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Plot Size and Maize Productivity in Zambia: The Inverse Relationship Re-examined

by

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Plot Size and Maize Productivity in Zambia: the Inverse Relationship Re-examined

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Abstract

Agricultural productivity is known to decline with farm size in many developing countries. This may be a result of market imperfections, such as missing rural labor markets. On the other hand, there may be economies of scale in farming, due, for instance, to the importance of lumpy inputs. Hence, it is not theoretically obvious that the inverse relationship prevails in all situations. Indeed, several studies found non-monotonic relationships between productivity and farm size, with productivity decreasing with size up to a certain size and increasing beyond that point.

This paper examines the relationship between Maize productivity and plot size in Zambia. It offers a unique empirical approach. First, it focuses on Maize, which is the major crop on small and medium size farms in Zambia, but also accounts for the endogenous determination of the size of the plot devoted to Maize. Previous studies used total farm size or harvested area. Second, it corrects for selectivity into Maize cultivation. Third, it controls for differences in land quality and weather conditions across districts. Finally, it offers a structural interpretation of the above framework by modeling farm decisions in two recursive stages, where land is first allocated to the different crops based on the information set of the farmers at the time of planting, and the yield is affected by subsequent application of inputs, the quantities of which may depend on additional information that is revealed after planting. We use this recursive structure and the differences in the information sets over time to identify the model.

The results show that the endogeneity of plot size is very important in this analysis. When considering plot size as an exogenous explanatory variable, we find a monotonic positive relationship between the yield of Maize and plot size, indicating that economies of scale are dominant throughout the plot size distribution. However, when we correct for the endogeneity of plot size, we find that the inverse relationship dominates the economies of scale in all plots up to 3 hectares, which constitute 86% of our sample. These results suggest that market imperfections should be targeted by any policy aimed at increasing Maize productivity in Zambia.

JEL Classifications: O1 (Economic Development); Q1 (Agriculture).

Key Words: Maize Yield; Plot Size; Inverse Relationship; Recursive Decisions; Two-Stage Estimation; Two-Sided Tobit; Selectivity Correction.

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Introduction

It is a well-known empirical regularity (although there are exceptions) that agricultural productivity decreases with farm size in developing countries. Theoretically, this may be a result of market imperfections. For example, when rural labor markets are not functioning, the surplus labor of family members is available for farm work at a very low shadow price. In small farms, therefore, the labor to land ratio would be higher than in large farms, and the output to land ratio would also be higher. On the other hand, there may be economies of scale in farming, due, for instance, to the importance of lumpy inputs such as heavy machinery. Hence, it is not clear from a theoretical point of view that the inverse relationship is the rule. Indeed, several studies found non-monotonic relationships between productivity and farm size, with productivity decreasing with size up to a certain size and increasing beyond that point. Below we review the relevant literature in more detail.

The purpose of this paper is to examine the relationship between Maize productivity and plot size in Zambia. In doing so, the paper offers an empirical approach with several distinct features: (a) we focus on Maize, which is the major crop on small and medium size farms in Zambia, but account for the endogenous determination of the size of the plot devoted to Maize. Previous studies used total farm size or harvested area, and hence could not separate the crop composition effects of size and the genuine productivity effects; (b) we correct for selectivity into Maize cultivation, because not all farms grow Maize; (c) we control for differences in land quality and weather conditions across districts; and (d) we offer a structural interpretation of the above framework, by modeling farm decisions in two recursive stages. In the first stage, which is associated with the planting season, land is allocated to the different crops based on the information set of the farmers at that time. The yield is determined in the second stage by subsequent application of inputs, the quantities of which may depend on additional information that is revealed after planting. We view farmers as operating within imperfect factor markets. The relatively high uncertainty prevailing in large parts of rural Zambia, not only with regard to input availability and prices, but also with regard to rainfall, highlight the important role of information in this context. We use this recursive structure and the differences in the information sets over time to identify the model.

