm size, as farm yield declines after operation reaching a certain scale (Huang and Ding 2016). While recent studies suggest that institutional arrangements in the labor and capital markets could affect technology adoption and input choice by differently-sized farms (Foster and Rosenzweig 2010; Otsuka, Liu, and Yamauchi 2013, 2016), it is unclear whether this newly proposed mechanism will explain the farm size–productivity relationship in China.

In this paper, we investigate the farm size–productivity relationship and its underlying determinants for maize producers in Northern China since 2003 by using a farm fixed-effect model with an instrumental variable. Both labor and capital intensities are incorporated into the model to quantify the impact of farm input choice on the size–productivity relationship. Our time period of analysis covers the land rental market reform period, when there is an increase in average farm size for the cropping industry, and focuses on household farms specializing in maize production (whose output quality and market demand variations are very small) in 2003, 2008, and 2013. The data were collected from six provinces in Northeast and North China, accounting for around 60% of total maize production in the country in 2013 (National Bureau of Statistics of China 2014).

Our paper makes three main contributions to the literature. First, it is the first attempt to investigate the farm size–productivity relationship among maize producers in Northern China after 2000 when land rental market reforms relaxed the rigid land allocation system. Second, we attempt to profile the farm size–productivity relationship across different farm size classes by augmenting a base fixed-effect specification using additional data on labor and capital. Differences in labor and capital choices is found to explain the changed size–productivity relationship between farms of different size classes. Third, we show that an inverse farm size–productivity relationship persists for most small-sized farms, and that this is possibly caused by their choice to use a relatively higher proportion of labor to substitute capital when land reforms enlarge the average scale of production.

Farm Size–Productivity Relationship: Natural Endowment Difference or Market Frictions?

Under the standard neoclassical assumptions, the farm size–productivity relationship usually depends on size-related costs and benefits. If the benefits obtained from enlarging size (i.e., adopting advanced technology and obtaining increasing returns to scale and market power in product and factor markets) are larger than the costs incurred by efficiency loss in management (i.e., monitoring hired labor and sunk costs related to investment), farm productivity will increase with size and vice versa.

While clear in theory, empirical evidence on the farm size–productivity relationship is mixed and differs between countries. On one hand, there is a positive relationship between farm size and productivity in new continental countries such as the United States, Canada, Australia (MacDonald, Hoppe, and Newton 2017; Sheng and Chancellor 2018), and some Latin American countries (Deininger and Byerlee 2012). On the other hand, an inverse relationship between farm size and productivity is widely observed in many Asian countries (Sen 1962, 1966, 1975; Bardhan 1973; Lipton 1993; Dyer 1996; Heltberg 1998; Hayami 2001, 2009). Recently, more evidence for the inverse farm size–productivity

[1] Deininger, K., S. Jin, Y. Liu, and S. Singh. 2014. Labor Market Efficiency and Inverse Productivity-Farm Size in India. Unpublished. International Food Policy Research Institute.

relationship are also found in Sub-Saharan Africa (Barrett, Bellemare, and Hou 2010; Carletto, Savastano, and Zezza 2013; Larson et al. 2014; Bevis and Barrett 2017; Desiere and Jolliffe 2018). The observation of ambiguous farm size–productivity relationships across countries has aroused interest from policy makers, as rationality suggests that common factors must explain the difference.

In the literature, there are generally three groups of studies that attempt to explain the aforementioned phenomenon. The first group attributes the inverse farm size–productivity relationship to unobserved factors such as soil quality and climate condition, as these factors could be unevenly distributed between farms of different sizes (Bhalla and Roy 1988; Benjamin 1995). However, some studies, like Liu, Violette, and Barrett (2013) found that unobserved soil quality was not related to the inverse farm size–productivity relationship.[2] The second group is more concerned with the inverse farm size–productivity relationship resulting from measurement error (Lamb 2003). Using GPS-based plot area information, Gourlay, Kilic, and Lobell (2017) and Desiere and Jolliffe (2018) examined the size–productivity relationship for crop farms in Uganda and Ethiopia. Their focus was on measurement error in farm self-reported crop production, particularly with regard to the smallest farms. Bevis and Barrett (2017) examined the "edge effect" discussed in the agronomy literature wherein productivity is highest around the periphery of the plot as an alternative explanation of the inverse farm size–productivity relationship. Although both explanations found supportive evidence in the African context, they cannot explain a more general case. For example, Carter (1984) and Deolalikar (1981) found that, even after controlling for village fixed effects and possible selection biases, the inverse farm size–productivity relationship persisted in India over the period 1969 to 1972. Recently, Carletto, Savastano, and Zezza (2013) also used geospatial and self-reported data on plot size to identify measurement error on farm size, but did not find that it contributes to the inverse farm size–productivity relationship in Uganda.

The third group of studies focuses on imperfect competition and distortions in land and labor markets. In particular, this group concentrates on technology adoption and input choice between labor and capital between farms of different sizes (Feder 1985; Eswaran and Kotwal 1986; Otsuka, Liu, and Yamauchi 2016). Liu, Violette, and Barrett (2013) investigated machine usage and the farm size–productivity relationship in Vietnam from the 1990s to the 2000s using four rounds of Vietnam Household Living Standards Surveys (VHLSS). These authors found that the inverse relationship between paddy rice yield and farm size was likely to be lessened or even reversed when machinery had been widely used (in substitution of labor). Yamauchi (2016) examined the farm size–productivity relationship in Indonesia using the farm-level panel data from seven provinces, revealing that an increase in real wages caused large farms to use more capital in order to substitute labor, and this turned the farm size–productivity relationship to be positive. Finally, Deininger et al. (2014) examined the dynamic relationship between farm size and land productivity in India between 1982 and 2008, and found that the inverse farm size–productivity was significantly weakened over time when capital was used to substitute labor.

Only a few studies have thus far explored the farm size–productivity relationship in China. Benjamin and Brandt (2002) found a weak inverse relationship between farm size and productivity in China in the 1990s, which they attribute to local administrative land distribution policies and uneven off-farm employment opportunities. Chen, Huffman, and Rozelle (2005, 2011) used instrumental estimation to examine the relationship between land productivity and farm size between 1995 and 1999. After controlling for the egalitarian land allocation principle, these authors found that the inverse relationship in the Chinese grain industry might result from a failure to account for the unobserved land quality (which is unevenly distributed between farms of different size). Li et al. (2013) noticed a strong inverse relationship between farm size and land productivity for rice production, but found a positive relationship between farm size and labor productivity when using farm survey data from Hubei province between 1999 and 2003. Recently, Wang et al. (2014) and Huang and Ding (2016) found that both farm size and yield increased in Chinese grain

[2] Liu, Y., W. Violette, and C. Barrett. 2013. Real Wage, Machine Use, and Inverse Farm Size–Productivity Relationship in Vietnam. Unpublished. International Food Policy Research Institute.

production as the land rental market became increasingly active after 2003.[3] However, Huang and Ding (2016) also found that the relationship between crop yield and farm size reversed once farm size reached a particular scale.

