Impact of mechanization use of farming systems and rural economies: evidence from Ghana

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Abstract:
The benefits of agricultural mechanization are often touted by policy makers as reducing the drudgery associated with agricultural work and advancing the agricultural production systems, especially in contexts where traditional technologies appear to be stagnant. However, little rigorous work has been done to confirm the claims of both policymakers and theory regarding the impacts and benefits of mechanization. This is partly due to the challenge of quantitatively identifying these impacts and attributing changes in production systems and household welfare to the use of mechanized technology, rather than general improvements to agricultural production and associated infrastructures. Furthermore, many of the changes to agricultural systems associated with mechanization take place over the long term as associated markets and institutions adapt to the new technology.

This paper exploits a government scheme that included the phased distribution of agricultural machinery in Ghana over 2008-2010. The focus of the paper is on the short-term impacts of improving the supply of agricultural machinery. Agricultural machinery has been widely used in Ghana for several decades, but farmers frequently complain of inadequate supply of machinery services. The government scheme simulates an exogenous positive shock to the supply of machinery services at the district level. This allows us to identify the short-term impact on a range of variables relating to the farming system and household welfare. The 2009-2010 EGC-ISSER Socioeconomic Panel Survey is used to create pseudo treatment and control groups from those districts, which received the same treatment but in different phases.

I. Introduction

Agricultural mechanization is often considered in the context of large-scale commercial farming, in the style of agricultural production systems of north America and Europe, where each stage of agricultural production has been mechanized. However, there is growing evidence that farmers in developing country contexts, where labour is still relatively cheap, are using agricultural machinery for some operations. In particular, farmers in the cereal-producing areas of northern Ghana have adopted mechanization as part of their preferred set of agricultural technologies. This is in a context where average farm sizes are less than 5 hectares. This observed trend raises theoretical and empirical questions around the conditions under which mechanization of at least some operations becomes profitable for small-scale farmers in sub-Saharan Africa, and also the implications of machinery use for other farming decisions over land, labour, and other input use.

Theories of agricultural transformation have made some contributions to understanding the role of mechanization. Boserup (1965) and Pingali et al. (1987) consider farmer demand for mechanized technology to be a result of the agricultural intensification process, which is fundamentally driven by agro-ecological conditions, population pressure, and market demand. Hayami & Ruttan (1985) and Binswanger & Ruttan (1981) consider that farmer's will demand technology innovations that are biased to using the factor of production with relative abundance. Mechanized technology will be demanded when there is relative land abundance. The indivisibility of production factors, such as machinery or draft animals, has led several to posit that in the presence of weak credit markets, high transaction costs associated with rental markets will prohibit investment in mechanization (Binswanger & Rosenzweig 1986). However, the availability of smaller and cheaper machinery reduces this problem (Schultz 1964). Furthermore, evidence from northern Ghana demonstrates that a strong rental market for machinery services has overcome the lumpiness of investment in agricultural machinery.

Schultz (1964) challenged a number of old doctrines about the transformation of traditional agriculture. These prior views tended to assume (i) that larger farms were necessary for higher productivity and lower prices; (ii) that there is zero marginal productivity of labor in agriculture, and (iii) that there are factor indivisibilities for certain capital goods such as tractors. Schultz challenged all of these views. Instead of a focus on land size and mechanization, he argued that agricultural growth is driven more by the quality of material capital such as tractors and the capabilities of those engaged in agriculture. Farm size often is increased simultaneously with the change in technology, and other inputs may change as well – such as agricultural chemicals. It is also true that the change in labor per unit of land is ambiguous; it will depend on the change in labor requirements for other operations that have not yet been mechanized. The process of mechanization is one of change in relative factor use and of intensification through scaling up production. As these effects occur simultaneously in the farmer's decision to change technology, careful analysis is required to understand the drivers and impacts of mechanization in the local economy.

The mechanization of agricultural operations in Sub Saharan Africa has been low, especially among smallholder farmers, which dominate agricultural production (Mrema et al. 2008). In the 1970s and 80s, when state-led industrialization was popular with SSA governments in the post-independence era, public mechanization programs were common. This was also true of Ghana where state farms and the government's Operation Feed Yourself included promotion of mechanized agriculture. In order for this to benefit small-scale farmers, rental services for mechanized plowing and other services would be organized by the state. Pingali et al. (1987) documented the failure of these state-sponsored mechanization programs across SSA, which were not sustained by the private sector once government support was withdrawn. Reasons that were provided were that there was a lack of demand for machinery use among farmers on the one hand, and poor management of public mechanization programs on the other. In this context, the emergence of a private sector led rental market for tractor services is particularly interesting.