The stylized fact that farm productivity varies with farm size has attracted the attention of many researchers over the years. It has important policy implications, for example with regard to the potential benefits of land reforms (Cornia, 1985; van Zyl et al., 1995). The effect of size on productivity was established in many empirical contributions to the literature. Most researchers found that productivity or efficiency declines with size, and attributed this to several factors, including imperfect land and labor markets (Sen, 1966; Bardhan, 1973) and in particular family labor surplus (Mazumdar, 1965; Carter, 1984; Reardon et al., 1996; Newell et al., 1997), and advantages in hired labor supervision (Yotopoulos and Lau, 1973). Byiringiro and Reardon (1996) find that the inverse relationship can be also explained by higher land conservation efforts on small farms, Barrett (1996) finds support to an explanation based on price risk, and Assuncao and Ghatak (2003) show that heterogeneity in farmer ability and endogenous time allocation in the presence of imperfect capital markets could lead to a similar result.

Feder (1985) shows that a necessity to supervise hired labor and capital market imperfections could lead to a systematic relationship between yields and farm size, and this relationship could be positive or negative. Binswanger et al. (1995) suggest several sources of economies of scale that could create a productivity advantage for large farms. Zaibet and Dunn (1995) found that small farms faced a binding constraint in the use of mechanization in Tunisia. Kevane (1996) found that insurance and financing constraints created a positive relationship between wealth and yields in western Sudan. Kumbhakar and Bhattacharyya (1992) found that price distortions reduced allocative efficiency of small farms in India. Sawers (1998) attributed the lack of an inverse relationship in the Argentine interior to policy distortions and credit market imperfections. Dorward (1999) found that farm size had a positive effect on productivity in Malawi due to land, capital and output market failures. Eswaran and Kotwal (1986) claim that family labor availability creates advantages for small farms but indivisibility of capital works in favor of large farms. Hence, a possible outcome is that yields will be decreasing with farm size for relatively small farms and increasing with farm size above a certain size threshold. Deolalikar (1981) found evidence for productivity advantages for small farms in districts in which traditional technologies dominate, and the opposite in districts in which modern technologies dominate. Carter and Wiebe (1990) found a U-shaped effect of farm size on both farm output and family income, and attribute it to access to capital. Heltberg (1998) allowed for a third-degree polynomial in operated land to affect farm value added, and found a U-shaped effect, after controlling for various market imperfections.

Barnum and Squire (1978) could not find statistically significant yield differences between small and large padi farms in northwest Malaysia. They avoided the potential bias caused by crop composition effects in multi-crop farms. Binswanger et al. (1995) claim that crop composition is a key element and should not be ignored. The empirical analysis in this paper is consistent with both arguments: we use the yield of a single crop as the dependent variable but also control for the endogenous determination of the output mix. Several studies have found that the inverse relationship weakens considerably after differences in land quality are taken into account (Bhalla and Roy, 1988; Benjamin, 1995). This study controls for both land quality and weather differences across geographical regions. Recently, Lamb (2003) showed that the inverse relationship could be explained by a combination of land quality differences, rural market imperfections, and a measurement error in farm size. Both Lamb (2003) and Benjamin (1995) corrected for measurement errors in plot size using instrumental variable techniques. Our approach of correcting for endogeneity in plot size also accounts for the measurement error. However, neither Lamb (2003) nor Benjamin (1995) considered the possibility of nonlinear effects of size on productivity, which is pursued in this paper.

The following section outlines the theoretical framework that underlies this analysis and the empirical approach. The data set is described next, and the results are presented after that. Conclusions are presented in the last section.