Despite lessons from previous literature, the farm size–productivity relationship in China remains a puzzle. Ongoing reforms gradually change the way that land is allocated between farms, and land consolidation increasingly occurred through the transaction of land use rights under the policy of "subsidizing the large". However, it is unclear whether there is still an inverse farm size–productivity relationship in China. Does the inverse farm size–productivity relationship come from measurement error or from a rigid institutional arrangement in land markets? What is the role of farm technology choice and input usage in determining productivity when they grow large? To answer these questions, further empirical studies are needed.

Model Specification and Data Collection

Model Specification

Beginning with a standard neoclassical production model, we assume that a representative farm production function takes the Cobb-Douglas form. The farm output is thus determined by various factor inputs including land, labor, capital and intermediate inputs, and the Hick-neutral production technology, such that

$$(1) \qquad Y_{it} = AN_{it}^{\alpha}L_{it}^{\beta}K_{it}^{\gamma}M_{it}^{\delta}$$

where $\alpha, \beta, \gamma, \delta < 1$. A denotes production technology (containing the gain or loss of productivity efficiency), and N, L, K, and M are land, labor, capital, and intermediate inputs. Further, α, β, γ, and δ are the output elasticity of each input.

Dividing N_{it} on both sides of equation (1) and taking the logarithm, we can derive farm land productivity (or yield) as the function of farm size, production technology, and other inputs

$$(2) \qquad \ln\left(\frac{Y_{it}}{N_{it}}\right) = lnA + (\alpha + \beta + \gamma + \delta - 1) \times lnN_{it} + \beta\ln\left(\frac{L_{it}}{N_{it}}\right) + \gamma ln\left(\frac{K_{it}}{N_{it}}\right) + \delta\ln\left(\frac{M_{it}}{N_{it}}\right)$$

Equation (2) shows that a farm's land productivity should be either positively or not related to the land size operated if the production function demonstrates increasing or constant returns to scale $(\alpha + \beta + \gamma + \delta - 1 \geq 0)$ and unobserved measurement errors are properly controlled. However, in practice, the inverse relationship between land productivity and farm size could also arise due to at least three reasons. The first is that farms of different sizes could adopt different production technologies (lnA). There could be an inverse farm size–productivity relationship if the efficiency loss is not properly accounted for, particularly when production efficiency declines with farm size. The second reason is that farms may use different combinations of capital, labor, and intermediate inputs and/or use these inputs with different qualities to offset the declining marginal return to land when expanding operational scale. In this case, land productivity declines with farm size but farms will still enlarge their operational scale. The third reason is that there is decreasing return to scale, such that $\alpha + \beta + \gamma + \delta < 1$.

Based on equation (2), we defined the baseline empirical specification to examine the relationship between land productivity and farm size, following Benjamin and Brandt (2002) and Chen, Huffman, and Rozelle (2005, 2011)

$$(3) \qquad y_{it} = \theta_0 + \theta_1 n_{it} + \theta_2 n_{it}^2 + u_i + D_t + \varepsilon_{it}$$

where $y_{it} = ln(Y_{it}/N_{it})$ denotes land productivity or maize yield, and $n_{it} = ln(N_{it})$ denotes farm size or maize cropping area. Both land productivity and farm size are in logarithm, u_i represents farm fixed effects and is used to capture farm specific characteristics, and D_t is year-specific effects and captures technological progress, weather variations, and other changes over time. We also note that a square-term of farm size (n_{it}^2) has been added into the regression to capture the potential

[3] Wang, X., F. Yamauchi, K. Otsuka, and J. Huang. 2014. Wage Growth, Landholding, and Mechanization in Chinese Agriculture. Unpublished. China Centre for Agricultural Policy.

non-linear relationship between land productivity and farm size.

The baseline model can be used to examine the farm size–productivity relationship when farm fixed effects control for the factors that do not change over time such as soil quality, land market distortions and some measurement errors, or even farmer ability. However, other farm characteristics, management practices and their choice of labor and capital usage, which change over time, could also affect the farm size–productivity relationship. To identify the impact of farm input choices on the farm size–productivity relationship, we include three groups of variables representing farm characteristics and management practices (X), labor input intensity (l), and capital input intensity (k) into the baseline model one after another, in addition to control for the farm fixed effects:

$$y_{it} = \theta_0 + \theta_1 n_{it} + \theta_2 n_{it}^2 + \theta_3 X_{it} + \theta_4 l_{it} + \theta_5 k_{it} + u_i + D_t + \varepsilon_{it} \tag{4}$$

where X_{it} denotes number of plots and some farm management practices (such as share of land irrigated and share of land for maize production); and l_{it} and k_{it} denotes labor and capital use per hectare and their quality, respectively. In order to account for time-variant change in soil quality, we also include a measure of self-reported soil quality as a control variable. By comparing the estimated results obtained from each of these groups, we can establish how the farm size–productivity relationship is determined. As discussed above, we expect that incorporating farm input choice into the model will not only improve model fit but also help to better profile the use of labor and capital and the related factor market frictions in affecting the farm size–productivity relationship.

Equations (3) and (4) can be estimated using the pooled general least square (GLS) regression technique; however, the obtained elasticity in front of farm size (θ_1 and θ_2) may be biased from the real relationship between farm size and land productivity. This is due to the potential endogeneity problem or reverse causality resulting from the correlation between unobserved variables (either time invariant or time variant) and farm operational scale. For example, overestimation of the farm size–productivity relationship will occur if farms with higher crop yields tend to be more likely to rent land.

To overcome this problem, we adopt an instrumental variable regression to control for time-variant unobserved variables and use a panel regression model to control for farm-level fixed effects. We use three instrumental variables to identify farm size. The first is the initial land areas allocated (by villages) to farms through the household responsibility reform, which is also used by Foster and Rosenzweig (2017). The second and third are related to the reallocation of "flexible land" or "wasteland exploration" between farms, determined only by local government land policies. The validity of these instrumental variables deserves some explanations.