Apart from import data on agricultural machinery, there is little reliable information on the total stock of tractors and other machinery either currently or over previous decades. Diao et al. (2012) show import data from Customs and Excise that indicates that 200-900 pieces of agricultural machinery were imported annually over the period of 2002-2012. This is likely an over-estimate as the data may also include some construction machinery. Another indication is administrative data from the Ministry of Food and Agriculture, which shows that approximately 900 pieces of newly imported agricultural machinery have been distributed since 2007 under their mechanization programs. Whilst there is no clear data on the number of functional pieces of equipment in use, these data on government programs and imports indicate that there is a nontrivial stock of machinery in the country.

Furthermore, there is evidence of high level of agricultural machinery use amongst farmers from recent household surveys. The 2009-10 Ghana Socioeconomic Panel Study Survey that is a nationally representative survey of over 5,000 households in Ghana. The survey is a joint effort undertaken by the Institute of Statistical, Social and Economic Research (ISSER) at the University of Ghana, and the Economic Growth Centre (EGC) at Yale University[1]. It was funded by the Economic Growth Center. 31% of farm households across Ghana were using agricultural machinery for cultivation on at least one of their plots in 2009 (Table 1). Once this is broken down by region, 88-95% of farm households in the three northern regions used tractors for cultivation. The representativeness of this survey confirms that tractor use is not isolated to a few large-scale farmers but mechanized land cultivation is now standard amongst farmers of all scales in large parts of Ghana.

[1] Disclaimer: ISSER and the EGC are not responsible for the estimations reported by the analyst(s).

Table 1: Levels of tractor use in Ghana by region

Region	% of farm households using tractor on at least one plot	No. of farm households surveyed
Western	0%	262
Central	1%	156
Greater Accra	46%	28
Volta	24%	243
Eastern	4%	267
Ashanti	7%	181
Brong Ahafo	6%	282
Northern	95%	347
Upper East	88%	125
Upper West	95%	56
Total	31%	1947

Source: 2009-10 Ghana Socioeconomic Panel Study Survey, EGC-ISSER.

Ghana provides an excellent case study in which to investigate the impact that machinery use has on other farming decisions. As will be discussed below, the paper considers a positive shock to the supply of tractors and uses this shock to identify the impact of a household using machinery for land preparation on other farming decisions. In the process of mechanization, what are the associated changes to farm-level production and for the wider farming system? At the farm-level, what is the associated change in land and labor productivity, labor use per hectare, cultivated area, and crop choice? We focus on the short-term impact of increased machinery use of within season farming decisions. Subsequent work could look more widely at impact on the local economy, land distribution, and household time use.

The next section outlines theory regarding the changes that would be expected due to increased mechanization used. This is followed by discussion of the empirical strategy with its strengths and weaknesses. The results are then presented, followed by a concluding discussion.

II. Theoretical impact of mechanization use

Underlying the theoretical framework elaborated below, is the assumption that farm households are profit maximizers with regards to agricultural production. Farmers are profit maximizers and make choices within the season on the area cultivated for each crop, the type of technology to adopt, and the use of other inputs. Their ability to maximize is constrained by both their budget constraint, and the availability of each of these inputs to production. This assumes that not all input markets are complete. In particular, we assume that that hiring market for machinery services is incomplete. Based on qualitative interviews, farmers frequently indicate that they have to wait to receive hiring services from tractor service providers. It is not unusual that they plant late because they have waited for machinery services to plow their land, or that they end up cultivating less or a different crop. There is a peak demand for machinery plowing services over a 1-2 month period at the beginning of the farming season, and it seems that not all demand is satisfied by the current level of supply. For the purposes of this paper, the focus is on machinery use for land preparation (plowing) as this is the only operation that is mechanized by a large proportion of cereal-producing farmers in Ghana. The theoretical discussion which follows is routed in the work of Boserup (1965), Pingali et al. (1987), and Binswanger & Ruttan (1978), combined with observations from qualitative fieldwork.