Analytical framework and empirical approach

Our analytical framework is based on the McGuirk and Mundlak (1992) framework, which relies on the recursive nature of decisions on a farm: *"...Initially, farmers decide, given information at planting time, how to allocate land among different crops. Farmers then can change output only by influencing yield*" (pp. 133). Specifically, we assume that at the time of planting the farmer is making land allocation decisions based on the available information set. This may include the levels of fixed inputs, expectations about the availability of purchased inputs and about output prices, and environmental variables (weather, soil conditions, market situation, policy, etc.). Note that we consider the availability of inputs rather than input prices as the relevant information, because farmers in Zambia are often subject to input availability constraints.[1] We assume that farmers maximize a multi-crop profit function, the solutions of which include the size of plot allocated to each crop as a function of conditioning variables known at the time of planting.[2]

Between planting and harvest, new information may be revealed. This new information certainly includes weather conditions such as rainfall, but also new expectations about the availability of inputs. Both may alter the solutions of the profit maximization problem. However, as land allocations have already been made, all farmers can do is influence the yields by changing the levels of other inputs. The yield is therefore a function of all conditioning variables known up to the time of harvest, including the size of plot. Using the plot size as a variable that explains yield is problematic, though, because it may be endogenous. For example, a farm attribute that increases the yield of a specific crop, and is known to the farmer but not to the econometrician, may induce the farmer to allocate more land to that crop. In this case the plot size and the residual in the yield equations may be correlated, yielding inconsistent parameter estimates. A simultaneous equations estimation procedure is therefore necessary.

In our data set, Maize accounts for 65% of all cultivated land. We therefore treat all other crops as a composite crop.[3] We treat the land allocated to Maize and the yield of Maize as recursive simultaneous equations. Our estimation procedure is a version of Two-Stage-Least-Squares, where the land equation is estimated in the first stage, and its predicted value is used as an explanatory variable in the second stage. This is how we account for the endogeneity of plot size. In addition, we have a selectivity issue to deal with, because we observe the yield of Maize only in farms that grow Maize, which constitute 84% of our sample. We correct for selectivity by including a Heckman (1979) selectivity correction term among the explanatory variables in the yield equation.

A major determinant of the size of plot allocated to Maize is the total land available. The influence of total land on land allocated to Maize may be nonlinear. Instead of including higher polynomials of total land, we chose to use the fraction of land allocated to Maize as the dependent variable. This also simplifies the treatment of censoring of the dependent variable. Both the land allocated to Maize and the fraction of land allocated to Maize are censored from below by zero. However, the land allocated to Maize is censored from above by total land, which is farm-specific, while the fraction of land allocated to Maize is censored from above by one. We therefore estimated, in the first stage, an equation for the fraction of land allocated to Maize which is censored from below by zero and from above by one. Maximum Likelihood methods were used for the estimation.

The predicted values from the first stage were multiplied by total land in order to obtain the predicted value of land allocated to Maize. This value was used as an explanatory variable in the second-stage yield equation. We included predicted land and its square, in order to allow a nonlinear effect of land on yield and therefore test for the existence of the inverse relationship.

Data and descriptive statistics

We use data from two separate surveys that were conducted in Zambia within several months. Both surveys were conducted by the Central Statistical Office in Zambia, and were administered over the same sample of farmers. The sample is representative for Zambia. In the Crop Forecast Survey, farmers were asked about their access to particular services such as extension, credit and marketing channels, and about their irrigation practices. Demographic information about the household was also collected. The survey included 7269 farmers, 87% of which were defined as "small-scale farmers" and the other 13% were defined as "medium-scale farmers."[4] The Crop Forecast Survey was matched to the 1993/94 Post Harvest Survey, in which detailed input-output data were collected, and from which knowledge of and access to modern production techniques such as improved seed varieties and chemical fertilizers can be inferred. The post-harvest survey included 6469 farms. We do not know for sure why the numbers of observations in the two surveys are different.

The merged data set was checked for consistency of the cropping information by checking whether a farmer who indicated that he grows a certain crop also reports a positive amount of land allocated to that crop. 5903 farms (91%) passed this test for all crops reported. The two data sets were then merged, resulting in 5329 matched observations (90% of the consistent observations in the post-harvest survey). Some other observations were excluded due to missing explanatory variables. The estimation procedure eventually used 5280 observations. Table 1 includes definitions of variables used in the analysis and their sample means.