First, the initial land areas obtained by farm households are unlikely to be related to crop yield, since the land was allocated according to population characteristics of each family and village endowment (Lin 1992; Brandt, Huang, and Rozelle 2004), and the land allocation was based on the egalitarian principle (Zhu and Prosterman 2007). However, farm households initially owning a relatively large land area are more willing to expand their operational scale since they have accumulated experience in operating larger land areas.[4] Second, the land area obtained by farms from the reallocation of "flexible land" or "wasteland exploration" by village government. According to the current land law, each village has the privilege of holding a small proportion of agricultural land (usually, less than 5% of total land, called the "flexible land"), and used it for adjusting land allocation between farms due to population change and social welfare rebalancing. The allocation of these two types of land between farms is only determined by local land endowment availability and policy, which has nothing to do with crop yield. However, farm households holding more land through these two channels usually have closer relationships with the local government, and thus are more capable of expanding their land scale through land reallocation by government and land rental markets. All three instrumental variables are expected to be positively related to maize cropping areas (or farm size) and satisfy the exclusive

[4] A correlation test shows a 0.46 coefficient between the initial land areas and farm cropping areas for 2003, 2008, and 2013.

condition, and thus they could be regarded as valid instruments.

Finally, we estimate equation (4) using three scenarios that include the model specification with control of X (e.g., self-reported soil quality and some farm practices only), the model specification with the control of X and l (e.g., labor intensity), the model specification with the control of X and k (e.g., capital quality and intensity), and the model specification with the control of X, l, and k. In all four scenarios, cluster effects have been accounted for at the county level and sample weights are adjusted for each farm. The results obtained from these scenarios are thus compared with those obtained from equation (3) (the baseline model).

Data Collection and Variable Definitions

The dataset is from an annual maize farm survey conducted by the China Centre for Agricultural Policy (CCAP), which conducted this survey in 2008 and in 2013. The survey was conducted immediately after the harvest season, and collected information on crop yield, land use, labor and capital assets, and other characteristics at the farm, village, township, and county levels.[5] The survey focused on maize farms in three provinces (Heilongjiang, Jilin, and Liaoning) in Northeast China and three provinces (Hebei, Shandong, and Henan) in North China—the major maize production regions in China. In both 2008 and 2013, we used the same questionnaires and traced farms between the two rounds of surveys, and only 13 farms out of the total of 641 farms were not properly tracked.

In the surveys, we employed a stratified random sampling approach to choose farm households in Northeast and North China. Specifically, two maize-dominated counties in each Northeast province and three maize-dominated counties in each North China province were randomly selected. Within each of the 15 counties selected, two townships were randomly selected, with each representing the above- and below-average levels of farm size. Within each township, two villages were randomly selected. In total, we have 30 townships and 60 villages. All farms in each village were divided into two groups: large and small farms. Because the average farm size in Northeast China is much larger than that in North China, the cut point used to split between the large and small farms is 100 mu (or 6.67 ha) in Northeast China (except Liaoning) and 50 mu (or 3.33 ha) in North China and Liaoning.[6] Further farm households were then randomly selected, with seven households from the small farm group and three from the large farm group. When there were not enough large farms for selection, we added small farms to make up a total of 10 sample farms from each village. In total, we surveyed 631 maize farms. Among these we eliminated 57 farms due to incomplete data, outliers, and other statistical reasons.[7] The final sample used in this study contains an unbalanced panel of 1,618 observations for 574 farms in 2003, 2008, and 2013, with each farm observed for at least two consecutive years.

Although our samples are for Northeast and North China only, we believe that they have good representation for maize production in China. As major maize production regions in China, these six provinces in Northeast and North China accounted for 59% of Chinese maize production in 2013 (National Bureau of Statistics of China 2014). Figure 1 provides the location of these surveyed counties and their geographical distribution in the maize production belt for Northeast and North China. Moreover, a majority of maize farms in Northeast and North China used almost 100% of their land for maize production at least for one growing season, and treat maize production as the main source of their income.[8] According to our survey, 96% of household farms

[5] The farm-level information at 2003 is recovered from farmers' memory in the 2008 survey since the first-round survey was conducted in 2008.

[6] The term "mu" (also called "mou") is a unit of land measure widely used in Asian countries. In our study, one "mu" equals one-fifteenth of a hectare.

[7] Among the 57 farms eliminated from our sample, 18 farms have incomplete information on output, inputs, and other control variables; 13 farms are not properly traced over time; 12 farms are obvious outliers as they report no or very low output; 8 farms have no or very little cropping areas; 6 farms act as "farm cooperatives."

[8] Operating on a small piece of land, maize farms always choose to specialize in maize production in the maize growing season even if they own a multi-plot area. In Northeast China, there is only one growing season each year, and thus most farms use 100% of their land for maize production. In North China, there are two growing seasons each year (i.e., winter season and summer season), and most farms can choose to produce the combination of maize and wheat or the combination of maize and cotton. However, in each growing season, only one crop is produced: maize or wheat/cotton.

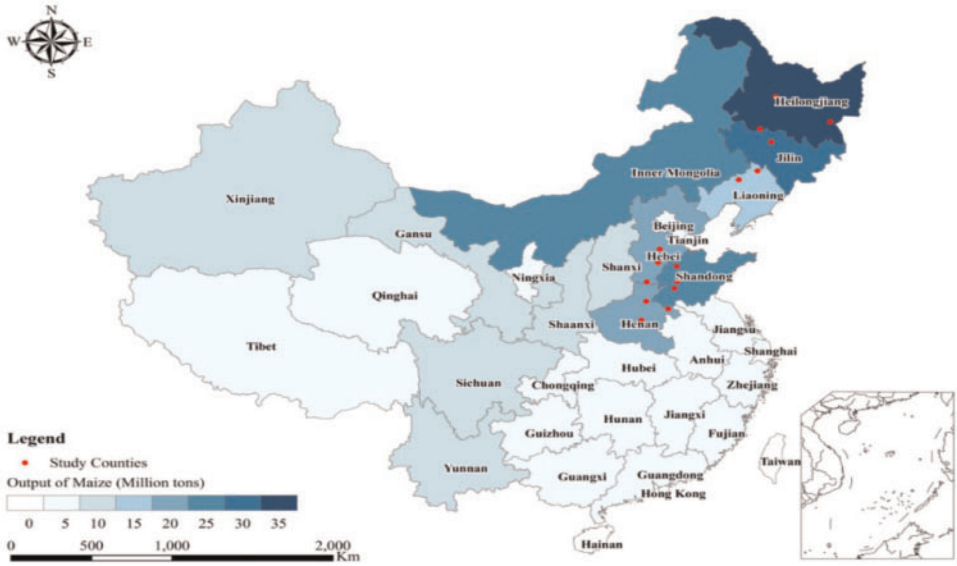

Figure 1. The geographical distribution of maize production in 2013 and the sample counties

Source: National Bureau of Statistics of China (2014).

produced maize in our sample villages in 2013. In this sense, the input–output relationship at the farm level reflected the characteristics of maize production in Northern China.