Productivity

If only agronomy is considered, it is not expected that mechanized plowing will make any significant difference to the yield, compared to preparing the land by hand. The benefit of mechanization is to reduce labour inputs required for land preparation, with little impact on yield. However from observations and in the context of rain fed agriculture, the use of machinery reduced the time required for land preparation and ensures that farmers are able to plant within the optimal planting period. For crops such as maize (in northern Ghana), there is a limited planting period due to the longer growing period needed for maize and the volatile rain patterns. Therefore, I will test whether machinery use has an impact on yield, in addition to the direct substitution of labour.

We also expect use of machinery to lead to increased use of inorganic fertilizers. The reasoning for this is that getting timely access to machinery services will lead farmers to cultivate higher value crops, such as maize, which also require higher levels of fertilizer use. By removing one constraint on farmers profit maximization (i.e. access to machinery services), they will be motivated to make investments in modern inputs.

Land

The total land available for farming is constrained, but moreover, the individual farmer is constrained in accessing land due to non-market allocation mechanism. Land allocation in Ghana is governed by the traditional tenure system. Family land was allocated in previous generations and this is the primary land which an individual farmers access for agriculture. A farmer can easily cultivate more family land, but access to virgin or skin land will require either payment in formal market or negotiation with the local chief or farmers. Therefore, increased availability of machinery may or may not lead to a farmer increasing their cultivated area, depending on the ability to access more family land within the season. We assume that family land can be accessed costlessly within the season, but other land requires negotiation and search costs. The extent to which access to land is a constraint on the farming system will depend on the local population density. In areas with high population density, farmers may want to cultivate more land (e.g. as a result of accessing machinery services) but are unable to due to competition over land from other farmers and for non-agricultural uses.

Labour
As has been discussed above, we would expect to see labour inputs for land preparation to decrease when the farmer uses machinery for plowing. The impact on labour use for other operations is less clear. Where machinery has lead to an increase in the scale of cultivation, the labour in puts required for weeding, fertilizer application, harvest, and post-harvest processing will increase. The increase would be in total, rather an increase in labour use per acre for other operations. There is likely also an impact on intra-household labour allocation.

Women are able to cultivate more land. Traditionally, women are less able to participate in communal labour due to reproductive activities in the household, and household labour may be prioritized for 'main' plots. In this way, not only will increased availability of machinery increase the total area cultivate, but it will disproportionately increase the land area that women are cultivating. The corollary of this, and of reduced household labour use for agricultural activities, will mean children's attendance at school increase. Women often cite using their income from farming to pay for school fees.

III. Empirical strategy

Over the long term, areas with high agricultural potential (good agro-ecological conditions, and proximity to markets) will attract investment in infrastructure and investment in modern technologies. Therefore, mechanization use is highly endogenous to many of the left-hand side variables described. The main strategy to tackle this is to instrument for farmer mechanization use using exogenous variation the district machinery stock due to phased introduction of a government mechanization program.

Household survey data
The 2009-10 Ghana Socioeconomic Panel Study Survey that is a nationally representative survey of over 5,000 households in Ghana. The survey is a joint effort undertaken by the Institute of Statistical, Social and Economic Research (ISSER) at the University of Ghana, and the Economic Growth Centre (EGC) at Yale University[2]. It was funded by the Economic Growth Center. The survey includes approximately 2,800 households that responded to a detailed agricultural module relating to the 2009 main season. Survey was administered over November 2009 – April 2010 and questions were asked of the last main season and the last minor season. Our attention is on the last main season that would have been May-October 2009. The data currently available is a single cross section, although subsequent rounds of the panel survey are to be made available in due course.

[2] Disclaimer: ISSER and the EGC are not responsible for the estimations reported by the analyst(s).

