INVERSE RELATIONSHIP BETWEEN PRODUCTIVITY AND FARM SIZE: THE CASE OF CHINA

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In developing agricultures, past research has suggested an inverse relationship between farm productivity and size. The raw data from China show such an inverse relationship. However, the inverse relationship disappears after we instrument for land area using the fact that one of the objectives of the land allocation process in rural China is to ensure local households to meet their nutritional needs. The empirical inverse relationship is likely due to the failure to account for the unobserved land quality that is unevenly distributed across the farm size continuum, rather than inherent to China's agriculture. (*JEL* O13, Q12, Q15)

I. INTRODUCTION

In the development literature, it is alleged that farm size (e.g., land area) and productivity (e.g., total farm output divided by land area) are inversely related in developing countries (Sen 1962).[1] Although Chayanov (1926) is credited with being the first to suggest this relationship for prewar Russian agriculture, Sen (1962) is considered the earliest modern reference on the subject. If the inverse relationship does exist, then policies such as "small but efficient" come into play, and land redistribution to break up large farms may be proposed. The Kerala Land Reforms Act of 1963 imposes a ceiling of 15 acres for land owned by individuals and joint farming families in the Indian state of Kerala.

In China's agriculture, results from investigating the relationship between farm productivity and farm size are of interest to policy makers. Many Chinese farms are tiny and their small size limits mechanization. A rapidly growing Chinese nonfarm economy has attracted large numbers of rural labor into the major cities, which has provided opportunities for land consolidation in rural areas to reduce fragmentation and to increase farm size through land rental markets (Deininger and Jin 2005). If, indeed, small farms are more efficient than their larger counterparts, efforts to promote consolidation should not be pursued.[2] A recent resolution of the Central Committee of the Communist Party

*The authors thank participants at the American Agricultural Economics Association 2005 Annual Conference in Providence, RI for helpful comments. The authors also wish to thank Drs. Jinyong Hahn and Jerry Hausman for sharing their codes of the Hahn-Hausman (2002) test and Dr. Robin Burgess for sharing his working papers. Comments from Drs. Xiao-Yuan Dong and Dennis Tao Yang are greatly appreciated. The views expressed in this paper represent those of the authors. No official support or endorsement by their employers or funding agencies is intended, nor should be inferred.

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1. Note that, Benjamin (1995) uses an alternative specification by regressing output on farm size and suggests that an inverse relationship exists if the coefficient estimate of farm size is less than 1. The two specifications generally produce consistent inference, but the Benjamin specification can better address the issue of measurement error in farm size than the other because farm size does not appear in the left-hand side.

2. Note that the relation between farm size and productivity should be distinguished from the study of technical efficiency, which is the engineering efficiency in the production process (Berry and Cline 1979). The efficiency in the "small but efficient" refers to the overall land utilization of the available land resource.

ABBREVIATIONS

HRS: Household Responsibility System
IV: Instrumental Variable
LRLC: Law on Rural Land Contract
OLS: Ordinary Least Square
RCRE: Research Center for Rural Economy

Contemporary Economic Policy (ISSN 1465-7287)
Vol. 29, No. 4, October 2011, 580–592
Online Early publication October 8, 2010
doi:10.1111/j.1465-7287.2010.00236.x

of China quelled speculations that land privatization, or other radical forms of land reform, was on the immediate agenda.[3] Meanwhile, the resolution asserted both the importance to exploit the scale economies of modern agricultural technologies and an increasing role of land rental markets, which are in line with recommendations made by Deininger and Binswanger (1999).

With the notable exceptions of Benjamin and Brandt (1997, 2002), few studies have examined the relationship between productivity and farm size in China's agriculture.[4] Since the implementation of the Household Responsibility System (HRS) during 1978–1984, most arable land in rural China is owned collectively by rural communities and distributed by village councils to local families for farming (Dong 1996). Following the initiative in the 1982 Chinese Constitution, the Agriculture Law, approved in 1993 and amended in 2002, stresses collective ownership by rural communities over rural land and the allocation of rights of use to land area to rural households.

The objective of this article is to examine the empirical relationship between farm productivity and farm size in China's agriculture over 1995–1999 when farmers were gaining better access to modern farming technologies and equipment. We conclude that the inverse relationship between farm productivity and farm size can be attributed to measurement error arising from improper measurement of farmland, for example, failure to account for land quality.

This article contributes to the literature in the following areas. First, although China's land tenure system is unique, it is not uncommon to observe similar collectively held land ownership in developing or transition countries, for example, in Vietnam (Deininger and Jin 2008), Central Europe (Rozelle and Swinnen 2004), and in certain countries in Africa (Deininger and Feder 2001). Hence, conclusions from this study may provide useful insights to land policy and land reforms in other economies. Second, we exploit the fact that an objective of rural village councils is to ensure local families to meet basic nutritional needs (Burgess 2007; Deininger and Binswanger 1999) and the variation in the number of dependents and *hukou* registration in rural households (note that it is possible for a rural household to have members with urban *hukou* registration) to motivate an instrumental variable estimation. Although our use of instrumental variable estimation is similar to that in Benjamin (1995), the mechanism we hypothesized is new to the literature. Third, using new econometric techniques (Hahn and Hausman 2002), we explicitly address the weak instrument problem that has been raised in the literature (Heltberg 1998). Fourth, we use a household-level data set that allows us to avoid the "ecological fallacy" that arises when aggregate data are used (Heltberg 1998).

