Are Women Less Productive Farmers? How Markets and Risk Affect Fertilizer Use, Productivity, and Measured Gender Effects in Uganda

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Abstract African governments and international development groups see boosting productivity on smallholder farms as key to reducing rural poverty and safeguarding the food security of farming and non-farming households. Prompting smallholder farmers to use more fertilizer has been a key tactic. Closing the productivity gap between male and female farmers has been another avenue toward achieving the same goal. The results in this paper suggest the two are related. Fertilizer use and maize yields among smallholder farmers in Uganda are increased by improved access to markets and extension services, and reduced by ex ante risk-mitigating production decisions. Standard ordinary least squares regression results indicate that gender matters as well; however, the measured productivity gap between male and female farmers disappears when gender is included in a list of determinants meant to capture the indirect effects of market and extension access.

Keywords: Smallholder farmers, productivity, gender, maize, Uganda

JEL codes: D13; O12; 013; Q12; Q18

1. Introduction

In Africa, many smallholder farmers are reluctant or unable to purchase fertilizer and apply it to the staple crops they grow, despite evidence that doing so would improve their incomes. This is worrisome for policy makers since fertilizer is needed to sustain the fertility of African soils and to take full advantage of the potential gains from new varieties of staple crops developed with smallholder farms in mind. Furthermore, the places where agricultural productivity is low are often also the places where households are disproportionately poor and rely more on agriculture for their livelihoods. The welfare and productivity of smallholder farmers are entwined with future gains in affordable food supplies for many African countries as well. The agricultural sectors of Sub-Saharan Africa are largely made up of small farms and there is evidence that the average African farm has become smaller rather than larger in recent decades (Lowder, Skoet and Singh 2014). Consequently, African governments, development organizations, and many NGOs see boosting productivity on smallholder farms as a key way to reduce rural poverty and safeguard the food security of farming and non-farming households (Otsuka and Larson 2013). In turn, finding ways to prompt African smallholders to use more fertilizer is often a key tactic in rural development strategies.[1]

In this paper, we examine the role general market participation has for smallholder decisions about fertilizer and the consequences for smallholder maize yields in Uganda. Many smallholder farmers growing maize in Uganda harvest two crops and we exploit a 2009-10 survey that covers both cropping seasons to

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[1] A partial list of organizations promoting smallholder productivity gains as a pathway for rural development includes the World Bank, FAO, IFPRI, AGRA and the Gates Foundation (Larson et al. 2013).

examine how diversification and other ex-ante risk mitigation strategies across growing seasons sets the stage for productivity outcomes.

Recently, some researchers have argued that poorly functioning fertilizer markets constrain smallholder productivity by limiting the availability of fertilizer and keeping its price unreasonably high. With this as prologue, we consider an empirical model of productivity in which the choice about using fertilizer is endogenous, but is constrained by market performance and social norms. Controlling for heterogeneous farm-gate prices using fixed spatial effects, we use instruments that address the informational, social, and financial constraints that might additionally limit fertilizer demand. The empirical model performs well overall and passes a variety of tests designed to detect problems associated with our choice of instruments.

An important empirical result from our research has to do with gender. In productivity studies, the gender of the farmer, included as an exogenous control, often suggests that women are less productive farmers than men. We find this as well in simple OLS regressions. However, the measured gender gap goes away once we use variables associated with market and extension interactions that are potentially influenced by traditional gender roles. The model is consistent with the notion that the gender of the farmer per se does not directly affect productivity outcomes, but does influence fertilizer purchases, which affect eventual productivity outcomes. The results indicate that what does matter for productivity outcomes are weather outcomes, and choices about input use and ex ante risk mitigation strategies.

The organization of this paper is as follows. Section 2 reviews the literature on the effects of market access, production risk, and gender on input use and agricultural productivity in developing countries. We describe the characteristics of our study sites in Uganda in terms of access to markets and maize yield variations in Section 3, and report regression results on fertilizer use, hired labor use, and maize yields in Section 4. We conclude by drawing implications for a potential African Green Revolution in maize in the final section.

2. Markets, Risk, and Decisions about Applied Technologies

The Role of Market Access

Providing better access to agriculture input and output markets is an often stated policy goal in African countries. The underlying rationale is that input markets provide key productivity-enhancing inputs that farmers cannot produce on their own and that markets are needed to vend surpluses. As a consequence, markets are often seen as the main driver of technology adoption (Boserup 1965; Pingali, Bigot, and Binswanger 1987; Binswanger and Pingali 1989; Rosenzweig and Binswanger 1993). What's more, recent evidence suggests that the intensification of farming systems over much of Sub-Saharan African countries has been more limited and less beneficial to farmers in comparison to tropical areas of Asia and Latin America, and several researchers point to poor access to markets or inefficient markets as root causes (Heady et al. 2013; Binswanger and Savastano 2014).

For example, Dorosh et al. (2012) find that adoption of high-productive and high-input technology declines with increases in travel time to urban center in Sub-Saharan Africa. In northwestern Ethiopia, Minten et al. (2013) find that transaction and transportation costs increased fertilizer prices at the input distribution center between 20 and 50 percent; Zerfu and Larson (2010) show that transportation time and other measures of remoteness explain the reduced use of chemical fertilizers by farmers in rural Ethiopia; and

Sheahan and Barrett (2014) find a downward trend between fertilizer application levels and distance to a major market center in Ethiopia, Malawi, and Nigeria. Another set of studies show how distance from market affects the price and availability of improved seeds in Africa (Heisey et al. 1997; Shiferaw, Kebede and You 2008; Yorobe and Smale 2012; Heady et al. 2013).

A related area of research investigates the underlying causes of high transaction costs. These studies examine both observable (tangible) costs, such the costs associated with transport, handling, packaging, storage costs and spoilage, and unobservable (intangible) costs, including information asymmetries, search costs, bargaining costs and the costs of enforcing contracts (Cuevas and Graham 1986; Staal et al. 1997; Hobbs 1997; Key et al. 2000; Holloway et al. 2000; Birthal et al. 2005; Jensen 2007).