The most important two variables used in our study are crop yield and farm size. We define crop yield as total maize output (quantity) divided by maize cropping area and farm size as total cropping areas for maize production.[9] In the literature, many studies have found that measurement error on crop output and land area arise from using the self-reported data, thereby contaminating the farm size–productivity relationship (Gourlay, Kilic, and Lobell 2017; Desiere and Jolliffe 2018). However, this is not the case in China since household farms have better knowledge about the land areas in operation and their output.[10] Meanwhile, a comparison analysis shows that our estimates of average maize yield and farm cropping area are consistent with the estimates based on the National Survey for Agricultural Production Costs (National Development and Reform Commission 2004, 2009, 2014) in the six provinces and the plot-level data for 2013.[11]

Based on our estimates, average maize cropping area at the farm level has increased from 1.10 hectare to 1.77 hectare in Northeast and North China between 2003 and 2013, partly due to rapid land rental-market reforms (Huang and Ding 2016). This land consolidation trend between maize farms in our sample is consistent with that for maize farms in Northeast and North China estimated by using the national wide farm surveys, where average farm size increased from 0.92 hectares in 2003 to 1.73 hectares in 2013 (National Development and Reform Commission 2004, 2009, 2014). Along with an increase in cropping area, average maize yield at the farm level increased from 7.45 tons in 2003 to 8.22 tons in 2013, which is also consistent with the estimates obtained by using the national wide farm survey data (National Development and Reform

[9] For consistency, all output measures have been converted into metric tons and all farm size measures have been converted into hectares despite their initial units in data collection.

[10] Maize produced in Northeast and North China is mainly used as feed for livestock production, and most maize farms sell their output directly to the market immediately after harvest. According to the “annual statistics on the costs and benefits of major agricultural products,” (National Development and Reform Commission 2014), in 2013 the commercial rates for maize in the harvest season were 100%, 99.68%, and 98.35% for Jilin, Heilongjiang, and Liaoning (Northeast China), and 97.92% and 95.1% for Shandong and Hebei (North China), respectively. This allows maize farms to have a good knowledge about the quantity of the maize harvest, along with reliable information on sowing area for maize. Thus, our maize yield estimate should be deemed accurate.

[11] Please refer to the online supplementary appendix B for a detailed discussion on measurement issues related to maize yield and farm size in China.

Table 1. Descriptive Statistics on Major Variables

	Average		2003		2008		2013	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Maize yield (ton/ha)	7.92	1.74	7.45	1.62	8.10	1.53	8.22	1.94
Maize cropping area (ha)	1.39	1.56	1.10	1.14	1.31	1.50	1.77	1.88
Share of high quality land (%)	23.58	37.80	22.53	37.58	24.32	38.4	23.90	37.29
Share of land irrigated (%)	65.60	46.85	61.44	48.04	66.29	46.65	69.19	45.55
Number of plot (num. per farm)	3.33	2.22	2.85	1.75	3.15	2.11	4.00	2.59
Share of land for maize production (%)	61.78	23.11	62.35	23.19	61.77	23.40	61.21	22.75
Age of household head (year)	46.82	10.78	41.85	9.98	46.67	9.95	52.12	9.92
Labor intensity (person/ha)	5.44	8.73	5.39	6.44	5.42	5.59	5.53	12.61
Share of off-farm labor (%)	7.31	15.84	3.19	11.35	5.32	13.85	13.63	19.43
Share of family helper (%)	6.64	15.90	4.86	14.04	5.75	15.18	9.39	17.97
Share of part-time labor (%)	5.82	15.84	4.96	15.19	5.65	15.75	6.88	16.55
Income per capita (yuan/person /year)	3,668.85	2,144.16	2,773.16	1,699.77	3,701.94	1,953.75	4,559.08	2,358.70
Plough machinery	0.09	0.29	0.03	0.16	0.09	0.28	0.16	0.36
Harvest machinery	0.03	0.17	0.01	0.07	0.02	0.14	0.06	0.25
Share of labor plough (%)	1.20	10.80	2.08	14.15	1.10	10.43	0.39	6.16
Share of no-tillage (%)	57.59	49.24	56.80	49.42	56.92	49.36	59.11	48.98
Share of animal plough (%)	3.15	17.28	7.02	25.52	2.24	14.48	0.10	1.75
Share of custom services (%)	69.39	30.86	57.55	32.9	72.94	27.75	77.92	27.86
The initial land (ha)	0.87	0.70	0.87	0.70	0.86	0.69	0.88	0.72
The allocated flexible land (ha)	0.19	0.76	0.14	0.66	0.19	0.76	0.23	0.85
The allocated wasteland (ha)	0.02	0.12	0.01	0.07	0.02	0.12	0.03	0.15

Source: Authors' estimation using the CCAP farm survey data.

Commission 2004, 2009, 2014). The increasing within-farm variations of farm size, maize yield, and input mix affected the farm size–productivity relationship for maize production in Northeast and North China, making it different from what we observed before 2003—when average cropping land area declined over time. This provides a good opportunity to re-investigate the farm size–productivity relationship using the farm fixed-effect model to split the within-farm effects from the between-farm effects.

Other variables to be controlled in the model include the share of land irrigated, the number of plots, the share of high-quality land, the share of land for maize production, total household labor, off-farm labor use, machinery used in major activities (e.g., plowing and harvesting), share of custom services, and so on.[12] The descriptive statistics for all variables are presented in table 1.

[12] Please refer to the online supplementary appendix A for a detailed definition of all variables.

Empirical Results

The Apparent Relationship between Maize Yield and Farm Size

What is the relationship between farm size and productivity for maize production in Northern China? To answer this question, we first pool all the observations for 2003, 2008, and 2013 and scatter maize yield against farm size (or the maize cropping area). As shown in figure 2, maize yield at the farm level appears to increase with cropping area initially. However, as cropping areas further increase, maize yield at the farm level declines, particularly when cropping area is more than around 3.0 hectares. The pattern of changing maize yield along with the enlarged cropping areas is stable, even if we split our sample by year and region. This seems to imply that there is an inverse U-shaped relationship between land productivity and farm size for maize production in Northern China.