II. THE RELATIONSHIP BETWEEN FARM PRODUCTIVITY AND SIZE

A. *Existing Theories and Empirical Evidence*

A number of theories and explanations for the inverse relationship between farm size and productivity exist. First, labor market imperfections are a potential source. For example, Sen (1962) attributed the inverse relationship to labor dualism, in which large and small farms are assumed to have the same technology, but small-scale farmers have lower opportunity costs of their labor than operators of large farms. Deininger and Feder (2001) suggest that a farm using only family labor is more efficient because it is free of principal-agent problems, that is, family members have a long-run interest in the success of the farm. When a farm is small and labor markets are not functioning, small-scale farms use only family labor and do not hire labor or sell labor in the nonfarm labor market (Taylor and Adelman 2003). In an economy with private land ownership, family members have a strong incentive to work, because they share the farm output directly, and in the long run, they might expect to inherit the farm. Second, Barrett (1996) argues that the combined effects of nondegenerative land distribution and price risk could produce an inverse relationship. Third, Assuncao and Ghatak (2003) present a theoretical model showing that endogenous occupational choice and heterogeneity in farming skills, coupled with credit market imperfections, can explain

3. The 17th Session of the Central Committee, the Communist Party of China. Resolutions on advancing rural reform and development and other major issues (Zhonggong zhongyang guanyu tuijin nongcun gaige fazhan ruogan zhongdawenti de jueding). Approved on October 12, 2008, at the third plenary meeting. http://www.most.gov.cn/yw/200810/P020081021325175156415.doc. Accessed on February 27, 2009.

4. Burgess (1997) appeared to have addressed the inverse productivity issue using data from two provinces of China as cited in other studies. We, however, were not able to acquire the manuscript and the later versions (Burgess 2001, 2007) seemed to have dropped the analysis.

the inverse relationship when there is a constant return to scale and no labor market imperfection.

Fourth, Benjamin and Brandt (2002) attribute the inverse relationship between farm productivity and size in China's agriculture to local administrative land distribution policies and uneven off-farm work opportunities.[5] Fifth, measurement error in land input due to heterogeneous land could also explain an inverse relationship. For example, Benjamin and Brandt (2002) and Lamb (2003) investigate the role of measurement error in labor and land, respectively, and show how it creates the observed relationship. Deolalikar (1981), Bhalla and Roy (1988), and Benjamin (1995) suggest that unobserved land quality is positively related to farm productivity but inversely related to farm size. Lamb (2003) confirms that inclusion of land quality adjustments largely explains the inverse relationship between farm size and profit. However, Heltberg (1998) claims that Bhalla and Roy's conclusions are undermined by their use of district aggregate data rather than household-level data, but Carter (1984) finds a significant within-village inverse relationship between farm size and productivity using farm level data for Haryana, India. Finally, Heltberg (1998) cautions researchers against the weak instrument problem that may have undermined some previous instrumental variable estimation.

B. Land Allocation in China and Instruments for Land

We propose that heterogeneity in land quality introduced by the local village council's allocation process contributes to the observed inverse relationship between farm size and productivity. The argument is similar to that by Benjamin (1995), albeit via a different mechanism. Benjamin (1995) suggests that in rural Java, "[I]f farms were subdivided through inheritance over time, egalitarian motives on the part of the benefactor would result in higher quality parcels being divided more often than low quality parcels," which would impart a negative correlation between farm size and land quality, particularly at the local or village level. In contrast, the correlation between farm size and land quality in China is a result (at least in the past) of a proactive land allocation process instead of a natural process of inheritance.

5. Note that the villages in northeast China appear to be in the same counties as villages studied by Benjamin and Brandt (1997).

Under the HRS, the majority of arable land in rural China is owned by rural communities and managed by a local village council (Burgess 2007). The politics in rural China are characterized by a mixture of an authoritarian command system and grass-roots democracy, which has established the legality of egalitarian principles during land distribution and ensures its implementation. The Law on Rural Land Contract (LRLC), which was approved in August 2002, and went into effect in March 2003, stipulates that equity is a prime objective during land allocations (the 9th Standing Committee 2002). However, at the same time, the legislation also states that no land reallocation is allowed before the contract expires, and it is illegal for local village councils to void HRS contracts. Therefore, if during the contract period demographic or employment factors change, it is possible that the egalitarian allocations of land could be compromised. Any late changes need to be ratified by at least two-thirds of a village council (Article 48 of the LRLC). Although LRLC became effective after the study period, it reflects prevailing practices (and changes in prevailing practices) of land allocation in rural China during the study period.

Land allocation in rural China had been a two-step process (Chen and Brown 2001; Dong 1996) during the study period. First, each rural household receives "subsistence" land—enough land to guarantee the basic food and nutritional needs of its members, and second, any remaining land is to be rented out to willing rural households. A member of a household, usually the household head, presents to the council his or her household's needs, and there may be negotiations. Major quality differences in the local land are due to the amount of water and potential for irrigation as well as the general soil quality. Those dimensions of land plots are considered during the land allocation process.