Risks and Livelihood Strategies

Agricultural productivity outcomes observed in cross-country, household and farm surveys are highly heterogeneous and this implies that the choices farmers make about applied technologies are heterogeneous as well (Mundlak, Butzer and Larson 2012; Larson et al. 2014). This is partly explained by transaction costs and heterogeneous farm-gate prices, but other factors are thought to influence livelihood choices as well. In particular, the pervasive presence of uninsurable risk, poorly functioning labor and credit markets, and high transaction costs have been used to explain the diverse livelihood strategies of rural households, and choices about production technologies (e.g., Norman 1978; Morrison 1980; Feder 1985; Lipton and Lipton 1993; Rosenzweig and Binswanger 1993; Croppenstedt et al. 2003).

Without access to formal markets for risk, poor households implement ex ante risk mitigation strategies, often preferring to invest effort and resources in low-risk-low-return activities and technologies rather than in riskier but potentially more profitable alternatives (Binswanger and McIntire 1987; Rosenzweig and Binswanger 1993; Morduch 2005; Carter et al. 2007; Larson and Plessman 2009). Key ex-ante mitigation strategies also include farm management practices and crop diversification. This set of actions includes introducing different types and varieties of crops, planting the same crop at different times or on spatially separate plots, investing in soil and water management, and irrigating land (Bezabih and Sarr 2012; Kurukulasuriya and Mendelsohn 2007; Maddison 2007; Nhemachena and Hassan 2007). In addition, mixed crop-livestock farming systems are often used to diversify income, and manage soils and other farm resources (Hoddinott and Kinsey 2001; Yamano, Otsuka and Place 2011; Muraoka et al., forthcoming).

Still, risks are not fully mitigated, so many farming households also adopt ex post smoothing or coping strategies, often by reducing consumption, liquidating assets or drawing down savings. It has been shown that these behaviors have short-term negative welfare effects and income instability in the long run (Morduch 1995; Dercon 2004; Dercon and Hoddinott and Woldehanna 2005; Dercon and Christiaensen 2011; Hoddinott 2006; Kazianga and Udry 2006; Carter et al. 2007; Carter and Lybbert 2012). In addition, while effective in the face of idiosyncratic risks, these informal risk mitigation strategies can fail in the face of repeated or systemic shocks. Consequently, without adequate insurance markets for weather or price risks, households often come to rely on safety nets or periodic disaster relief interventions (Larson, Anderson and Varangis 2004; Skees et al. 2005).

Gender and Agricultural Productivity

A fairly consistent finding in the literature is the negative relationship between female-managed agricultural plots and agricultural productivity in Sub-Saharan Africa. Estimates from a number of studies suggest that the gender gap in agricultural productivity ranges from 4 to 40 percent. The finding of a gender gap is pervasive across studies that are quite heterogeneous, with differences in the representativeness of the data, the composition of households, the type of crop considered, model specification, and estimation method (Akresh 2005; Alene et al. 2008; Gilbert et al. 2002; Goldstein and Udry 2008; Peterman et al. 2011; Oladeebo and Fajuyigbe 2007; Quisumbing et al. 2001; Saito et al. 1994; Tiruneh et al. 2001; Udry 1996; Hill and Vigneri 2014; Palacios-López and López, forthcoming 2015; Kilic et al., forthcoming).

A set of overlapping reasons have emerged for the gender gap in agricultural productivity. These include a reduced tendency to use agricultural inputs and improved technologies; gender-linked barriers to markets and credit; lower investments due to land tenure insecurity; lower stores of human and physical capital, and informal and institutional constraints (Peterman et al. 2011). Nevertheless, differences in input use by gender is a leading proximate explanation for the gender gap in agriculture, and a focal point for most policy recommendations (Palacios-López and López, forthcoming ; Kilic et al., forthcoming).

The role of input use in explaining the gender gap in agricultural productivity naturally leads to the exploration of gender differences in obstacles faced in agricultural technology adoption. Peterman et al. (2010) provide a comprehensive examination of the gender differences in the adoption of technology drawing from findings in 24 studies. Most (18) of the studies are based on inorganic fertilizer use and they conclude, after controlling for several factors such as differences in land endowment, that access to other relevant agricultural inputs, education, and endowments, the rate of adoption of inorganic fertilizer is similar between men and women. What's more, there is some evidence that technology adoption rates may be higher for females. A recent study by Fisher and Kandiwa (2014) found that the subsidies for seed and fertilizer increase the probability of adoption of improved maize for female headed households in Malawi, thereby reducing the gender gap in the adoption of modern technologies.

3. Markets and Productivity in the Study Area

The Geography of Market Participation

Figure 1 is a map showing the location of cities in Uganda with more than 20,000 inhabitants and the road network connecting them. The map also reports the average share of agricultural production (by value) that households sell. To be clear, this is not the share of maize sold, but rather the accumulated value of all agricultural goods produced and sold. The shares are calculated for each household and averaged for each enumeration area, the basic area-based unit from the sampling strategy.

In general, the map shows that rural households are clustered around major roads and that market shares are also higher near major roads and cities, although there are exceptions. However, it is almost always the case that enumeration areas where the share of production marketed is less than 10 percent are situated in remote places. What is perhaps most surprising is the overall low share of marketed output in Uganda. In most enumeration areas, less than 40 percent of output is marketed.

Yields and Seasonal Outcomes

Table 1 reports sample statistics for the data used in our analysis for the sample as a whole and sub-set averages for male and female-headed households. Maize yields, reported at the top of the table, are production weighted averages. The average yield of 1.2 tons per hectare is lower than the average in SSA, which is more than 1.5 tons per hectare. As discussed, there are two growing seasons for maize in the southern and eastern sections of Uganda. Figure 2 shows weather outcomes and the gray area in the right-hand portion of the figure indicates the parts of Uganda that are generally not favorable for a second maize harvest.