The major crop in these farms is Maize, which is grown by 84% of the farmers in the merged data set, and accounts for 78% of the cultivated land in the farms that do grow Maize, and 65% overall. About a third of the farmers grow nothing but Maize.

Among the quantitative variables in the data set, we treat total land, credit, fertilizer, draught animals, machines, and family and hired workers as quasi-fixed inputs, whose quantity is given in the short run. We observe the total quantity used by the farm but not the allocation among crops (except for the land allocation). Other conditioning variables include infrastructure indicators (distance to road and access to market),[5] exposure to extension services through direct and indirect channels, an irrigation dummy and the reasons for not irrigating. We also include the gender, age and education of the household head as explanatory variables. In addition, each stage of the estimation procedure includes district dummies, which are controlling for land quality and weather differences across districts. We have tried to use land quality indicators and rainfall data directly instead of the district dummies, but we did not have rainfall data for all districts and the difference between districts with and without rainfall data was statistically significant, hence we decided to stick with the district dummies.

Results

The results of the censored regression of the fraction of land allocated to Maize are reported in table 2.[6] Other than extension, irrigation, and family labor, all explanatory variables affect the fraction of land allocated to Maize significantly. In particular, the fraction of land allocated to Maize is negatively associated with total land,[7] female household headship, remoteness and market accessibility, lack of irrigation knowledge and number of draught animals, and positively associated with age and education of the head of household, number of permanent hired workers and number of animal-drawn implements. The results of the yield equation are reported in table 3.[8] Two versions are reported: the version on the left-hand column is using actual plot size as an explanatory variable, while the version on the right-hand column is using the predicted plot size instead. Other than that, the two versions are identical. We observe a nonlinear dependence of yield on plot size in both cases. While the overall trend in both cases is positive, yield is first increasing and then decreasing with size when actual size is used, but is first decreasing and then increasing with size when predicted size is used.[9] This difference demonstrates the importance of controlling for the endogeneity of plot size in such analyses.[10]

In figure 1 the dependence of yield on size is shown graphically. We find that despite the nonlinear relationship, yield is monotonically increasing with plot size throughout the size distribution, when actual size is used. When predicted size is used, the yield is first decreasing with size and then increasing. The size in which the minimum yield is attained is approximately 3 hectares. About 86% of our sample is below 3 hectares of land. Hence, the inverse relationship between plot size and the yield of Maize is relevant for most small- and medium-size farms in Zambia. This result is similar to the findings of Heltberg (1998) for Pakistan.

The statistically significant positive effects of family labor, machines, credit and fertilizer on the yield of Maize are fairly consistent across the two specifications of the yield equation, and confirm the earlier results of Jha and Hojjati (1993), Holden (1993), and Kumar (1994). However, after correcting for the endogeneity of plot size, the negative effect of the female dummy and the positive effects of education and hired labor become statistically significant, while the negative effect of age loses significance. The infrastructure, extension and irrigation variables do not come out statistically significant in any of the specifications, although extension is close to having a significant positive effect on yield. The district dummies were jointly statistically significant.[11]

Summary and conclusions

This paper examines the relationship between Maize productivity and plot size in Zambia. It accounts for the endogenous determination of the size of the plot devoted to Maize. Previous studies used total farm size or harvested area and treated them as exogenous. The paper also corrects for selectivity into Maize cultivation, and controls for differences in land quality and weather conditions across districts. We model farm decisions in two recursive stages, where land is first allocated to the different crops based on the information set of the farmers at the time of planting, and the yield is affected by subsequent application of inputs, the quantities of which may depend on additional information that is revealed after planting. We use this recursive structure and the differences in the information sets over time to identify the model.