Instrumenting for machinery use

Over 2008-2009-2010, the government distributed packages of 5-7 tractors and implements to entrepreneurs under hire purchase arrangement, and with subsidized cost. The machinery was imported new from India and Brazil. The distribution was phased, coinciding with each round of imports. The documentation relating to the program indicated that allocation was based on (i) having one mechanization centre per district, and (ii) that the entrepreneur demonstrate ability to pay and operate a hiring business with the machines. From interviews with government officials involved in the program, there is no indication that the selection of districts in each phase was based on prioritizing areas with more agricultural potential, or with a deficiency in tractor stock. In fact, there is no record of the stock of tractors by district in Ghana. This administrative data on the district location and the timing of machine delivery will be exploited to create treatment and control groups. The treatment group is those districts for which a mechanization centre received a package of tractors before the 2009 main season (April 2009). The first control group is those districts that received a package of tractors after the 2009 main season. The second control group includes all the other districts in the survey that did not receive a package in pre April 2009. Table 1 indicates the survey coverage in terms of districts and households, by treatment and control group. A total of 848 surveyed households are included in the treatment and control districts.

Whilst there is no policy documentation indicating a systematic selection of districts between the two rounds, the selection into the two groups cannot be considered random. There are likely political and undocumented reason for the phasing of the government intervention that could well be correlated with machinery use. Table 2 considered a range of variables which are unaffected by the intervention but may be related to the uptake of machinery services. I also draw upon the drivers of mechanization use that have been theorized in the literature by Boserup (1960), and Binswanger, Pigot, and Pingali (1987). These works consider mechanization as a component of the process of agricultural intensification, which, over the long term, is driven by population pressure and by the underlying agro-ecological conditions that make mechanization both feasible and favourable for farmers. An example of this is the rapid re-growth of weeds between seasons in tropical agriculture, including Ghana, which can make plowing by machine necessary given time constraints. Also, land that has heavy soil requires more effort to hoe or plow, therefore areas with these soil characteristics are more likely to be using machinery. The importance of the government intervention for increasing farmers' use of machinery will also depend upon the relative cost of land, labour, and capital (Binswanger & Ruttan 1981). In this case, we are effectively reducing the price of capital (machinery services) by a supply shock. The extent to which this induces farmers to use mechanized technology, instead of manual labour, will depend upon the relative availability (and cost) of land and labour. This is accounted for in the model through controlling for district-level population density.

Controls for population density will be included in the regressions model. Population data is from IPUMS and uses the Population and Housing Census conducted in 2010 and 2000. To control for agro-ecological conditions, a farmer-reported variable describing the type of soil in their land is used, as well as regional dummies that account for the diversity in farming conditions across the country. A control for household size is also included as table 1 indicates this is significantly different across the two groups.

Table 3 shows the results of a first stage regression of tractor use (by the household on at least one plot), on treatment dummy, household size, district-level population density, percent of land that the farmer describes as heavy clay soil, and dummies for each region. Each of the models indicates that being in the treated group increases the probability of the household using machinery by 8-10 percentage points. The coefficient is significant across the specifications and the F statistic for the join significance is consistently greater than the rule-of-thumb value of 10. This indicates that the instruments is valid and is partially correlated with tractor use.

The model is estimated using OLS and IV methods. The IV method is use both using OLS for the first stage regression, and probit for the first stage as the endogenous variable is binary. Tables 5a-e show the results of the IV regression, including reporting the F statistic from the first stage to test for the significance of excluded instruments. As discussed in Stock & Yogo (2002), this F statistic can be compared to the relevant critical value as a test for weak instrument[3]. From this test, it seems the IV method using probit in the first stage is a better estimation method and there is more evidence that the resulting instrument is strong. As a further robustness check, the model was estimated with two instruments using the heavy clay soil variable. The results were very similar for the coefficients and their significant, although the F statistic form the first stage improved. Whilst the soil type has a big impact on the ease of hand hoeing versus machinery use, it is hard to argue that it is exogenous to the outcome variables related to output, labour use, and crop choice.

The question of not only whether the instrument – situated in a treated district – is valid but is strong is an important one. In small samples and with a weak instrument, the estimated coefficients may be biased and the standard errors are very large, making it difficult to find a conclusive relationship. This should be borne in mind as the results are discussed in the next section.

IV. Discussion of results

For each of the outcome variables of interest, I will discuss both evidence of correlation with tractor use, and also what evidence there is that any causality can be attributed to the

[3] For one endogenous regressor, one instrument, 5% significance level, and a desired maximal size of 0.25 for a 5% Wald Test of B=Bo, the critical value is 5.53. If the F-stat is greater than the critical value, we reject the null of a weak instrument, and can conclude that the instrument is strong.

increased use of machinery, as a result of the government-induced increase in supply of machinery services.