Our finding of this apparent inverse U-shaped relationship between crop yield and farm size for maize producers in Northern China deserves some further discussion as it

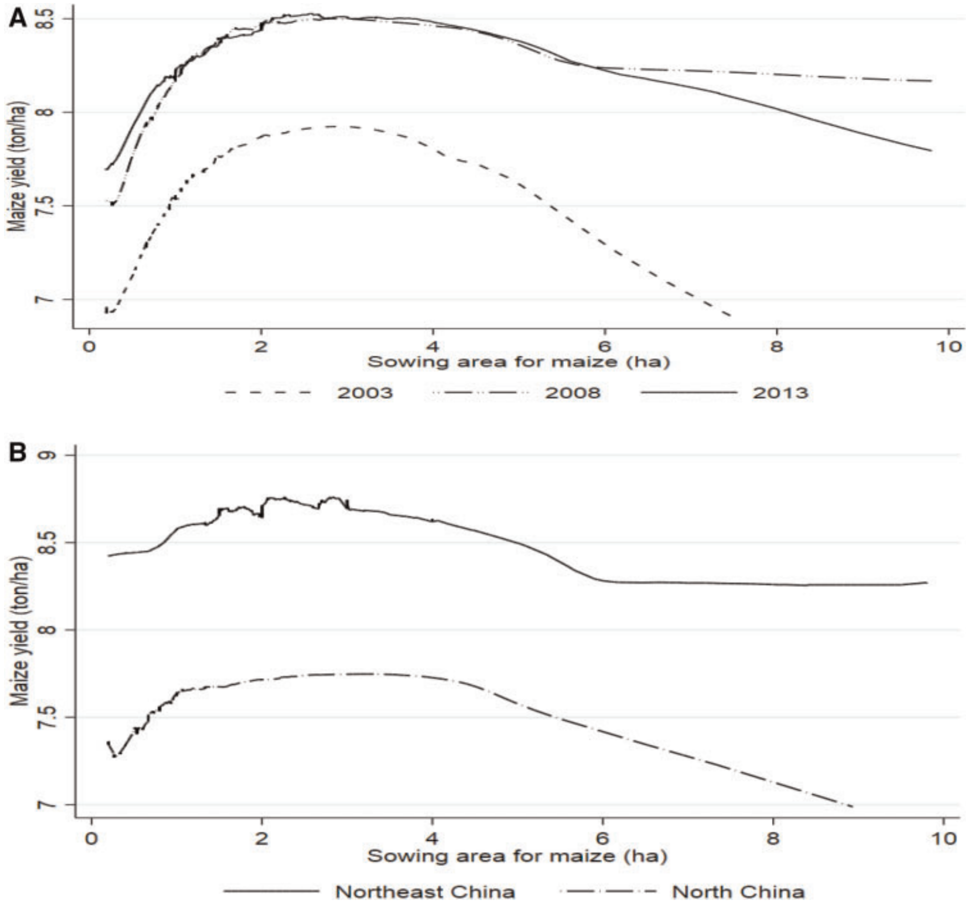

Figure 2. The apparent relationship between maize yield and cropping area: 2003, 2008, and 2013

Note: Estimates are made using the LOWESS regression. Panel (A) comparison by year; Panel (B) comparison by region.

is quite different from the experience of other Asian and African developing countries—where crop yield usually declines with farm size (Otsuka, Liu, and Yamauchi 2016).[13] On one hand, the phenomenon suggests that small maize farms will increase land productivity by enlarging the operational scale in China. As regulations for land rental are gradually relaxed, the rise in average farm operational scale for maize production in recent years, particularly the rapid growth of medium- and large-scale farms, has provided additional supportive evidence (Huang and Ding 2016). On the other hand, this phenomenon also suggests that farm size in China does not follow "bigger is better" under the current production arrangement. In particular, when farm size increases above a certain scale (i.e., around 3–4 hectares), land productivity (or crop yield) starts to decline—though, the trend has flattened in Northeast China in recent years.

Although the inverse U-shaped interpretations sound reasonable, they are based on descriptive statistics. The farm fixed effects and potential endogeneity problem could ruin the observed farm size–productivity correlation. In addition, as ongoing institutional reforms gradually relax the land rental market from 2003, land consolidation accelerates, particularly for maize producers in Northeast and North China. In 2013, the average farm size in Northeast and North China had doubled (88% increase) compared to 2003, and the average farm size had reached 1.73 hectares. As in figure 3, the share of farms with more

[13] An initial decline in maize yield along with farm size (when farm size is less than 0.2 ha) is partly due to outliers, as they only accounts for less than 5% of samples.

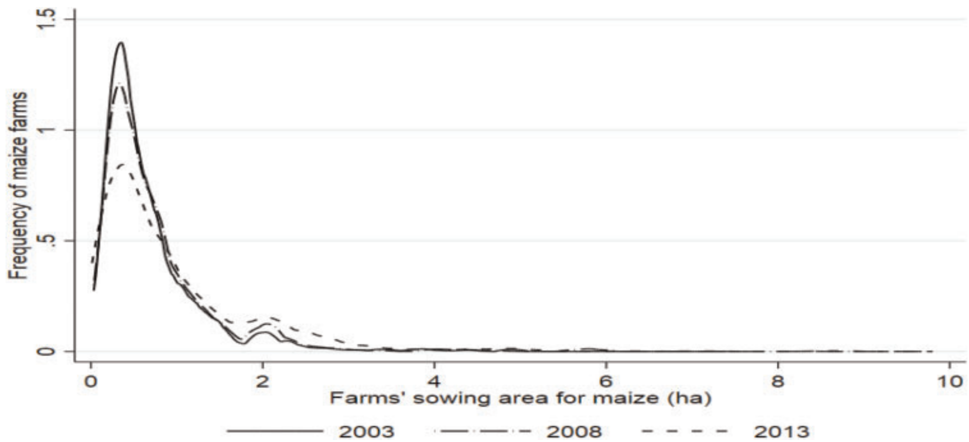

Figure 3. Distribution of size of maize farm in Northeast and North China: 2003, 2008, and 2013

Source: Authors' estimation using the CCAP farm survey data.