Burgess (2007), using household-level data for the two distinct provinces of Jiangsu and Sichuan, could not reject the hypothesis of universal and egalitarian access to land and allocations satisfying nutritional needs of rural households. With equity being one of the primary objectives during the land allocation, it is likely that average land quality and farm size are, indeed, negatively correlated. Although land allocation arrangements across geographic regions have been somewhat heterogeneous in recent years, the egalitarian motives have generally persisted to serve equity purposes and as a practical social safety net. Hence, in rural China, a negative relationship seems likely to exist between land area and land quality.

III. DATA AND THE ECONOMETRIC MODEL

In this section, we describe the data sets, the variables of interest, and the econometric model. The Research Center for Rural Economy (RCRE), Ministry of Agriculture, China, conducted the survey used in this study.

A. Description of the Data Set and Main Variables

The data are taken from a large comprehensive survey of Chinese rural households, which started in 1986, covered 29 provinces, and included about 20,000 households. Sample attrition has been low, which is considered as a major advantage of the data set (Chen 2003). However, the survey was temporarily discontinued in 1992 and 1994 for financial reasons. The data set for this study consists of 591 randomly selected (and then made available to the authors) farm households from 29 villages and 9 provinces. The nine provinces are Hebei, Shanxi, Heilongjiang, Liaoning, Anhui, Jiangsu, Shandong, Sichuan, and Yunnan. Data are pooled from 1995 to 1999.

Sampling for the original data set was conducted by provincial offices under the Ministry of Agriculture (see details in Benjamin, Brandt, and Giles 2005). Each provincial office first selected equal numbers of upper, middle, and lower income counties, then chose a representative village in each county. In total, 40–120 households were randomly surveyed within each village. Village officers and accountants completed a survey form on general village characteristics every year. RCRE claimed that 80% of the households that enrolled in 1986 remained in 1999. Although the original RCRE survey does not have an explicit panel structure, an earlier study by Chen (2003) identified the panel structure by matching household characteristics. More information is available from the RCRE Web site.[6]

The panel of farms and farm households is unbalanced because not all households responded to the survey every year. We deleted a small number of observations (a negligible fraction of the sample) because of obvious data recording errors and missing information. After such adjustments, we still have a total of 2,693 valid observations (years and farm households).

Total farm output is the total quantity of all grain output produced in a reporting year (e.g., Lin and Wen 1995; Kimhi 2006). Specifically, total farm crop output is the summation by the quantity (weight) of production of rice, sorghum, wheat, and corn. Because we are concerned with productivity and not just average yield of a specific crop, we do not consider each crop output and area sown separately. We also refrain from using the aggregated sales of grain to avoid introducing noise due to inventory changes.

Farmland is measured as total cultivated area for grain crops measured at year end. Similar measures have been used extensively in the literature, see, for example, Fan and Zhang (2002) and Fan (1997), among others.

Table 1 provides summary statistics for variables used in the econometric analysis. Average annual grain output per household is 3,176 kg. Average farm size is about 9.9 Mu (1 Mu = 1/15 hectare), so average farm productivity is 320 kg/Mu. The average number of plots cultivated is six. A typical family has one or two dependents, one male rural laborer, and one female rural laborer. Most household heads are between ages 30 and 60. The most common-level education completed is less than 12 years. About 4% of the households have a dependent who has an urban *hukou* registration.

B. Control Variables in the Productivity Equation

Besides land area cultivated, other explanatory variables included in the productivity equation are the numbers of female and male laborers in the household, household head's age (proxy for farming experience), and education of the individual in the household who has completed the most schooling (proxy for managerial ability, e.g., Huffman 1974; Yang 1997a, 1997b). Total number of plots cultivated is also included as an explanatory variable to control for land fragmentation (Fleisher and Liu 1992; Wan and Cheng 2001). This variable is also squared and included to permit nonlinear productivity effects of land fragmentation. Village fixed and random effects are used to capture location, climate, regional irrigation system, cropping mix, output and input price differences,

6. http://www.rcre.org.cn/RCRE/GDGC/gdgcposition.htm.

TABLE 1
Chinese Farm Household Data (RCRE): Summary Statistics

Variable	Mean	SD
Continuous variables		
Output (1000 kg)	3.176	3.628
Land (Mu)	9.914	8.785
Number of plots	5.847	4.603
Number of dependents	1.685	1.129
Male rural labor	1.351	0.681
Female rural labor	1.212	0.734
Binary variables (1 if true, 0 otherwise)		
Head's age: <31 (reference)	0.078	
Head's age: 31–40	0.323	
Head's age: 41–50	0.383	
Head's age: 51–60	0.170	
Head's age: >60	0.047	
Highest education: <9 years (reference)	0.320	
Highest education: 9–11 years	0.549	
Highest education: 12+ years	0.131	
Head's education: <5 years (reference)	0.082	
Head's education: 5–8 years	0.398	
Head's education: 9–11 years	0.407	
Head's education: 12+ years	0.112	
Presence of dependents with urban (*hukou*) registration	0.036	
Number of observations	2,693	

Note: Authors' tabulation from the Research Center for Rural Economy Survey 1995–1999.

and multiple cropping factors. Year fixed effects are included to capture year-specific effects, such as unusual weather conditions.