The results show that the endogeneity of the plot size is very important in this analysis. When considering plot size as an exogenous explanatory variable, we find a monotonic positive relationship between the yield of Maize and plot size, indicating that economies of scale are dominant throughout the size distribution. However, when we correct for the endogeneity of plot size, we find that the inverse relationship dominates the economies of scale in all plots up to 3 hectares, which constitute 86% of our sample. These results suggest that market imperfections should be targeted by any policy aimed at increasing Maize productivity in Zambia.

Notes

[1] Holden (1993) cites the highly imperfect labor markets as the main problem in Zambian agriculture. Wichern et al. (1999) attribute part of the labor shortage to poor health and education of hired workers, as well as to social norms that restrict the optimal allocation of labor. Jha and Hojjati (1993) show that credit is the most limiting factor. Kimhi and Chiwele (2002) also find that shortage of funds for buying inputs is the major constraint reported by farmers. Jha (1990) mentions animal traction (oxen and implements) as a major constraint, at least in the Eastern Province, while Foster and Mwanaumo (1995) claim that "more emphasis is needed on support systems such as extension education, agricultural research, infrastructure, and marketing." Wanmali (1990) also mentions the need for investments in various rural services. Alwang et al. (1996) claim that market liberalization cannot benefit remote households unless infrastructure and market access are improved. They also show that lack of male labor for land preparation is a major constraint in poor households. Seshmani (1998) adds, on top of all these constraints, the inadequate availability of on-farm storage facilities.

[2] Hassan (1996) shows that both socioeconomic factors and agroclimatic conditions explain a significant proportion of the variability of Maize planting decisions in Kenya.

[3] We also tried to treat other crops individually, but the results were disappointing due to the small numbers of observations for each crop other than Maize.

[4] Large commercial farms were excluded from the survey. Farm categories are defined on the basis of the technologies applied (Government Republic of Zambia, 1994). Commercial farmers are characterized by extensive mechanization, use of modern technology and management, and heavy reliance on hired labor. They number less than 1,500 and are concentrated in the narrow corridor of the line-of-rail. Small-scale farmers, on the other hand, depend mostly on hand-hoe cultivation and unpaid family labor, and use little of modern farm inputs which, when used, consist mostly of chemical fertilizer and hybrid seeds on Maize cultivation. There are about 600,000 farm households classified as small-scale farmers in the country. Medium-scale farmers, also called emergent farmers, who number about 100,000 farm households, fall in between these two categories but are mostly distinguished by their use of animal power. This is a transitional phase prior to commercial farming. Small- and medium-scale farmers contribute between 40% and 60% of agricultural output in Zambia.

[5] Jacoby (2000) showed that roads and access to markets were important for the welfare of Nepalese farmers. Smale et al. (2001) found that infrastructure affected land allocation among Maize varieties in Mexico. Foster and Mwanaumo (1995) found that infrastructure was one of the most important determinants of Maize productivity in Zambia.

[6] The coefficients of the district dummies were omitted from both table 2 and table 3; these coefficients were found to be jointly significant. The importance of the district dummies can be explained in part by the fact that different species of Maize may be advantageous in different climatic areas (Chipanshi, 1989). In addition, land quality and rainfall, that vary across districts, can increase both expected and actual yields within species.

[7] Fafchamps (1992) showed that farm size affects land allocation decisions in the presence of food price uncertainty. Omamo (1998) attributes this phenomenon to transport costs. Zulu et al. (2000) claimed that market liberalization has lead to a downward trend in Maize cultivation in Zambia.

[8] We had to exclude a number of observations that apparently devoted land to Maize but did not report the yield.

[9] We also estimated a third-degree polynomial in size but we could not reject the hypothesis that this specification is no different than the one reported in table 3.

[10] We also estimated both models without correcting for selectivity, but this did not change that pattern of the size-yield relationship. One can also observe that the coefficient of the selectivity correction term is not statistically significant at the 5% level. Note that the Heckman (1979) procedure may be vulnerable to collinearity between W and λ, yet informal tests revealed little if any collinearity in this case.