Table 2. The Results of the Farm Size–Productivity Relationship Based on GLS and Farm Fixed Effect Models

	GLS	FE	FEIV
Dependent variable: Maize yield (ton/ha)			
Maize cropping area (ha)	0.642**	−0.391**	−2.143***
	(0.241)	(0.170)	(0.814)
Maize cropping area square	−0.083**	0.051**	0.568**
	(0.036)	(0.022)	(0.235)
Constant	6.796***	6.425***	7.458***
	(0.247)	(0.216)	(0.537)
Centered R-squared	0.073	0.698	0.564
First-stage F test of excluded IV			
Maize cropping area	–	–	312.63
Maize cropping area square	–	–	45.43

Note: Robust standard errors appear in parentheses; asterisks *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively. Time dummies for 2008 and 2013 are included in regressions but not reported. The total number of observations is 1,618, which covers 574 farms. Results from the first-stage regression for the FEIV regression are reported in the online supplementary appendix D.

than 3.0 hectares had increased to 8.8% of the total Northern China maize farms. Yet it is still not known whether the inverse U-shaped relationship between land productivity and farm size will completely explain within-farm size change and its impact on farm productivity over time. Thus, a more thorough regression analysis is required to further explore the farm size–productivity relationship.

The Non-Linear Farm Size–Productivity Relationship and Farm Fixed Effects

Based on equation (3), we first examine the causal relationship between maize yield and cropping area using the farm fixed-effects model (or the panel data regression with fixed effects; FE) and the FEIV model (FE with instrumental variables to deal with the potential endogeneity problem). These estimation results are compared to those obtained from the general least square (GLS) regression and all results are presented in table 2.

As shown in table 2, the inverse U-shaped relationship between maize yield and farm size are overturned. In other words, the farm size–productivity relationship shifts from the inverse U-shaped curve under GLS model to a mild U-shaped one when the farm fixed effects are well accounted for. This finding is consistent with the estimation result obtained from the FEIV regression (column 3, table 2).

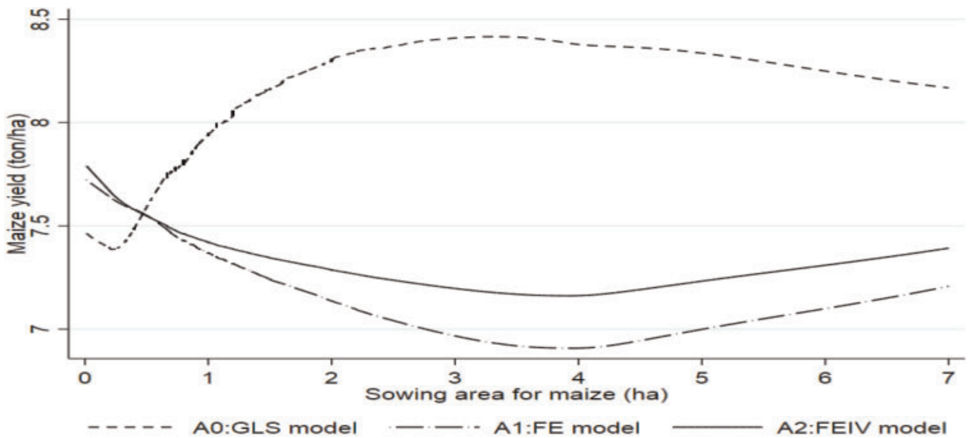

Figure 4. The projected farm size–productivity relationship for farms holding less than 7 hectares

Source: Authors' estimation using the CCAP farm survey data.

Although land consolidation gradually accelerated in China between 2003 and 2013, particularly for Northeast and North China, more than 99% of maize farms still hold land area less of than 5 hectares. In 2003, 2008, and 2013, around 95% of maize farms held land areas less than 2.0 hectares, 2.1 hectares, and 2.7 hectares, respectively. Further, around 99% of maize farms held land areas less than 3.4 hectares, 4.0 hectares, and 4.7 hectares, respectively (figure 3). Considering the possibility of representation issues in our sample, we drop off the projected trajectory on the farm size–productivity relationship for maize farms holding more than seven hectares.

Using the estimated coefficients in table 2, we draw the relationship between farm size and yield. As is shown in figure 4, an inverse U-shaped relationship between maize yield and cropping area is restored when farm-specific characteristics (or farm fixed effects) are controlled for. This implies that the initial positive farm size–productivity relationship for small farms (shown in descriptive statistics) might come from time-invariant farm-specific characteristics. In the literature, Benjamin and Brandt (2002) and Chen, Huffman, and Rozelle (2005, 2011) attributed such farm fixed effects to differences in soil quality between farms of different size and rigid institutional arrangements in land market.[14]

However, land market rigidity probably could not explain the farm size–productivity relationship after the 2000s, as was done for the 1990s in Benjamin and Brandt (2002) and Chen, Huffman, and Rozelle (2005, 2011). As land transaction service centers were established throughout the country after 2003, farmers were more able to transfer agricultural land through the land rental market. Thus, it is hard to understand why a more competitive land market is likely to reallocate land to farms of relatively larger size and with relatively lower land productivity. Moreover, this finding seems inconsistent with the prediction of Adamopoulos et al. (2017), which indicated that the land market reform in the 2000s helped to correct resource misallocation and significantly improve farm productivity through enlarging the average operational scale.

Farm Choice of Labor and Capital and the Farm Size–productivity Relationship

Farm technology adoption and input choice between labor and capital, if correlated to farm size, will affect the farm size–productivity relationship. This provides an alternative mechanism through which the change in the farm size–productivity relationship could be explained. To test this hypothesis, we incorporate farm input choice of labor and capital into the regressions, while controlling for soil quality and some farm management practices. To account for differences in quality of labor and capital usage, the components of

[14] In the online supplementary appendix C we also examine the impact of self-reported soil quality, share of irrigated area, and some farm management practices on the farm size–productivity relationship.