C. Farm Productivity and Farm Size

The econometric model of farm productivity is

$$\text{(1)} \qquad \ln y_i = \alpha + \gamma \ln l_i + X_i\beta + \eta_i$$

where y_i is total annual farm grain production by the ith farming household, l is a measure of farm land cultivated, X is a set of control variables, α, γ, and β are parameters to be estimated, and η is a zero mean random disturbance term. Ideally, we would like to have a measurement of farmland that is homogenous, but working with the existing data provides opportunities and challenges. If γ is equal to 1 in Equation (1), then a 1% increase in land area results in a 1% increase in total grain output. If γ is less (greater) than 1, then a 1% increase in land area will result in a less (more) than 1% increase in farm output or a decline (increase) in farm productivity.

To accommodate the panel nature of the data set, Equation (1) is modified to become

$$\text{(2)} \qquad \ln y_{it} = \alpha + \gamma \ln l_{it} + X_{it}\beta + \xi_i + \eta_{it}$$

where t is the index of time, y, l, X, β, γ, and η are defined as before, and ξ is a farm- or household-specific effect that captures possible heterogeneity at the farm/household level. It can be modeled as either random or fixed effects, depending upon the assumption of the correlation between ξ and covariates (Wooldridge 2002).

In the fixed-effects specification of Equation (2), the individual fixed effects (ξ_i) might be correlated with farm size (i.e., the between effects), and then γ reflects only the partial effect (within effects) of farm area. Therefore, the total change in grain output can be decomposed as the sum of changes due to γ and to changes in fixed effects. Note that in the fixed-effects specification, γ no longer represents the full effect of log land area on log output but is the within effects identified through changes in land area among households. The issue with using the fixed effects in our context is that they could lead to overparameterization and poor out-of-sample prediction. Alternatively, under random effects, $\xi_i \sim N(0, \sigma_\xi^2)$, we need ξ_i to be uncorrelated with the regressors, including the farm size. Lamb (2003) suggested that the random-effects model is a better representation.[7] Nonetheless, we provide estimates of both random- and fixed-effects models to examine the robustness of our results. With 5 years of data and year fixed effects, autocorrelation in the data can be ignored, which was confirmed by hypothesis testing including two versions of

7. Hausman test in this case prefers the fixed-effects model, which was not surprising given that we have a large number of household effects. We have not relied on a Hausman test in this case for three reasons. First, a significant Hausman statistic usually suggests a tension between the "within" and "between" estimation approaches. Fixed-effects model estimates only the *within* variation, while lumping the *between* variation into the fixed effects, which is critical in our case. The second reason, which relates to the first point, is that the "exchangeability" test would suggest a random-effects model (Nerlove 2007). Lastly, it is also well known that Hausman tests tend to favor fixed-effects model due to their large number of estimation parameters. The large number of parameters introduce overfitting and pose difficulty for prediction or extrapolation of the sample. More on the pros and cons of fixed- and random-effects models can be found in the study by Hsiao (2007). We estimate both models to examine the robustness of the results.

Durbin-Watson test, that is, the Bhargava et al. (1982) test and Baltagi-Wu (1999) LBI test.

D. Identification Strategy

Equation (2) may be viewed as the "true model" of the relationship between total farm output and farm size. However, what we observe is a measure of cultivated area that is of heterogeneous quality, which creates potential measurement error problems when the measurement error is correlated with one or more regressors. One solution is to instrument farm size (Benjamin 1995). Valid instruments should be correlated with farm size (cultivated area) but not with the disturbance term in the productivity equation (Greene 2005).

The institutional structure of the farm land allocation process by rural village councils suggests that a correlation exists between a rural household's land area and nutritional needs (Burgess 2007). Furthermore, the number of household dependents is strongly correlated with total nutritional needs of the household (Burgess 2007), and there is no reason to believe that the number of dependents in a household is related to farm productivity.[8] In addition, the residence *hukou* registration system in China classifies residents into two types: urban and rural. Rural residents are entitled to receive farmlands but urban residents are not. In the data set, about 3.6% of the rural households have at least one dependent who has urban *hukou* registration. However, we are unable to determine whether these dependents also have an entitlement to farmland in the rural community. Many college students from rural areas are registered as an urban resident but continue to receive land from their rural home communities.

We argue that the total number of dependents in the household and the presence of a dependent with urban *hukou* registration are valid instruments for farmland area. The variation in the number of dependents and *hukou* registration serves as a "natural experiment" that can be used to identify the true relationship between farm size and productivity (Angrist and Krueger 2001, 73). The number of dependents relates largely to the number of children and of elderly dependents. Fertility decisions were made based on how strictly family planning policies were enforced and the gender of the first born, among other factors.[9] The number of elderly dependents is determined by mortality shocks. There is no reason to believe that mortality shock and the factors related to fertility decisions would be related to current shocks in farm productivity. The number of dependents relates to the effective land that is allocated to a household to meet the household's nutritional needs (Burgess 2007) but does not directly relate to the agricultural productivity shocks. A similar strategy was used by Benjamin (1995).