The map also shows the spatial variation in moisture, measured in terms of Water Requirement Satisfaction Index at the close of each growing season. The index is crop specific and, in this case, indicates whether or not the soil moisture is adequate for a healthy maize crop. The map shows that weather conditions were dry during the first season of our sample, with severe weather to the west of Lake Victoria and along the northern section of the Kenyan border. Weather during the second season was much better with average to excellent conditions through the south-western part of the country.

As is frequently the case for smallholder producers in Africa, the seasonal distribution of yield outcomes, shown as thin lines in Figure 3, and the weighted average, shown as a histogram, are skewed toward low-yield outcomes, with a long tail containing higher yields. The first-season distribution is more skewed to the left than the distribution of second season yields, consistent with the relative weather outcomes.

Returning to Table 1, there are some differences in the sample averages for male and female-headed farms; however the differences are not compelling in either an absolute or statistical sense. Female farmers obtained slightly lower yields than did male farmers. Most farmers sold very little of what they produced. Few farmers in the sample received visits from an extension agent, and women received fewer visits than men. Female-headed farms used less fertilizer and more family labor. They were slightly less likely to participate in markets – to sell their produce, buy fertilizer, or hire workers -- than male-headed farms (reported in the lower rows of Table 1). They were also less likely to report additional income from wages or a household-owned business. Most farmers did not use improved maize seeds, although men were more likely to do so.

Farmers planted slightly more than half of their maize plots as pure stands, with the rest planted in a mixed crop setting. Additionally, it was not uncommon for the same farmers to devote some plots exclusively to maize while mixing maize with other crops on other plots or switching from pure to mixed stands according to the season. Figure 4 plots maize yields against the share of pure-stand plots on each farm. As the graph shows, many farmers used a combination of cropping systems and there was no observable pattern for associated yield outcomes.

The table also reports total area planted with maize for both seasons rather than seasonal average. In general, farms are small (nearly 70 percent of the farms planted less than 2 hectares to maize per season) and the averages in the table are inflated by a small set of larger farms. Farmers tended to manage multiple crops (an average of about 5 unique crops across growing seasons) and multiple plots on the same farm. The fragmentation statistic reported in the table gives the ratio of the area planted with maize divided by the number of plots that the farmer managed and is intended to give a notion of overall land fragmentation relative to production scale. On average there were only minor differences between men and women on the diversification and fragmentation measures.

To finish the comparison, female-headed households were slightly older than their male peers and they headed households with slightly fewer family members. They also had slightly lower stores of wealth. For the year, total rainfall amounts were slightly above the long-run average, and roughly the same for male and female-headed households. On average, the rains came on time, missing the ten-year average start time by less than a week for both seasons.

The maize production system in Uganda is different in key ways from the Kenyan system described in Muraoka et al. (forthcoming). As in Uganda, pure maize stands are not common in the highlands of Kenya and many farmers intercropped maize and beans. However, in contrast, most Kenyan farmers in their study applied manure and more than three-quarters applied chemical fertilizer; 78 percent used improved seeds. As a consequence, the farmers in the Kenyan study achieved yields that were about 75 percent higher.

4. Estimation Results

The estimation strategy we employ entails two steps. As discussed, few farmers in our sample used fertilizer or hired workers, resulting in a truncated set of observed values populated with many zeroes. To explore why, we used a tobit regression, in which observations of fertilizer use per hectare are regressed against the farmer's gender and six additional variables related to markets, household assets, knowledge and social norms participation and household financial and labor resources. The results from the regressions are reported in Table 2. The tobit regression results are of interest on their own and are also useful for our estimation strategy, as we use the predicted values from the regressions as instruments in an IV regression to explain maize yields. The approach addresses the endogeneity of the truncated input observations, thereby avoiding the so-called forbidden regression problem.[2]

Step One Results

The results in Table 2 suggest that farmers who participated in output markets were more likely to use fertilizer and employ workers. There are potentially two channels: the sales may provide the liquidity needed to purchase fertilizer, and market participation may also provide vent-for-surplus opportunities – the ability to profit from producing more than can be consumed (Myint 1971; Hayami 2001). Higher population densities can lower transaction costs through scale and tighter information channels, providing greater opportunities for farmers. Also according to the Boserupean and induced innovation hypotheses (Boserup 1965; Hayami and Ruttan 1985), higher population density stimulates the adoption of land-saving technology, including the application of chemical fertilizer. The associated coefficient, positive and significant in the fertilizer demand regression, is consistent with this notion. Labor markets are likely more fluid where populations are denser. This can make it harder to find farm workers, since farm wages are usually lower than non-farm wages, an idea that is consistent with the negative and significant coefficient in the hired labor regression.

Surprisingly, coefficients on the two variables that might address liquidity constraints, household wealth and non-farm income had no measurable impact on fertilizer demand. In contrast, the variables helped explain choices about hiring workers significantly, suggesting higher opportunity costs for wealthier farmers and farmers who engaged in other money-making activities.

As mentioned, only 23 percent of the households in our sample were visited by extension agents; however, those that were called upon were more likely to use fertilizer and hire workers. This finding is consistent with results reported in Kijima (forthcoming) for rice production in Uganda. The household head's

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[2] See Wooldridge (2002, p. 236) and Angrist and Pischke (2009, p. 190).

gender mattered for fertilizer use, with women significantly less likely to use fertilizer than men. In contrast, a farmer's gender did not appear to affect worker hires.