[11] It is possible to find the effects of district-specific variables on the yield when estimating the model with district dummies, by running a linear regression of the estimated district dummies on the set of district-specific variables (Borjas and Sueyoshi 1995). We were not able to get interesting results from this last regression and hence it is not reported here. The reason is that we had very few observations due to the missing rainfall data.

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van Zyl, J., Binswanger, H., Thirtle, C., 1995. The Relationship between Farm Size and Efficiency in South African Agriculture, Policy Research Working Paper No. 1548, The World Bank.

Figure 1. Calculated Yield as a Function of Plot Size

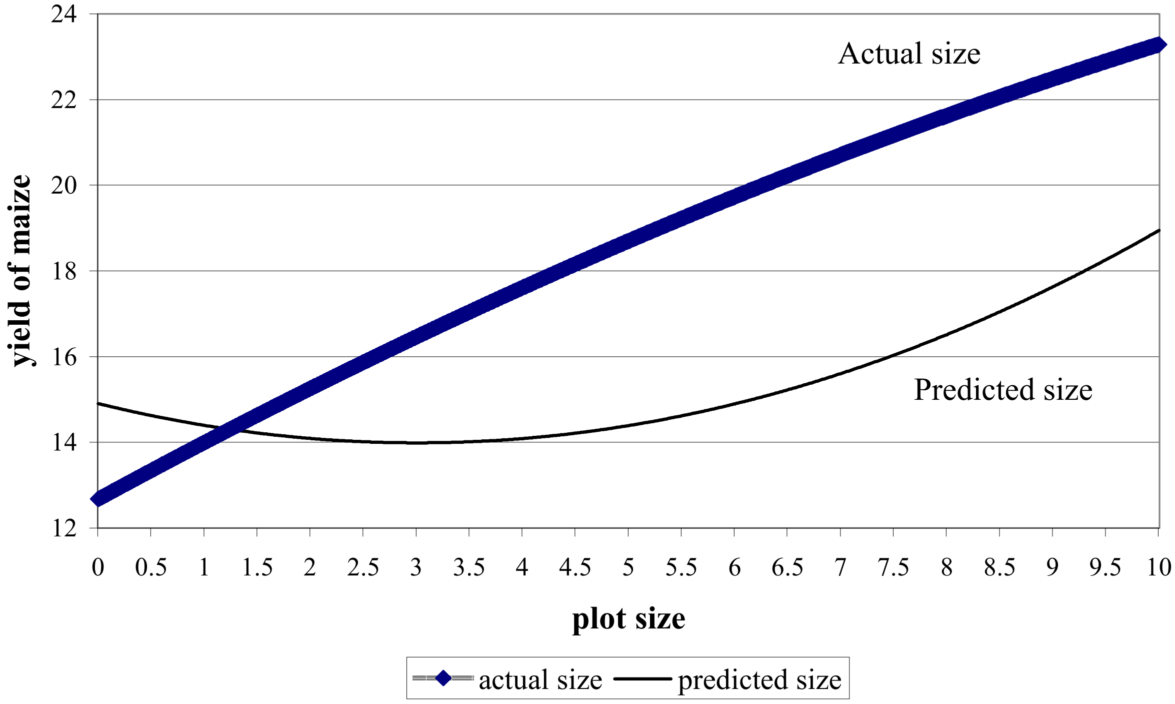

Table 1. Variables Used in the Estimation

Name	Description	Mean
Total land	total land used for seasonal field crops (Hectares)	1.780
Maize land	fraction of land used for maize	0.654
Maize yield[a]	yield of maize (100 kg/Hectare)	1.420
Female	1=female head of household	0.212
Age	age of head of household (years)	44.89
Higher education	1=head of household with higher than primary education	0.188
Distant road	1=nearest road is more than 5 kilometers away	0.179
Distant market	1=distance to nearest output market is more than 20 kilometers	0.116
No market access	1=household has no access to output markets	0.374
Extension	1=exposed to at least one kind of extension service	0.547
Irrigation	1=some of the land is irrigated	0.117
No irrigation-know	1=not irrigating more due to lack of knowledge	0.294
No irrigation-funds	1=not irrigating more due to lack of funds for equipment	0.263
Hired workers perm.[a]	number of permanent hired workers	0.011
Family male workers[a]	number of male family members employed on the farm	2.659
Family female work.[a]	number of female family members employed on the farm	3.117
Draught animals[a]	number of draught animals used on the farm	0.203
Machines[a]	number of animal-drawn implements	0.246
Credit received[ab]	amount of credit received (10000 Kwacha)	0.986
Chemical fertilizer[ab]	total amount of chemical fertilizers used (100 kg)	1.122

a. These variables are expressed per hectare of Land Total.

b. These means are based on the 3973 “clean” observations who reported maize output.

Table 2. Results of the Fraction of Land Allocated to Maize