The presence of a household member with urban *hukou* registration derives from two types of events, being admitted to a college and being recruited for a position in state-owned enterprises or government agencies.[10] The variation associated with these events does not correlate to land quality, nor the grain production but does reduce the likelihood of receiving land from the home community. We, hence, use the number of dependents and a dummy variable indicating presence of a household member with urban *hukou* registration as the basic set of instruments for land. The quality of the instruments will also undergo a battery of statistical tests.

Note that the instruments are related to land areas, which is intended and desired. In examining the relationship between productivity and farm size, we would be interested to have a measurement of land area that is homogenous in terms of land quality. Essentially, the instruments are used to predict a homogenous measure of land area to be used in the main estimation equation. Arguments against using the instruments include that more dependents might push the household labors to work harder and that dependents may work on the farm to increase productivity. However, the main impact of the dependents on grain output (which is the variable of interest in this study) seems through the increased allocation of (quality adjusted) land. The increased living cost induced by more dependents might be covered through works on cash crops or off-farm activities. Nonetheless, the overidentification test in Section IV addresses the issue of the correlation between instruments and disturbance terms in the main estimation equation.

8. Dependents include both children and elders, who do not undertake farming activities due to physical limitations.

9. In rural China, the family planning policy allows a second child if the first born is female. Households of minority ethnicities (other than *Han*) may be exempted from the "one-child" policy.

10. Note that this refers to the case during the study period. The role of *hukou* registration is diminishing over time. Several administrative regions have attempted to abolish the *hukou* registration or limit its role.

E. Who Rules the Roost, and on What? Revisiting Roles of Household Head and Village Officers

We also attempted to examine an expanded set of instruments. China's agriculture has undergone many dramatic transitions and has its own unique features aside from the land allocation system. The role of education in agricultural production has been scrutinized intensively in the literature, see, for example, Huffman (2001) for a review of literature. For China's agriculture, in particular, Yang (1997a, 1997b) found that the highest level of education among all household members has a stronger correlation with agricultural output than household head's education or average years of schooling across household members. He hypothesized that collectivized decision making was used in agricultural household in rural China, and hence, the highest level of education matters most for production decisions. However, during meetings with the village council dealing with land requests, the household head normally represents his or her household. The exact amount and type of the land a household receives would thus depend on his or her negotiating skills as well as his or her access to and ability to process information. Thus, the household head's education seems likely to be more important in the land acquisition process than in determining farm productivity. The dummy variables indicating household head's education are included in the expanded set of instruments for farm size.

The role of a household having a member who is a village officer could affect access to farm inputs, for example, industrial inputs, and community productive capital (Brandt et al. 2002; Walder and Zhao 2006). However, with the dramatic development, expansion, and liberalization of industrial input markets, village councils have lost most of their control over industrial inputs to the market forces. Xu (1999) has attributed a large portion of farm productivity increase in the early 1990s to evolving industrial input markets. Rent seeking among village officers might continue to exist but shifted to off-farm economies (Chen and Rozelle 1999; Walder and Zhao 2006). However, under HRS, a household with a member holding a village officer position may be better informed about the quality of land plots being allocated and may also have better bargaining power or negotiating skills (Rozelle and Li 1998). Hence, membership on the village council is another potential instrument for effective farm size.

IV. RESULTS

A. Baseline Results

The baseline estimate of the productivity equation is reported in Table 2. Both random- and fixed-effects models of the output equation show that the estimate of γ is significantly less than 1. Hence, our results suggest an inverse relationship between farm size and grain output among Chinese farm households.

TABLE 2

Relationship between Output and Farm Size from the RCRE Data Set (Dependent Variable: Logarithm of Output Quantity; $N = 2{,}693$)

	Random Effects		Fixed Effects	
Land (logarithm)	0.841***	(0.014)	0.742***	(0.022)
Male rural labor	0.016*	(0.009)	0.026*	(0.015)
Female rural labor	0.015*	(0.008)	0.031**	(0.013)
Head's age: <31 (reference)				
Head's age: 31–40	−0.003	(0.023)	0.008	(0.041)
Head's age: 41–50	0.001	(0.022)	0.010	(0.041)
Head's age: 51–60	−0.025	(0.024)	−0.039	(0.044)
Head's age: >60	0.011	(0.033)	−0.049	(0.060)
Highest education: <9 years (reference)				
Highest education: 9–11 years	0.007	(0.013)	−0.004	(0.023)
Highest education: 12+ years	0.012	(0.020)	0.039	(0.048)
Village officer	0.050**	(0.024)	−0.010	(0.044)
Number of plots	0.018***	(0.004)	0.032***	(0.008)
Number of plots squared	−0.001***	(0.000)	−0.001***	(0.000)
Village fixed effects	Yes		No	
Year fixed effects	Yes		Yes	
Constant	5.760***	(0.044)	6.036***	(0.063)
σ_u	0.075	0.379		
σ_e	0.229	0.229		
$\rho(u, v)$	0.098	0.733		

Note: The statistical test and inference of the coefficient of land is based on the test of the null hypothesis that the coefficient is equal to 1 (not 0 as in the standard t value).