Table 3. The Estimation Results on Farm Labor and Capital Choice and the Size–Productivity Relationship

	Control L FE	Control L FEIV	Control K FE	Control K FEIV	Control KL FE	Control KL FEIV
Dependent variable: Maize yield (tons/ha)						
Maize cropping area (ha)	−0.662***	−2.532**	−0.733***	−2.156**	−0.678***	−2.603**
	(0.200)	(1.171)	(0.211)	(0.852)	(0.188)	(1.177)
Maize cropping area square	0.072***	0.614**	0.084***	0.547**	0.075***	0.616*
	(0.023)	(0.308)	(0.027)	(0.249)	(0.022)	(0.324)
Number of plot (num. per farm)	0.139**	−0.004	0.155***	0.049	0.147**	0.022
	(0.056)	(0.162)	(0.049)	(0.130)	(0.058)	(0.152)
Share of land for maize	−0.010	−0.038**	−0.010	−0.030***	−0.010	−0.037**
production (%)	(0.007)	(0.018)	(0.007)	(0.011)	(0.007)	(0.015)
Labor use intensity (person/ha)	0.007	0.057	–	–	0.008	0.057
	(0.018)	(0.045)	–	–	(0.017)	(0.043)
Share of family helpers (%)	0.011***	0.010***	–	–	0.011***	0.010***
	(0.003)	(0.003)	–	–	(0.003)	(0.003)
Share of part-time labor (%)	−0.007	−0.004*	–	–	−0.006	−0.004*
	(0.004)	(0.003)	–	–	(0.004)	(0.003)
Plough/harvest machinery	–	–	0.051	0.226*	0.063	0.300*
use intensity (unit/ha)	–	–	(0.187)	(0.169)	(0.171)	(0.157)
Share of no-tillage (%)	–	–	0.011***	0.013***	0.011***	0.012***
	–	–	(0.004)	(0.003)	(0.004)	(0.003)
Share of custom services (%)	–	–	−0.001	−0.001	0.000	0.002
	–	–	(0.003)	(0.003)	(0.003)	(0.003)
Constant	9.680	14.598	6.816***	7.981***	9.321	14.506
	(7.622)	(8.635)	(0.865)	(0.969)	(7.836)	(8.651)
R-squared	0.709	0.574	0.704	0.591	0.711	0.581
First-stage F statistics of excluded IV						
Maize cropping area	–	65.10	–	82.11		44.45
Maize cropping area square	–	15.15	–	11.96		14.42

Note: Robust standard errors appear in parentheses; asterisks *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively. The total number of observations is 1,618, which covers 574 farms. Other controlled variables also include the following: share of high quality land; share of land irrigated; age of household head; labor use intensity square; share of off-farm labor; share of animal plough; share of machinery plough; and farm income and year dummies for 2008 and 2013, but for simplicity their results are not reported. The Wald tests for the null hypothesis of joint insignificance of "labor," "capital", and "labor + capital" are rejected at the 1% level. The first-stage regression results for the FEIV regressions are reported in the online supplementary appendix D.

labor (such as age of household head, share of family helpers and part-time labor, etc.) and capital (such as dummy for ploughing machine, share of custom services, etc.) are also considered.[15] The estimation results for the most important independent variables are presented in table 3. Although not all variables representing labor and capital use intensities are significant, the Wald tests show that the labor and capital use intensities are jointly significant in the corresponding regressions.

Comparing the results obtained from the regressions, which control for the labor and capital use intensities in the baseline model, we show that farm input choice plays an important role in explaining the changed farm size–productivity relationship. Figure 5 shows that the restored farm size–productivity relationship becomes substantially more negative, with control of labor and capital use intensities (and their respective quality) and their combination. The Kolmogorov-Smirnov test statistics are 0.279, 0.286, and 0.140, respectively, with all rejecting the null hypothesis that the two distributions are same at 1% level. This suggests that the predicted farm

[15] Since there is no single variable that could capture the role of labor and capital usage in affecting the farm size–productivity relationship, we have to use two groups of variables in the regressions while acknowledging that the potential correlation between those variables in each ground could affect the reliability of the estimated coefficient for individual variable.

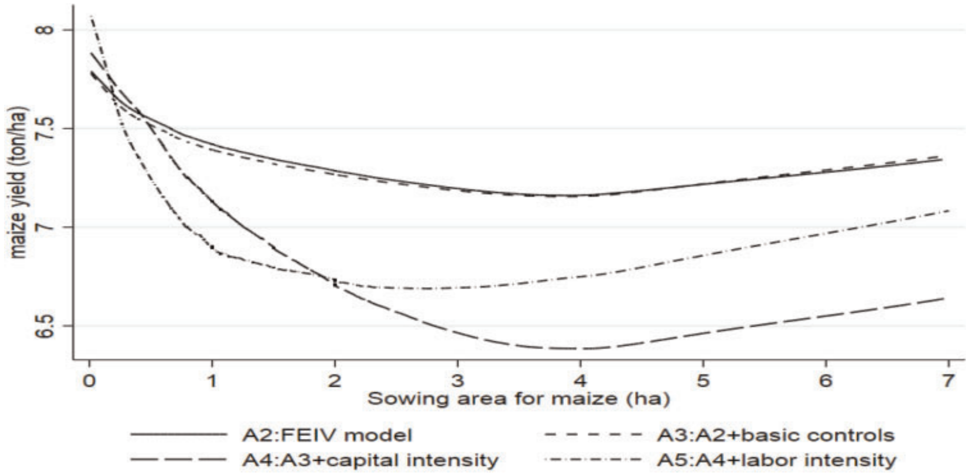

Figure 5. Impact of farm labor and capital choice on the size–productivity relationship

Source: Authors' estimation using the CCAP farm survey data.

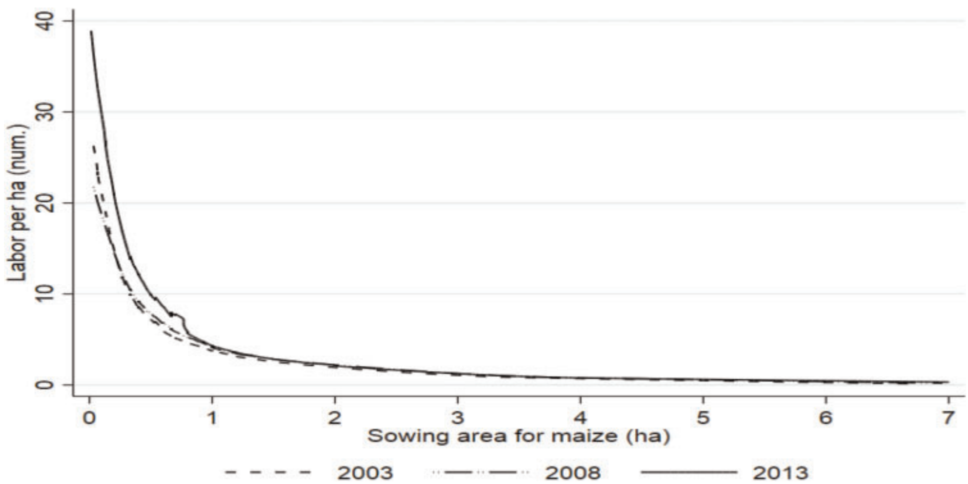

Figure 6. Correlation between labor use intensity and farm size

Source: Authors' estimation using the CCAP farm survey data.

size–productivity relationships (with control of labor and capital use intensities) are significantly different from those with control for basic variables. The implication is that as farm size increases, input choice is likely to change in order to compensate the loss in marginal product of land or land productivity due to enlarged operational scale.