Productivity

The estimated yield equation includes five inputs, land, chemical fertilizer, manure, household labor, and hired labor. It also includes additional variables related to risk management, farmer characteristics and weather outcome. The equation's parameters were estimated using a fixed-effect OLS regression and also using an instrumental variables (IV) regression with fixed effects. As mentioned, predicted values from the fertilizer and hired-labor tobit regressions reported in Table 2 were used as instruments in the IV regression. Before proceeding to a discussion of those results, it is worth explaining why the remaining inputs were not instrumented.[3]

Maize area: As has become standard practice, the decision about how much area to plant to maize is treated as non-contemporaneous and therefore predetermined in the regression.[4] The notion here is that cropping decisions are made ahead of choices about inputs. **Manure** is treated as an exogenous household resource, since it is seldom traded. As a consequence, the availability and use of manure depends on a priori decisions about whether or not to include livestock on the farm. In this sense, manure applications are predetermined in a way similar to area planted to maize. **Household labor**: Our survey data on the number of days household members devoted to maize production proved problematic, which ultimately led us to use an exogenous proxy in its place.

To understand this last point better, it is important to note that household labor measures are notoriously inaccurate, often with a bias toward inflating reported labor days (Beegle, Carletto and Himelein 2012). We find indirect evidence of this in our sample, with the distribution of household labor days per hectare skewed by a string of high-valued observations. This is illustrated by the box-plot shown in Figure 5, which condenses key aspects of our sample labor data into a single form. The top of the rectangular box shaded in the figure marks the 75th percentile of the data range, while the bottom "hinge" markets the lower 25th percentile. The "whiskers" extend another 1.5 times the interquartile range of the nearest quartile. The white line marks the median of the data. Intuitively, the range of the box delineates observations that are typical. The whiskers contain values that are somewhat atypical relative to most observations, while the dots mark observations that are extreme. Consistent with the tendency to over-report, the observations contain a number of suspiciously large values. Consequently, we decided to use an exogenous measure, available labor – that is the number of household members between the ages of 14 and 60 – to proxy household labor input, obviating the need to include household labor days as an instrumented variable.

With this as background, mean-valued elasticities from the second-stage are reported in Table 3.[5] For comparison purposes, elasticities from a corresponding OLS model are reported as well. In both estimation exercises, enumeration-area dummies were included to account for location effects; the effects are expected to sweep up the effects of any unmeasured differences in relative prices, market conditions, travel times and

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[3] We also estimated a version of the model that included self-reported use of "improved seeds" as an input. Including the variable had no significant consequences for our analysis; however, we report the results in Annex Table 2 and Annex Table 3.

[4] See Antle (1983) and related discussion in Larson et al. (2014).

[5] The estimated parameters themselves are reported in Annex Table A.1.

average soil and climate endowments. The regression suggests that location matters as the location dummies were statistically significant and explained a significant portion in the variation in yields.

Focusing first on the IV estimates, the results show that using fertilizer boosts yields in a statistically significant way. However, the average effect is not large, with an elasticity less than 0.10 evaluated at average values for yield and fertilizer use. There is a small, but statistically insignificant impact on yields from manure use. Higher levels of available family labor and hiring farm workers boost yields in a measurable way; at mean levels, the effects are not large and similar to the elasticity for fertilizer. As is often the case with maize in Africa, the elasticity of area is negative, although not significantly so.[6]

In terms of risk management strategies, the results suggest that growing maize in dedicated plots does not boost yields but rather reduces them. It is difficult to say exactly why this is the case, but it is consistent with the fact that very little of the maize grown in Uganda is harvested from pure-stand plots. It is also possible that nitrogen-fixing crops, such as beans, help compensate for low levels of applied chemical fertilizers. As discussed earlier, this type of intercropping is prevalent in the Kenyan highlands.

The IV results also suggest that farmers that diversify their risks by growing several crops also achieve higher yields, perhaps because they are able to use riskier-but-more profitable production strategies. However, diversification comes at a cost as it also results in fragmentation; the diversification elasticity is estimated at 0.167, while the fragmentation elasticity is at -0.084, suggesting that, in practice, the diversification benefits are partially off-set.

Weather mattered as much as any input for the rain-fed maize farmers in our sample, a finding consistent with observed risk mitigation strategies. Keeping in mind that conditions during the first growing season were dry, the results suggest that a 1 percent gain in rainfall would increase yields by 0.08 percent. The results suggest that the slightly late arrival of first-season rains had a small but statistically significant negative effect on yields. Average rainfall for the season was near climate averages, and the small differences did not have a measureable impact on yields.

In terms of farmer characteristics, age and gender did not appear to affect yields. The IV estimates suggest that that farmers, male and female, young and old, achieved identical yields, once other factors have been accounted for.

Gender and Estimation Method

As discussed, the lack of a gender-effect in our IV estimates is at odds with results from the OLS model. As Table 3 shows, most of the estimated coefficients were robust to the choice of estimation technique; only three of the thirteen estimated coefficients went from significant to non-significant or vice versa. Two of the changes had to do with the area planted to maize and the share of pure stands planted, and the differences are marginal. In the case of gender, the negative elasticity estimated under OLS is small, but significant at the 5 percent threshold. When instruments are used the estimated effect is quantitatively and statistically indistinguishable from zero.

Table 4 summarizes a set of tests concerning the validity of our instrumentation choices. The tests and the software used to generate them are described in Baum, Schaffer, and Stillman (2007). Overall, the tests

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[6] See Larson et al. (2014) for a related discussion.

indicate that our identification strategy works reasonably well. The hypotheses that the tobit predictions are not relevant can be rejected for both fertilizer use and labor hires individually and taken together. Because two instruments are used to treat the two endogenous variables in our model, the model is exactly identified. The three tests reported in the next panel in Table 4 suggest that the hypothesis that this leads to under-identification can be rejected. The next panel shows the results from tests about the strength of the instruments. Here the results are mixed. Overall, the combined instrument test, given by the Cragg-Donald Wald F statistic, signals an adequate level of strength. When this is decomposed, it appears that some weakness is associated with fertilizer use. Nonetheless, the next three tests reject the hypothesis that the instrumentation is weak and that this would reverse tests of significance for fertilizer and hired labor in our IV results.