***Significant at the 1% level; **significant at the 5% level; *significant at the 10% level.

The coefficient estimates of control variables agree with our expectation in general. There is a nonlinear correlation between the number of plots and output. Its interpretation, however, is complicated by the fact that the number of plots may relate to both farm size and land fragmentation. As a robustness check, we examined the specification without the number of plot variables and obtained qualitatively consistent results.

B. Instrumental Variable Estimation: Necessity, Appropriateness, and Results

Although the theory outlined in the previous sections suggests potential gains from instrumental variable estimation, we need to examine the validity and quality of the instruments. First, the specification test of Hausman (1978) is used to help determine whether the ordinary least square (OLS) estimates are consistent or an instrumental variable (IV) estimator is better. We follow Lamb's (2003) version of this test, which reduces to a z statistic. The test statistic for the Hausman test implies that OLS estimation is inconsistent and that IV is better. Second, do the orthogonality conditions between the instruments and the error term hold, which is an overidentification test (Ruud 2000, 573). The sample chi-square statistics and its statistical significance for this test are reported in Table 3; and we cannot reject the null hypothesis that the orthogonality condition holds. Third,

TABLE 3

IVs Estimation of the Relationship between Output and Farm Size ($N = 2{,}693$)

	Random Effects		**Fixed Effects**	
Regressors	**ln(Land)**	**ln(Output)**	**ln(Land)**	**ln(Output)**
Land (logarithm)		0.977 (0.040)		0.992 (0.104)
Male rural labor	0.176*** (0.011)	−0.003 (0.010)	0.157*** (0.015)	−0.007 (0.021)
Female rural labor	0.162*** (0.010)	−0.002 (0.010)	0.119*** (0.012)	0.007 (0.016)
Head's age: <31 (reference)				
Head's age: 31–40	0.056** (0.028)	−0.020 (0.023)	−0.048 (0.040)	0.013 (0.042)
Head's age: 41–50	0.071*** (0.028)	−0.013 (0.023)	−0.008 (0.040)	0.006 (0.043)
Head's age: 51–60	0.053* (0.030)	−0.028 (0.024)	−0.019 (0.042)	−0.029 (0.045)
Head's age: >60	−0.023 (0.041)	0.021 (0.033)	−0.085 (0.058)	−0.011 (0.064)
Highest education: <9 years (reference)				
Highest education: 9–11 years	0.012 (0.017)	0.002 (0.014)	0.023 (0.023)	−0.013 (0.024)
Highest education: 12+ years	−0.009 (0.025)	0.007 (0.020)	0.056 (0.046)	0.029 (0.049)
Village officer	0.064** (0.031)	0.036 (0.025)	0.046 (0.042)	−0.021 (0.045)
Number of plots	0.081*** (0.004)	0.005 (0.005)	0.088*** (0.007)	0.008 (0.013)
Number of plots squared	−0.002*** (0.000)	−0.000* (0.000)	−0.002*** (0.000)	−0.001 (0.000)
Number of dependents	0.136*** (0.007)		0.094*** (0.009)	
Presence of dependents with urban registration	−0.101*** (0.037)		0.012 (0.046)	
Village fixed effects	Yes	Yes	No	No
Year fixed effects	Yes	Yes	Yes	Yes
Constant	0.172*** (0.056)	5.708*** (0.047)	1.062*** (0.057)	5.728*** (0.140)
σ_u		0.075	0.732	0.338
σ_e		0.237	0.222***	0.236***
$\rho(u, v)$		0.091	0.916	0.673
Bhargava et al. (1982) Durbin-Watson test	1.725			
Baltagi-Wu (1999) LBI	2.288			
Hausman specification test (z value)	3.653***		2.468***	
Overidentification test: $\chi^2(2)$	0.269			
First-stage partial R^2	0.150			
Hahn-Hausman test statistics	1.394			

Note: The statistical inference of the coefficient of land is based on the null hypothesis that the coefficient is equal to 1.
***Significant at the 1% level; **significant at the 5% level; *significant at the 10% level.

are the instruments sufficiently correlated with the endogenous regressor? This is related to the discussion in the literature of "weak instruments," for example, Staiger and Stock (1997) and Nelson and Startz (1990). Weak instruments may make the second-stage inference invalid. Bound, Jaeger, and Baker (1995) suggested that the partial R^2 and the F statistic of the identifying instruments in the first-stage estimation are useful indicators of the quality of instruments. As the first-stage R^2 (the *partial* R^2 if there are included exogenous variables) increases, the instrumental variable estimation bias becomes smaller. In this study, the *partial* R^2 (*added* explanatory power using the excluded instruments) in the first stage is 0.15, which is reasonable considering the large sample size, the micro nature of the data set, and that we use few instruments.[11] Third, a new test proposed by Hahn and Hausman (2002) addresses explicitly the issue whether the conventional instrumental variable asymptotics are reliable. It compares the difference in the conventional 2SLS estimate of the coefficient of the right-hand side endogenous variable with the reverse 2SLS estimate of the same unknown parameter. The Hahn-Hausman statistic, which has a t distribution under the null hypothesis, is 1.394—smaller than the critical values at the 5% significance level. Hence, we cannot reject the null hypothesis that the instrumental variable estimator provides reliable inferences.