Table 5a shows the results for both land and labour productivity. No significant relationship between productivity measures and tractor use is found. Although not significant, the association between yield and machinery use is positive. The F statistic on the first stage regression for the IV-probit model indicates the instrument is strong, therefore it could be concluded that there machinery use has not effect on yield or labour productivity. One caveat to this is that the model is only run on a single year, 2009, therefore the lack of a significant effect may be due to weather shocks in that year, which counteract any positive effect of machinery use. In addition, survey recall data on farm output and plot measurement can make yield and labour productivity unreliable variables.

Given the year-specific weather shocks that can affect the resulting output from agricultural production, the farmers' decisions over use of land, fertilizer, and labour are better indicators of the farmers' response to increased use of machinery. These decisions are made at the beginning and during the growing season and under more direct control of the farmer. We are interested in how these within season farming decisions are affected by the use of agricultural machinery.

There is no significant effect of machinery use on area cultivated for all crops, neither using the OLS nor IV estimation methods (Table 5b). To some extent this is counter intuitive as the expectation would be that machinery use is associated with larger farm sizes due to scale economies. However, this result likely reflects the constraint of access to land, especially within the short time frame of the empirical approach. The result provides some evidence that farmers either do not have uncultivated land which they can easily begin to cultivate, or that farmers are restricted in the working capital for land preparation and other inputs that is available to them to increase the scale of production, or even with increased use of machinery farmers will allocate their resources to non-agricultural activities rather that increase the scale of production. Another hypothesis from the theoretical framework was that farmers would increase cultivation of maize when using machinery for plowing, due to its short planting season and higher market value. There is some evidence of a significant association between the area cultivated with maize and machinery use. However, the significance disappears and sign chances when endogeneity is accounted for in the estimation. The evidence may indicate that it is those farmers in areas that are appropriate for maize cultivation that are more likely to use machinery, rather than machinery inducing farmers to plant more maize.

Farmers that use tractors for plowing are associated with higher levels of fertilizer use for all crops, as well as for maize cultivation (Table 5c). The low response rate for the section on fertilizer use has reduced the sample size for these estimations; therefore the IV regressions should not be given much weight. The relationship between fertilizer use and machinery use may be due to maize cultivation being associated with machinery use, and fertilizer use is more prevalent with maize cultivation, than other crops in Ghana. It may be due to the greater confidence farmers have to make investments in modern inputs when they have been able to plowing their field at the right time in the season due to machinery use. When planting is done late, the risk with fertilizer application is that there will not be adequate rain to harness the benefits of fertilizer for seed growth.

Finally, I consider the effect of machinery use of labour use. For land preparation, farmers using machinery are also using less labour hours for land preparation (Table 5d). However, using the IV-probit estimation, we find that the relationship is not significant. An explanation for this may be that mechanization induces farmers to bring into cultivation land that has not been cultivated recently, or has as considerable re-growth of weeds between the seasons. In this case, labour will need to be used to do initial clearing of the land by hand or using herbicide before tractor plowing can be used to do the final preparation for planting. Use of tractor does significantly increase the labour hours used per hectare for all operations. This evidence is consistent with the idea that machinery use allows farmers to increase their investments in labour-intensive activities of field management (weeding, planting, chemical application), as the risk of poorer yield due to late planting has been reduced. Table 5e considered the effect of machinery use on the total labour use. There is no significant relationship found, which is consistent with finding to associated increase in area cultivated. Farmers are neither increasing their scale of production, nor the total labour use, for agricultural production.

V. Conclusions and further work

Overall, we can conclude that in the short term, the use of machinery for land preparation will lead to increased labour use per hectare, and is associated with higher levels of fertilizer use. This is consistent with the theory that my improving the supply of machinery services, farmers are able to access and use machinery services more reliably. This enables farmers to make within-season investment decisions to improve their output per ha. There is no conclusive evidence that machinery use is associated with increased area of cultivation or with improved productivity itself.