5. Conclusion

Fertilizer, more so than other inputs, is considered an entry point for utilizing the improved technologies developed by scientists with smallholder farmers in mind. It is also a key element of the technologies that drove Asia's Green Revolution. However, the data show that the production technologies employed by maize farmers in Uganda are highly varied, with farmers sometimes employing a mixture of strategies across seasons and among the separate plots that comprise their farms – farms that are often smaller than one hectare. In addition, outcomes from the varied technology choices do not follow the clear relationships between modern monoculture production techniques and improved yield found in organized field trials. In particular, it is hard to distinguish performance patterns when yield outcomes are graphed according to decisions taken by farmers to grow maize in pure stands or in mixed-crop settings.

Our study suggests that markets and ex ante risk mitigation strategies in the face of uninsurable risks contribute to the mixture of applied technologies employed by the maize farmers in our study. Social norms regarding gender seem to matter as well, most likely by limiting female farmers' access to markets and information, which leads eventually to lower yields.

Maps constructed for this study reveal the propensity of smallholders to locate near cities and transportation corridors and also the propensity of those households with better access to markets to sell more of what they produce. Our estimation results indicate that this also leads households to use more fertilizer when they grow maize.

Additional empirical results show that weather variations around climatic norms affect yields, as would be expected. Since insurance markets are lacking and the capacity to self-insure or borrow in bad times is limited, nearly all of the farmers in our study diversify production. But because farms in Uganda are small, diversification leads to fragmentation, which reduces yields. At the same time, growing maize in mixed stands, which may also help farmers manage risks, appears to improve yields, perhaps because it helps farmers manage the fertility of their soils. Still, mixed cropping comes at the cost of increased fragmentation given the limited area farmed by the smallholders in our sample.

After accounting for a variety of farming decisions, the results show that using fertilizer improves yields and that extension visits spurred fertilizer use, as did participation in output markets. However, even after adjusting for these factors, women who head farming households are less likely to purchase fertilizer than their male counterparts, which leads to a productivity gap. Using an instrumental variables approach motivated by the assumption that gender roles make it more difficult for women to interact with market agents and to receive extension information, we find that often observed gender-linked productivity disparities between female farmers and their male peers disappear. For policy, this suggests that lowering market and information hurdles for female farmers through female-focused programs and extension can directly boost productivity, although the potential gains are small. Still, doing so will benefit a group of farmers that are, on average, disproportionately poor. What's more, helping women access agricultural markets may lay the foundation for entrepreneurial efforts outside of agriculture.

More broadly, most of the estimated input elasticities are low for the average set of input values. In addition, the collection of risk-mitigating activities, though likely well justified, have a comparable impact on productivity outcomes. Consequently, there is little in the results to suggest that policy instruments that marginally improve input markets will have a transformational impact on farm productivity and farmer welfare via maize production alone. In all likelihood, agronomic research to enhance the productivity and profitability of maize-based farming system is badly needed to realize a maize Green Revolution in Africa.

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Table 1: Sample statistics by farmers' gender in Uganda

	Male-headed households		Female-headed households		All households	
	mean	std. dev.	mean	std. dev.	mean	std. dev.
Maize yield (tons/ha)	1.22	0.79	1.14	0.73	1.20	0.77
Maize area (combined all seasons in ha)	4.27	3.32	3.29	2.74	3.99	3.20
Share of agricultural output sold, by value	0.26	0.29	0.21	0.26	0.25	0.28
Extension officer visited	0.24	0.43	0.19	0.40	0.23	0.42
Fertilizer use (kg/ha)	0.38	2.40	0.16	1.07	0.32	2.12
Manure use (kg/ha)	28.70	204.28	6.11	34.89	22.31	174.27
Family labor (days/ha)	65.17	66.35	82.08	136.89	69.95	92.22
Hired labor (days/ha)	4.88	9.48	5.05	9.35	4.93	9.44
Wealth Index (Principal Component)	-0.33	1.21	-0.58	1.23	-0.40	1.22
Wage or business income ($US)	0.82	2.73	0.19	0.63	0.64	2.35
Share of maize area in pure stands	0.54	0.33	0.56	0.33	0.55	0.33
Maize area/ plots managed	1.02	0.87	0.83	0.65	0.96	0.82
Number of crops managed	5.01	1.88	4.88	1.76	4.97	1.85
Age of household head	45.99	14.45	51.76	14.49	47.62	14.69
Family members, ages 14-60 per ha	1.35	2.09	1.14	1.63	1.29	1.98
Population density (people/sq. meter)	317.28	206.92	336.67	206.68	322.81	206.97
Difference from average rainfall (mm)	87.30	108.13	89.81	114.36	88.01	109.89
Late start for season 1 rains (weeks)	0.67	3.81	0.44	3.82	0.61	3.82
Late start for season 2 rains (weeks)	1.03	1.94	1.05	1.88	1.04	1.92
Market participation (share of households)						
Output sold	0.67	0.47	0.62	0.49	0.66	0.47
Fertilizer used	0.06	0.24	0.04	0.20	0.06	0.23
Improved seeds used	0.30	0.46	0.22	0.41	0.28	0.45
Manure used	0.14	0.35	0.09	0.29	0.13	0.33
Labor hired	0.58	0.49	0.53	0.50	0.56	0.50

Source: LSMS-ISA Uganda, 2009-2010.

Table 2: Fertilizer and hired-labor demand in Uganda, tobit results

	Fertilizer use		Hired labor demand	
Market indicators	Coef.	z-score	Coef.	z-score
Share of agricultural output sold, by value	4.51^{2}	2.28	5.03^{1}	4.17
Population density (people/sq. meter)	0.02^{1}	2.85	-0.01^{1}	-2.97
Liquidity				
Wage or business income ($US 1000)	0.16	0.59	0.37^{1}	2.55
Wealth Index (Principal Component)	0.22	0.40	2.56^{1}	7.84
Knowledge/Social norms				
Extension officer visited	6.58^{1}	4.19	3.03^{1}	3.53
Female head of household	-4.23^{1}	-2.67	0.84	1.04
Labor assets				
Family members, ages 14-60, per ha.	-2.66^{1}	-3.28	-1.19^{1}	-4.28
Constant	-32.30^{1}	-7.48	2.15	1.52

Note: The superscripts 1, 2 and 3 signify significance at the .01, .05 and .10 thresholds. Enumerator-area dummies were included as random effects.