C. Main Results

The instrumental variable estimates are reported in Table 3. The first-stage fixed-effects results provide interesting implications. First, having a household member who is a village officer increases the amount of farmland allocated to the household. Household heads who are of 41–50 years of age and those with more dependents receive more land. Households who have a member holding an urban *hukou* registration receive less land (also see Burgess 2007).

The second-stage fixed-effects results show that the estimated coefficient of the logarithm of cultivated land area has increased from the baseline models of 0.74 with village fixed effects (Table 2) to 0.992 in Table 3. Similar large increases are reported for the model fitted with random effects. Hence, the inverse relationship between total farm output and total cultivated area disappears once land heterogeneity is controlled for using an instrument for land area.

D. Robustness Check

We investigate the robustness of the results with both fixed- and random-effects models as well as with an expanded set of instruments. The fixed- and random-effects IV models provide similar results. The IV estimation with the expanded set of instruments also produces consistent results, as shown in Table 4. An interesting observation is that the household head's education and the village officer dummy variable do appear to be an important factor in the land allocation process in rural China but not in the output equation (the latter was shown in the result for the baseline set of instruments). This substantiates the conclusion of Yang (1997a, 1997b) on the collective decision making within Chinese rural households and that household heads and village officers play critical roles in the land allocation process.

We also examined the relationship between total grain output and cultivated land area by replacing the number of dependents with its logarithm and the main conclusion did not change. These specifications consistently suggest that an inverse relationship in China's agriculture does not exist—output is proportional to farmland area cultivated.

V. DISCUSSION

When Deininger and Feder (2001) summarized several studies that documented an inverse relationship between farm size and productivity, they argued that supervision costs for hired labor that come with a larger farm are particularly large due to spatial dispersion, and thus, contribute to the inverse relationship. This could be interpreted as one reason why China's agriculture was transformed from collective farming to HRS in the 1980s. Microeconomic theory suggests that an optimum size exists for most production processes and institutional arrangements. Empirical evidence, as by Deininger and Feder (2001), indicates that the optimal farm size in most developing countries, given the existence of imperfect input/output/credit markets, low real wage, static agricultural technologies, and land heterogeneities, is small relative

11. Partial R^2 indicates the *added* explanatory power of the *identifying* instruments (Hall et al. 1996). It is used to determine whether the set of instruments is "weak," along with the Hahn-Hausman test.

TABLE 4
Instrumental Variables Estimation of the Relationship between Output and Farm Size (Expanded Set of Instruments; $N = 2{,}693$)

	Random Effects				Fixed Effects			
Regressors	**ln(Land)**		**ln(Output)**		**ln(Land)**		**ln(Output)**	
Land (logarithm)			0.986	(0.039)			0.968	(0.099)
Male rural labor	0.173***	(0.011)	−0.004	(0.010)	0.157***	(0.015)	−0.004	(0.020)
Female rural labor	0.160***	(0.010)	−0.003	(0.010)	0.119***	(0.012)	0.010	(0.016)
Head's age: <31 (reference)								
Head's age: 31–40	0.051*	(0.029)	−0.019	(0.023)	−0.050	(0.041)	0.013	(0.042)
Head's age: 41–50	0.067**	(0.028)	−0.012	(0.023)	−0.017	(0.041)	0.006	(0.042)
Head's age: 51–60	0.050	(0.031)	−0.028	(0.025)	−0.035	(0.043)	−0.029	(0.045)
Head's age: >60	−0.010	(0.043)	0.022	(0.034)	−0.099*	(0.059)	−0.015	(0.063)
Highest education: <9 years (reference)								
Highest education: 9–11 years	0.023	(0.019)	0.002	(0.014)	0.034	(0.023)	−0.011	(0.024)
Highest education: 12+ years	0.022	(0.037)	0.009	(0.020)	0.088*	(0.048)	0.030	(0.049)
Number of plots	0.080***	(0.005)	0.005	(0.005)	0.087***	(0.007)	0.010	(0.012)
Number of plots squared	−0.002***	(0.000)	−0.000*	(0.000)	−0.002***	(0.000)	−0.001*	(0.000)
Village officer	0.064**	(0.031)			0.053	(0.042)		
Head's education: <5 years (reference)								
Head's education: 5–8 years	0.088***	(0.027)		−0.009	(0.033)			
Head's education: 9–11 years	0.049*	(0.029)		−0.059	(0.037)			
Head's education: 12+ years	0.032	(0.044)		−0.158**	(0.068)			
Number of dependents	0.136***	(0.007)		0.094***	(0.009)			
Presence of dependents with urban registration	−0.103***	(0.037)		0.019	(0.046)			
Village fixed effects	Yes		Yes		No		No	
Year fixed effects	Yes		Yes		Yes		Yes	
Constant	0.118*	(0.061)	5.703***	(0.047)	1.108***	(0.066)	5.756***	(0.136)
σ_u			0.078		0.733		0.338	
σ_e			0.236		0.222		0.234	
$\rho(u, v)$			0.098		0.916		0.675	
Bhargava et al. (1982) Durbin-Watson test			1.725					
Baltagi-Wu (1999) LBI			2.288					
Hausman specification test (z value)			3.924***				2.339***	
Overidentification test: $\chi^2(2)$			0.539					
First-stage partial R^2			0.160					
Hahn-Hausman test statistics			0.752					

Note: The statistical inference of the coefficient of land is based on the null hypothesis that the coefficient is equal to 1. ***Significant at the 1% level; **significant at the 5% level; *significant at the 10% level.

to the optimal size of farm in high wage, technically advanced, developed countries such as the United States.