Several of these conclusions appear contradictory to theory and perceptions of machinery use i.e. that it leads to increased area of cultivation, and that it reduces the labour requirement for cultivation. The fact that farmers in Ghana may be constrained in increasing their area of cultivation due to population density and land institutions, does not appear to be a barrier to use of machinery for land preparation. Furthermore, the farming system overall is still highly labour-intensive, despite mechanization of land preparation. In fact, the evidence seems to suggest that farmers invest more in inputs per ha when land preparation is mechanized.

We can imagine that the effect of increased supply of machinery services will benefit those more marginal farmers who previously were willing to pay for services but because of geographical isolation or poor social capital, were not receiving services or receiving services late. Therefore, it would be interesting to explore whether there are heterogeneous treatment effects, based on geographic or social marginalization. Finally, inter-household time use across reproductive, agricultural, and non-agricultural activities will likely be affected by the change in labour requirements for agricultural production. For example, qualitatively farmers claim that children are able to attend school more because mechanization has reduced the need for household agricultural labour and because women are able to farm more and use the income for child school costs. This analysis could be extended to explore these further hypotheses.

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Appendix – Data tables

*Note: for all tables * indicates p>10%, ** indicates p>5%, and *** indicates p>1%. Standard errors are reported in parenthesis.*

Table 1: Survey coverage, treatment and control groups

	No. of districts			No. of households		
Region	All survey	Treated	Control	All survey	Treated	Control
Western Region	10	0	1	295	0	23
Central Region	13	1	3	205	15	22
Greater Accra Region	4	1	1	38	20	7
Volta Region	14	1	2	277	36	76
Eastern Region	18	1	0	365	11	0
Ashanti Region	24	0	3	434	0	27
Brong Ahafo Region	19	3	2	354	32	28
Northern Region	18	3	7	494	74	204
Upper East Region	6	2	1	198	68	58
Upper West Region	5	4	0	163	147	0
Total	*131*	*16*	*20*	*2823*	*403*	*445*

Table 2: Balance between groups

	Control villages		Treated villages		P-value for equality of means
	Mean	N	Mean	N	
Female hh head	0.2	445	0.19	403	0.68
Age of hh head	49.41	445	51.14	403	0.12
Education level of hh head	19.83	155	20.28	121	0.49
Size of hh	5.26	445	4.85	403	0.04
Urban EA	0.08	445	0.07	403	0.60
Land owned by hh (ha)	2.63	437	2.55	401	0.70
% of land described as heavy clay	0.07	445	0.06	403	0.35
% of land described as less wet than local community	0.09	445	0.08	403	0.75
Population density (district, 2000)	80.14	445	99.83	403	0.01
Population density (district, 2010)	111.34	445	161.32	403	0.00
Average length of growing period (region)	227.03	445	207.67	403	0.00
Agricultural suitability index for maize (mean, region)	3961.09	445	4617.17	403	0.00

Source: Data from EGC/ISSER Socioeconomic Panel Survey, except: Population density source from IPUMS using 2000 and 2010 Population and Housing Census (Government of Ghana); and length of growing period and agricultural suitability index are from GAEZ database (FAOStat).

Table 3 – summary of impact variables

	N	Mean	Std. Dev.	Min	Max
Yield (maize only, in kg)	416	512.19	403.36	55.60	1647.33
Output per person day of labour (kg)	413	0.92	0.96	0.01	5.70
Area cultivated	796	2.51	2.65	0.04	24.28
Area cultivated - maize	448	1.43	1.50	0.12	12.14
Fertilizer use per ha (inorganic, kg)	133	90.49	106.03	0.31	741.30
Fertilizer use per ha (inorganic, for maize, kg)	108	85.45	101.94	0.31	741.30
Labour use per ha (land preparation, hrs.)	799	253.15	202.96	37.07	677.55
Labour use per ha (women, land preparation, hrs.)	593	84.21	81.32	8.57	266.87
Labour use per ha (children, land preparation, hrs.)	247	62.57	65.75	5.93	207.56
Labour use per ha (all operations, hours)	726	879.62	622.55	192.74	2265.91
Total labour use	734	1492.81	1120.84	219.00	3700.00
Total labour use (maize plots)	428	791.02	589.54	193.00	2246.00
Total labour use (women)	769	476.87	390.30	48.00	1269.00
Total labour use (children)	367	272.15	251.17	24.00	765.00