Moreover, farm input choices between labor and capital affect the size–productivity relationship differently for farms of different size. In particular, small farms are more likely to increase their labor input to offset the declining maize yield when enlarging their land scale, while large farms are more likely to increase their capital input. To explain this phenomenon, we further present the correlation between farm labor input and land size, and the correlation between farm capital input (denoted by average power of self-owned machinery) and land size.

As shown in figures 6 and 7, farms that operate at a scale less than 1 hectare can usually increase labor input as they enlarge the operational scale through recalling back services from their off-farm family members or increasing their own on-farm work to full-time. This is a reasonable phenomenon because

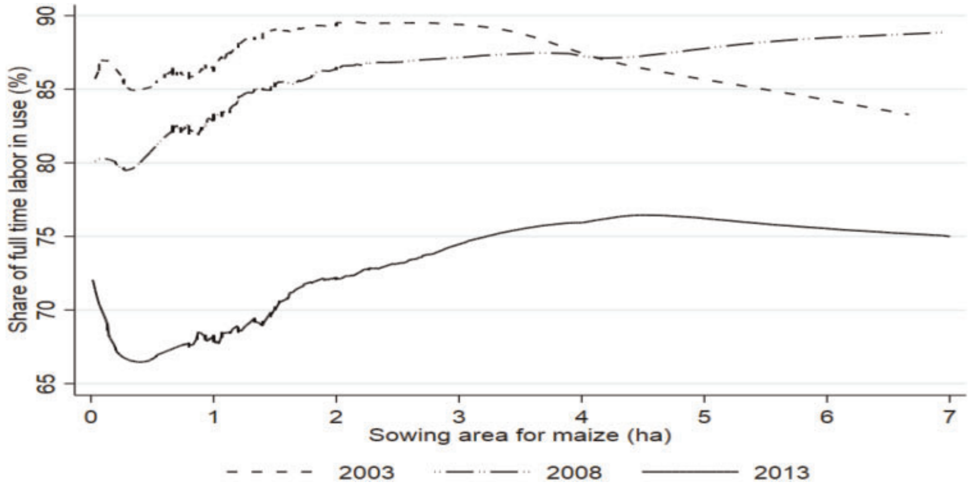

Figure 7. Share of full time labor in total labor use for maize production

Source: Authors' estimation using the CCAP farm survey data.

Figure 8. The share of hired labor and supervision costs along farm size

Source: Authors' estimation by using the CCAP farm survey data.

very small farms in China usually treat their on-farm work as a secondary source of income. However, as they decide to enlarge the operational scale by renting land, the farming business activities become more serious and they will reduce off-farm employment. Reflected in our regression results, the coefficients of part-time labor (for agriculture) are negative and significant, while that of family member is positive and significant (as is shown in table 3). Also, figure 7 shows that the share of full-time labor in agricultural production increases with farm size under 3–4 hectares. The increased family labor supply thus helps compensate the loss in marginal return to land or land productivity, and thus enables farms to make profits from enlarging their operational scale.

However, as farm size further increases, family labor is unlikely to be sufficient to support the expansion of agricultural production. Instead, hired labor is introduced into farm production. As shown in figure 8, the proportion of hired labor in farms operating between 1–6 hectares significantly increased, from approximately 10% to 30%. When more hired labor is used for agricultural production, the supervision costs gradually catch up. As the supervision costs grow at the same speed as hired labor, further increasing labor input may not increase yield.

From then on, if farms continue to enlarge their operational scale, they need to use machinery to substitute labor so as to compensate for the declined marginal land productivity due to enlarged operational scale. Above a certain operational scale, farms are more likely to adopt capital-intensive technology and, in this sense, capital input plays a more important role than labor input in affecting the farm size–productivity relationship. As shown in table 3, the significant level for the estimated coefficients of the farm size square term when both labor and capital inputs are controlled for. This suggests that the non-linear farm size–productivity relationship tends to disappear as capital input is well controlled for.[16]

Conclusions

Understanding the farm size–productivity relationship and its determinants in developing countries continues to be of interest to policy makers seeking to resolve the small-sized farm issue. This paper investigates the farm size–productivity relationship for maize production in Northern China by using a farm-level panel data covering six provinces in 2003, 2008, and 2013. In addition, we also examine the roles that different components of farm-specific fixed effects—including unobserved farm characters, farming practice, and farm input choice between labor and capital—play in affecting the farm size–productivity relationship.

We show that a mild U-shape relationship between maize yield and cropping area is restored from an inverse U-shape curve when the farm fixed effects are properly accounted for. In addition to differences in some farming practices, farm input choice between labor and capital may have played a more important role in contributing to the changed farm size–productivity relationship. Labor use plays a more important role in explaining the changed farm size–productivity relationship at the small scale, while capital use plays a more important role in explaining the changed farm size–productivity relationship at the large scale. Regarding the restored negative relationship between farm size and productivity for a majority of small-sized farms, our explanation refers to their sticking to using the labor-intensive technology. As farms enlarge their operational scale, the constrained labor supply is unable to compensate for the loss in land productivity.

Since 2004, a series of public policies have been implemented to subsidize large farms, which in turn results in land consolidation towards less efficient large farmers (Huang and Ding 2016). Our study suggests that rapid land consolidation is partly driven by the current land market reform, and the policy of subsidizing farms to rent land will result in resource misallocation between household farms towards the inefficient large farms. Instead, reducing market frictions and institutional barriers in labor and capital markets (rather than subsidizing large farms) will assist larger farms to substitute labor with capital, and thus become a better way to facilitate land consolidation.

Supplementary Material

Supplementary material are available at *American Journal of Agricultural Economics* online.

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[16] Note that our analysis could not provide many useful insights on maize farms above seven hectares due to a limited sample size for large farms and limited representativeness in our survey. Whether farm input choice between labor and capital may turn the inverse farm size–productivity relationship to positive for farms above seven hectares requires further empirical testing and better data collection.

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