In China, we see a complicated picture. First, China has a very large rural population relative to the amount of arable land. The arable land per rural person in the later 1990s was about 0.144 hectare, compared to 0.221 in India, 2.729 in the United States, and a world average of 0.426 hectare. Second, arable land in China is collectively owned by rural communities instead of individual households. Large privately owned farms rarely exist in China, although a small number of privately operated farms have emerged. One would expect large farms to be "specialized" and to have subleased land from the community or other households. Communities are more likely to put up for lease excess land which is of poorer than average quality, and to the extent that households lease out land, it is most likely less productive or remotely located. This may contribute to the spurious inverse relationship between productivity and farm size in some studies. Third, East and South China have seen an economic boost in the last few decades, and many previously rural laborers are now employed in industrial or service sectors. A land rental market might successfully transfer lands from households that are less involved in farming to those that are more "specialized" in farming. The rapid economic development in China in the 1990s may have improved the functioning of farm input and output markets and most likely contributes to the weakening of any inverse relationship between farm productivity and farm size that may have existed earlier. As China's agriculture becomes more mechanized and the input sector starts to produce a steady stream of new technologies, larger farms may have a comparative advantage over smaller farms.

Our results show that land heterogeneity contributes to the observed inverse relationship. This, as well as other studies (Benjamin 1995; Carter 1984; Deininger and Feder 2001), points to an important conclusion: the inverse relationship between farm size and output per unit of land is not inherent to China's agriculture but rather a consequence of heterogeneous land unevenly distributed across households and introduced during the land allocation process, as well as (labor) market imperfections, and unobserved factors. Therefore, a public policy of breaking up large farms is not currently justified (Deininger and Feder 2001). The hidden unemployment problem can be addressed by general economic development and investments in rural education (Huffman 2001; Huffman and Orazem 2007). A mechanism that consolidates land through more active land rental market to exploit the benefits of more advanced technology and to share such benefits between landowners and farmers is needed.

When new agricultural technologies are being developed and disseminated to farmers, the adoption decision includes a fixed cost of learning about and experimenting with the new technology. The returns to adoption are positively related to the size of the farming operation and the length of the farmer's planning horizon. Hence, other factors being equal, large farms have a comparative advantage over smaller farms when agricultural technologies are dynamic (Huffman and Evenson 2001). Traditionally, Chinese farms have been small. However, village councils' auctions of excess lands and the emerging land rental market have made it possible for some farmers to take in more land, which permits using new and large-scale machines. This study presents some evidence that, at present, there is no need to discourage large farms, because the inverse relationships could be due to unobserved land quality. A bold conjecture is that China's potential to improve agricultural productivity may be realized if the fragmented land parcels can be consolidated into larger farms, where modern technologies can be easily applied. Deininger, Jin, and Yu (2007) found that access to land offers rural Chinese households protection against idiosyncratic risks. Deininger and Jin (2005) show that decentralized land rent markets might contribute to both equity and efficiency and have advantages over administrative reallocation.

The importance of this study for policy makers, we argue, lies in the rejection of an observed inverse productivity relationship. Not only is land consolidation through institutions such as land rental markets a pressing policy issue in coastal areas, but there are also reports suggesting that out-migration has left only women and the elderly to work on the land in inland villages. This has led in some cases to land consolidation and higher agricultural productivity.

Although we provide econometric evidence that unobserved land quality explains the inverse empirical relationship between farm size and output in China, other possible explanations include market imperfections and institutional factors. Benjamin and Brandt (2002) suggest that administrative allocation of land may contribute to the inverse relationship. This article differs from that of Benjamin and Brandt (2002) in that we hypothesized a correlation between land quality and farm size that was introduced due to equity concerns. Interestingly, the result from our fixed-effects model, which estimates the impact of changes in land area on changes in total farm output, seems to be in line with Benjamin and Brandt's conclusion that land *re*allocation alleviates the inefficiency of labor use. Our policy recommendation to improve land rental market is similar to that of Benjamin and Brandt (2002), who argued for the importance of well-functioning factor markets. Examining the effect of farm size on total factor productivity as Ahearn, Yee, and Huffman (2002) might be a useful future line of research.

VI. CONCLUSIONS

This article has examined the empirical relationship between farm productivity and farm size in China's agriculture. Given that the local rural village council is the institution that holds the majority of China's farmland and makes land allocation decisions, we choose to use an instrumental variable estimation procedure to examine in detail the relationship between farm size and productivity in small-scale agriculture. The main data set that we used are from the RCRE survey in the late 1990s. In the raw data, we observed an inverse relationship between total grain output and cultivated area. However, after we used econometric methods to control for unobserved land quality, the inverse empirical relationship between grain output and cultivated area disappears. Hence, farm output is proportional to farm size currently in China, and there is no urgency to develop policies that would reduce farm size.

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