Table 4 – first stage regression

Dependent variable: Dummy for tractor use by hh on at least one plot

	(1)	(2)	(3)	(4)
treatment	0.09*	0.08*	0.10*	0.08*
	(0.04)	(0.04)	(0.04)	(0.04)
size of hh	0.04***	0.00	0.04***	0.00
	(0.01)	0.00	(0.01)	0.00
population density (district, 2000)	-0.00***	-0.00***	-0.00***	-0.00***
	0.00	0.00	0.00	0.00
% of land described as heavy clay			0.23**	0.16*
			(0.08)	(0.07)
constant	0.51***	0.14***	0.50***	0.13***
	(0.05)	(0.04)	(0.05)	(0.04)
region controls	no	yes	no	yes
adjusted R2	0.15	0.63	0.16	0.63
N	576.00	576.00	576.00	576.00
F statistic	43.84	641.51	37.03	518.42

Table 5a – Impact on productivity

	OLS	*OLS*	*IV*	*IV*	*IV-probit*	*IV-probit*
	Yield (maize)	Output per person day (kg, maize)	Yield (maize)	Output per person day (kg, maize)	Yield (maize)	Output per person day (kg, maize)
Tractor use on at least one plot	16.24	0	-284.18	-2.63	246.7	-0.33
	(69.83)	(0.15)	(571.85)	(1.65)	(248.77)	(0.52)
size of hh	13.31	-0.02	12.54	-0.03	13.68	-0.02
	(7.28)	(0.02)	(7.52)	(0.02)	(7.30)	(0.02)
population density (district, 2000)	0.75**	0.00**	0.61	0	0.85**	0.00*
	(0.27)	(0.00)	(0.38)	(0.00)	(0.31)	(0.00)
% of land described as heavy clay	-35.41	-0.16	53.5	0.52	-103.09	-0.08
	(98.89)	(0.28)	(180.46)	(0.57)	(121.12)	(0.30)
constant	-30.71	-0.08	-2.98	0.16	-178.65	0.01
	(80.56)	(0.16)	(98.18)	(0.24)	(283.79)	(0.61)
region controls	yes	yes	yes	yes	yes	yes
r2_a	0.06	0.04				
N	320	319	320	319	311	311
F-stat (2SLS)	7.09	12.55	6.96	10.17	3.03	3.37
F-stat (first stage excluded instruments)			2.87	4.75	11.15	11.47

Table 5b – Impact on area cultivated

	OLS	*OLS*	*IV*	*IV*	*IV-probit*	*IV-probit*
	Area cultivated (ha)	Area cultivated - maize	Area cultivated (ha)	Area cultivated - maize	Area cultivated (ha)	Area cultivated - maize
Tractor use on at least one plot	0.05	0.32*	-0.42	-0.82	-1.98	-0.16
	(0.21)	(0.16)	(3.46)	(1.70)	(1.33)	(0.49)
size of hh	0.18***	0.07*	0.18***	0.06*	0.18***	0.07*
	(0.05)	(0.03)	(0.05)	(0.03)	(0.05)	(0.03)
population density (district, 2000)	0	0	0	0	0	0
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
% of land described as heavy clay	-0.07	-0.40*	0	-0.13	0.29	-0.29
	(0.42)	(0.18)	(0.61)	(0.40)	(0.47)	(0.18)
constant	0.94*	1.71**	1	1.81**	2.84*	1.05
	(0.48)	(0.63)	(0.68)	(0.65)	(1.38)	(0.64)
region controls	yes	yes	yes	yes	yes	yes
r2_a	0.23	0.1				
N	556	347	556	347	496	333
F-stat (OLS/2SLS)	16.8	.	17.97	20.9	18	11.2
F-stat (first stage excluded instruments)			3.71	3.56	14	11.44