Table 3: Maize yields in Uganda, and mean elasticities from OLS and IV regressions

	OLS regression		IV regression	
	Elasticity	z-score	Elasticity	z-score
<u>Inputs</u>				
Fertilizer use (kg/ha)*	0.013^{1}	5.40	0.097^{1}	2.50
Manure use (kg/ha)	0.001	0.61	0.004	1.12
Family labor (available/ha)	0.086^{1}	6.99	0.107^{1}	5.37
Hired labor (days/ha)	0.060^{1}	7.43	0.111^{1}	2.12
Maize area	-0.092^{1}	-3.10	-0.062	-1.44
<u>Risk management</u>				
Share of maize area in pure stands	-0.020	-0.66	-0.083^{3}	-1.73
Maize area/ plots managed	-0.057^{2}	-2.06	-0.084^{2}	-2.11
Number of crops managed	0.264^{1}	4.98	0.167^{2}	2.12
<u>Farmer characteristics</u>				
Female head of household	-0.019^{2}	-1.97	0.000	-0.02
Age of household head	-0.034	-0.71	0.043	0.58
<u>Weather effects</u>				
Difference from average rainfall (mm)	-0.056	-0.27	-0.175	-0.50
Late start for season 1 rains (weeks)	-0.040^{1}	-3.29	-0.080^{1}	-3.49
Late start for season 2 rains (weeks)	-0.035	-1.14	-0.063	-1.38

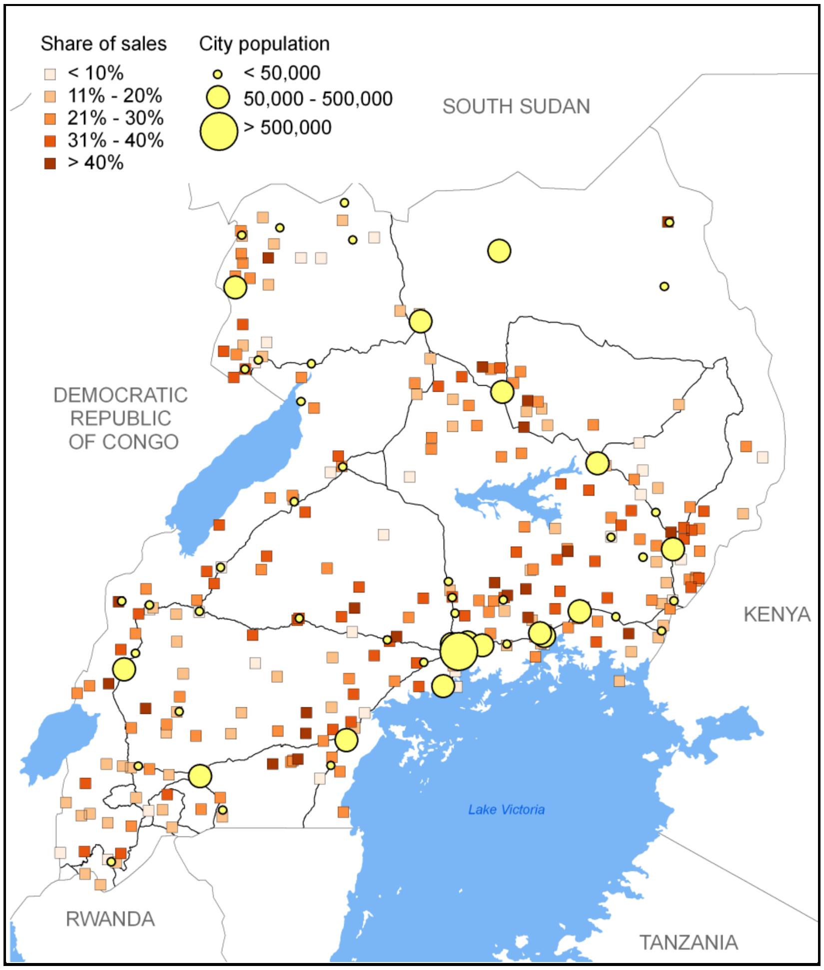
Note: The superscripts 1,2 and 3 signify significance at the .01, .05 and .10 thresholds. Both regressions included 215 fixed location-effects, which were significant in each regression at the .01 level. Fertilizer use and hired labor were treated as endogenous in the IV regression. The predicted values from the tobit regressions reported in Table 8.2 and their cross product were used as instruments. Available family labor is measured as family members, ages 14 to 60, divided by maize area planted. Underlying regression parameters given in Annex Table A.1).

Table 4: Tests related to the instrumental variables

Excluded instruments	
Combined instruments	F(1, 1391)=38.77^{1}
Fertilizer use	F(2, 1391)=5.89^{1}
Hired labor	F(2, 1391)=38.77^{1}
Under-identification test	
Combined instruments	Anderson LM χ2(1)=10.38^{1}
Fertilizer use	Angrist-Pischke χ2(1)=10.54^{1}
Hired labor	Angrist-Pischke χ2(1)=69.78^{1}
Weak identification test	
Combined instruments	Cragg-Donald Wald F statistic =5.18[b]
Fertilizer use	Angrist-Pischke F(1, 1391)=10.44
Hired labor	Angrist-Pischke F(1, 1391)=69.14[a]
Weak instruments robust inference tests	
Combined instruments	Anderson-Rubin Wald χ2(2)=29.68^{1}
Combined instruments	Anderson-Rubin Wald F(2, 1391)=14.70^{1}
Combined instruments	Stock-Wright LM S χ2(2)=29.06^{1}