Variable	Coefficient	T-value
Intercept	0.9666	30.529 **
Total land	-0.0146	-3.984 **
Female	-0.0626	-3.868 **
Age	0.0624	3.725 **
Higher education	0.1516	8.626 **
Distant road	-0.0764	-5.009 **
Distant market	-0.1028	-4.807 **
No market access	0.0435	2.408 **
Extension	0.0019	0.129
Irrigation	-0.0276	-1.322
No irrigation-know	-0.0332	-1.884 *
No irrigation-funds	0.0122	0.188
Hired workers perm.	0.1312	2.642 **
Family male workers	-0.0043	-1.583
Family female workers	-0.003	-1.217
Draught animals	-0.0225	-2.046 *
Machines	0.0523	4.225 **
Sigma	0.5427 [a]	
Number of cases	5280	
Log-likelihood	-4273.99	

Notes:

The model also included district dummies.

* Coefficient significant at the 5% level.

** Coefficient significant at the 1% level.

a. The standard deviation coefficient was transformed in the estimation, so the standard error of the untransformed estimate is not reported.

Table 3. Results of the Maize Yield Equation

	Actual Maize Land		Predicted Maize Land	
Variable	Coefficient	T-value	Coefficient	T-value
Intercept	9.6788	10.0739 **	11.3500	11.3067 **
Maize land	1.3486	7.6524 **	-0.6094	-2.4300 *
Maize land squared	-0.0288	-2.3330 *	0.1013	4.2906 **
Female	-0.4273	-0.9959	-0.9118	-2.0826 *
Age	-2.7361	-2.3890 *	-0.9763	-0.8371
Higher education	0.5412	1.2533	0.9814	2.2532 *
Distant road	-0.3519	-0.7735	-0.2104	-0.4379
Distant market	0.5598	0.9594	0.5735	0.9589
No market access	0.0552	0.1257	-0.3701	-0.8248
Extension	0.4723	1.3410	0.5978	1.6580
Irrigation	-0.2127	-0.3194	0.0109	0.0161
No irrigation-know	0.1157	0.2616	-0.0107	-0.0238
No irrigation-funds	-0.5401	-1.2554	-0.4491	-1.0275
Hired workers perm.	2.6201	1.8720	3.0567	2.1574 *
Family male workers	0.4711	7.3517 **	0.4052	6.2123 **
Family female workers	0.3259	5.8977 **	0.3052	5.2160 **
Draught animals	-0.2318	-1.1729	-0.1882	-0.9406
Machines	1.0100	4.2197 **	0.9679	3.9926 **
Credit received	0.3846	6.8329 **	0.4867	8.5920 **
Chemical fertilizer	0.0357	2.0076 *	0.0362	2.0056 *
Selectivity correction term			4.8091	1.8692
Sigma	9.86		9.98	
Number of cases	3973		3973	
R-squared:	0.207		0.188	
Adjusted R^2	0.193		0.173	
F-statistic	14.357		12.565	

Notes:

Both models also included district dummies.

* Coefficient significant at the 5% level.

** Coefficient significant at the 1% level.

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