Table 5c – impact on fertilizer use

	OLS	*OLS*	*IV*	*IV*	*IV-probit*	*IV-probit*
	Fertilizer use per ha (kg)	Fertilizer use per ha, maize (kg)	Fertilizer use per ha (kg)	Fertilizer use per ha, maize (kg)	Fertilizer use per ha (kg)	Fertilizer use per ha, maize (kg)
Tractor use on at least one plot	89.64**	96.34**	-13.7	162.51	-105.45	0.43
	(32.50)	(31.78)	(691.25)	(770.48)	(318.18)	(376.17)
size of hh	-5.57	-3.55	-5.71	-3.78	-5.84	-3.22
	(3.96)	(3.35)	(3.74)	(5.05)	(3.94)	(3.97)
population density (district, 2000)	0.22**	0.22*	0.16	0.26	0.11	0.18
	(0.08)	(0.10)	(0.39)	(0.37)	(0.17)	(0.18)
% of land described as heavy clay	-24.06	-31.06*	-9.77	-39.13	2.92	-19.35
	(18.93)	(14.25)	(95.01)	(95.15)	(51.61)	(48.35)
constant	-3.22	-13.75	13.71	-21.35	198.85***	227.15**
	(29.10)	(32.04)	(111.25)	(84.60)	(49.87)	(71.81)
region controls	yes	yes	yes	yes	yes	yes
r2_a	0.25	0.27				
N	113	95	113	95	112	94
F-stat (OLS/2SLS)	.	.	7.65	7.91	3.43	4.58
F-stat (first stage excluded instruments)			4.33	4.74	4.21	4.02

Table 5d – impact on labour use per ha

	OLS	*OLS*	*IV*	*IV*	*IV-probit*	*IV-probit*
	Labour use per ha, land preparation (hrs.)	Labour use per ha, all operations (hrs.)	Labour use per ha, land preparation (hrs.)	Labour use per ha, all operations (hrs.)	Labour use per ha, land preparation (hrs.)	Labour use per ha, all operations (hrs.)
Tractor use on at least one plot	-70.44*	8.83	165.68	1643.96	26.53	874.44*
	(28.94)	(97.27)	(264.56)	(867.76)	(125.20)	(410.26)
size of hh	11.42***	18.04*	12.11***	23.40*	12.21***	21.97*
	(2.82)	(8.26)	(2.96)	(10.48)	(2.92)	(8.99)
population density (district, 2000)	-0.21*	-0.2	-0.04	1.15	-0.13	0.59
	(0.08)	(0.31)	(0.20)	(0.78)	(0.11)	(0.45)
% of land described as heavy clay	-21.29	177.18	-56.15	-232.68	-44.26	-49.37
	(24.95)	(135.89)	(50.96)	(289.54)	(34.85)	(193.31)
constant	394.96***	1553.78***	367.84***	1382.25***	128.83	-207.94
	(49.93)	(195.52)	(57.81)	(216.86)	(97.03)	(399.26)
region controls	yes	yes	yes	yes	yes	yes
r2_a	0.09	0.12				
N	555	506	555	506	500	472
F-stat (OLS/2SLS)	8.19	8	10.95	5.76	9.58	6.2
F-stat (first stage excluded instruments)			4.99	8.1	16.4	27.41

Table 5e – impact on total labour use

	OLS	*OLS*	*IV*	*IV*	*IV-probit*	*IV-probit*
	Total labour use, all crops (hrs.)	Total labour use, maize (hrs.)	Total labour use, all crops (hrs.)	Total labour use, maize (hrs.)	Total labour use, all crops (hrs.)	Total labour use, maize (hrs.)
Tractor use on at least one plot	54.77	77.7	2277.28	842.32	628.49	342.05
	(116.58)	(81.99)	(1233.76)	(678.00)	(506.36)	(315.67)
size of hh	115.52***	49.12***	122.72***	50.96***	119.42***	48.23***
	(14.56)	(10.43)	(16.90)	(10.48)	(14.96)	(10.34)
population density (district, 2000)	-1.19	-0.44	0.64	-0.05	-0.65	-0.31
	(0.65)	(0.24)	(1.22)	(0.44)	(0.79)	(0.30)
% of land described as heavy clay	33.63	-26.38	-519.66	-241.24	-148.45	-98.98
	(202.92)	(113.87)	(392.59)	(229.00)	(219.06)	(143.24)
constant	1361.35***	1516.84***	1127.91***	1441.82***	183.19	236.38
	(237.51)	(217.38)	(286.84)	(224.22)	(573.20)	(284.58)
region controls	yes	yes	yes	yes	yes	yes
r2_a	0.28	0.19				
N	511	331	511	331	477	323
F-stat (OLS/2SLS)	33.94	10.95	18.89	8.93	39.6	9.98
F-stat (first stage excluded instruments)			8.32	5.97	27.71	12.99