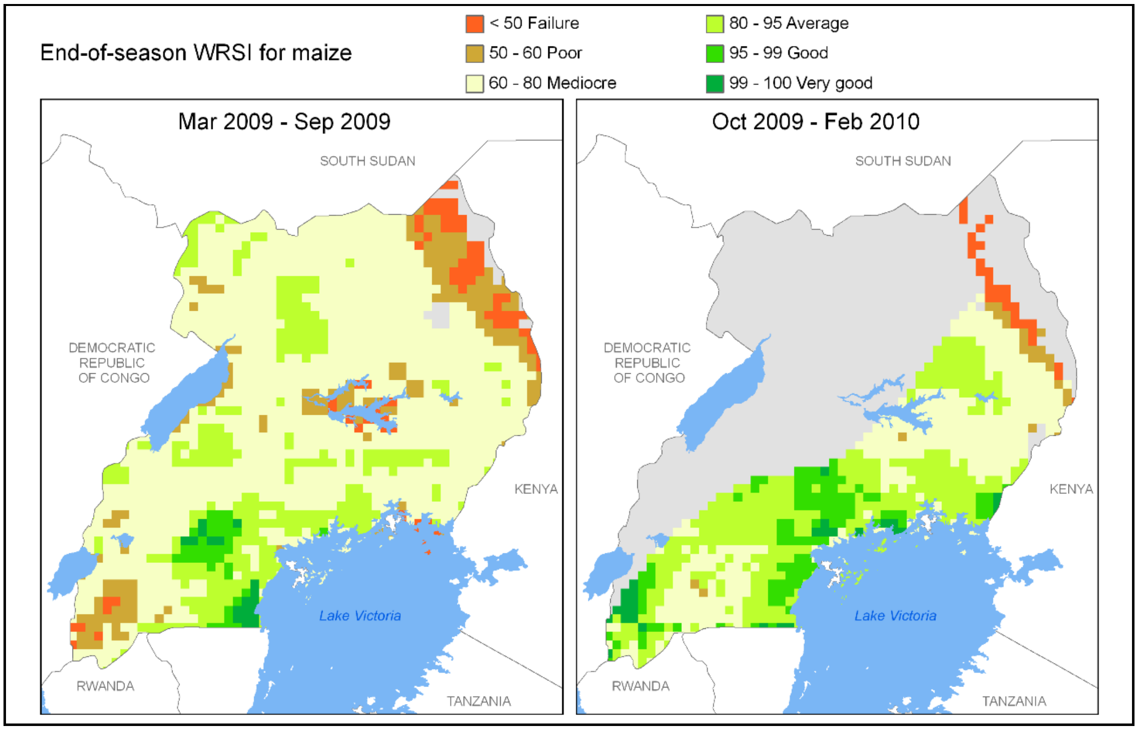
Note: The superscripts 1 and 2 indicate significance at the 0.01, and 0.05 thresholds. [a]Exceeds Stock-Yogo (2005) 0.10 critical value threshold (for a single endogenous regressor) of 16.38. [b]Exceeds Stock-Yogo (2005) 0.15 critical value threshold (when two endogenous regressors are exactly identified) of 4.58. The combined instrument test is the Agrist-Pischke multivariate F test. See Baum, Schaffer and Stillman (2007) for more on the estimation and interpretation of the tests reported in this table.

Figure 1: Average share of output sold by enumeration area, 2009-10.



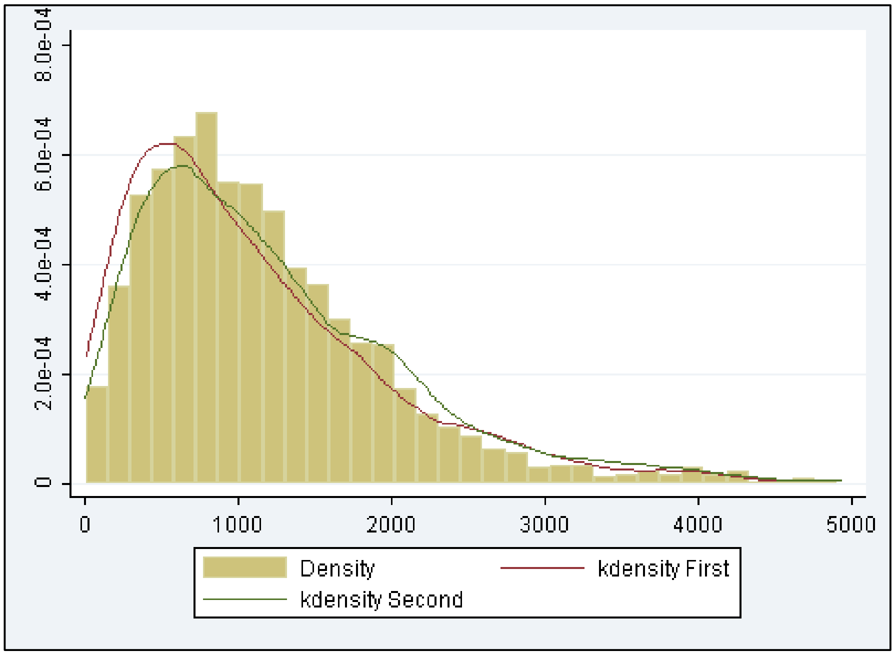
Source: LSMS-ISA (2014); Brinkhoff (2014).

Figure 2: Water Requirement Satisfaction Index for maize growing seasons in Uganda



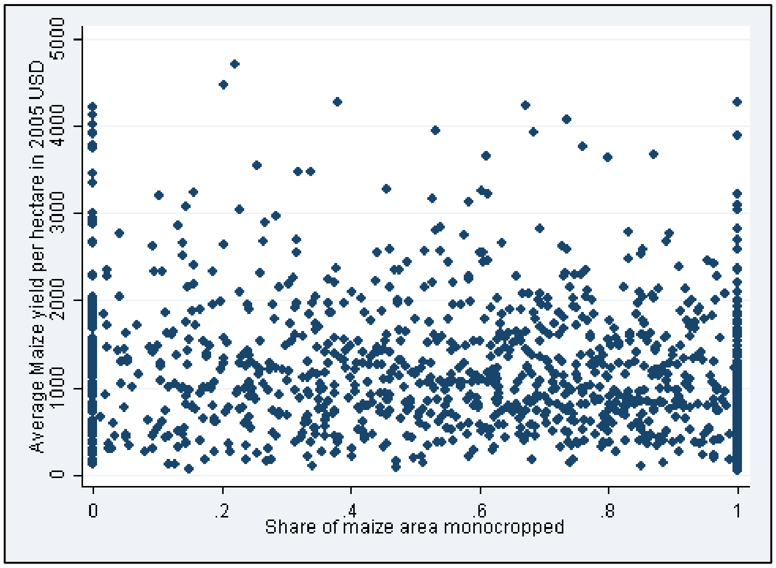
Source: WRSI computed using GeoWRSI software from USGS FEWS NET (2014)

Figure 3: Season 1 and Season 2 yields and weighted average yields.



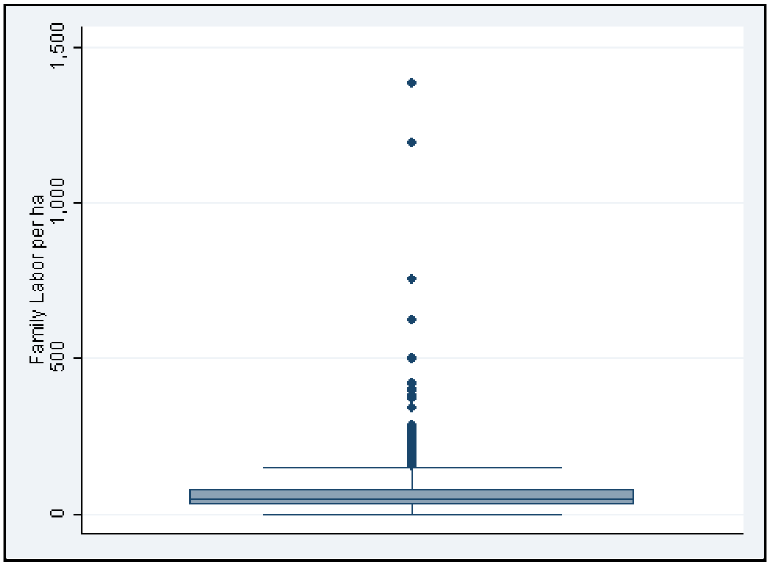
Source: LSMS-ISA Uganda (2009-2010)

Figure 4: Maize yields by production type



Source: LSMS-ISA Uganda 2009-2010

Figure 5: Outliers for family labor measures



Source: LSMS-ISA Uganda 2009-2010

Annex Table 1: Estimated coefficients used to evaluate the elasticities reported in table 3.

	OLS fixed-effects results				Instrumental variables fixed effects results			
	Coef.	Std. Err.	t-score	P>|t|	Coef.	Std. Err.	t-score	P>|t|
Inputs								
Fertilizer use (kg/ha)*	48.51	8.97	5.41	0.00	245.71	117.60	2.09	0.04
Manure use (kg/ha)	0.07	0.11	0.61	0.54	0.16	0.17	0.92	0.36
Family labor (days/ha)	80.39	11.46	7.02	0.00	91.09	15.47	5.89	0.00
Hired labor (days/ha)	14.65	1.96	7.46	0.00	23.74	10.79	2.20	0.03
Maize area	-27.65	8.91	-3.10	0.00	-19.56	10.87	-1.80	0.07
Risk management								
Share of maize area in pure stands	-43.17	65.13	-0.66	0.51	-137.58	88.30	-1.56	0.12
Maize area/ plots managed	-70.62	34.29	-2.06	0.04	-97.45	41.03	-2.38	0.02
Number of crops managed	63.79	12.79	4.99	0.00	45.49	16.02	2.84	0.01
Farmer characteristics								
Female head of household	-78.71	39.95	-1.97	0.05	-35.32	58.65	-0.60	0.55
Age of household head	-0.85	1.20	-0.71	0.48	0.58	1.56	0.37	0.71
Weather effects								
Difference from average rainfall (mm)	-0.77	2.82	-0.27	0.79	-1.63	3.89	-0.42	0.68
Late start for season 1 rains (weeks)	-78.72	23.88	-3.30	0.00	-115.32	32.22	-3.58	0.00
Late start for season 2 rains (weeks)	-41.04	36.07	-1.14	0.26	-58.84	43.16	-1.36	0.17

Note: Both regressions included 215 fixed location effects, which were jointly significant at the 0.01 threshold. The number of observations for the OLS and IV regressions were 1662 and 1617 respectively.

Annex Table 2: Elasticities for preferred model and alternative model that includes improved seeds.

	Preferred Model				Improved seeds included			
	Ordinary least squares		Instrumental variables		Ordinary least squares		Instrumental variables	
Inputs	Elasticity	z-score	Elasticity	z-score	Elasticity	z-score	Elasticity	z-score
Fertilizer use (kg/ha)*	0.013	5.40	0.097	2.50	0.013	5.23	0.178	1.94
Manure use (kg/ha)	0.001	0.61	0.004	1.12	0.001	0.62	0.006	1.04
Family labor (days/ha)	0.086	6.99	0.107	5.37	0.086	6.96	0.141	3.38
Hired labor (days/ha)	0.060	7.43	0.111	2.12	0.060	7.32	0.165	1.84
Area planted to improved seeds (share)					0.005	0.70	-0.212	-1.28
Maize area	-0.092	-3.10	-0.062	-1.44	-0.092	-3.11	-0.048	-0.70
Risk management								
Share of maize area in pure stands	-0.020	-0.66	-0.083	-1.73	-0.022	-0.73	-0.034	-0.41
Maize area/ plots managed	-0.057	-2.06	-0.084	-2.11	-0.058	-2.11	-0.029	-0.39
Number of crops managed	0.264	4.98	0.167	2.12	0.261	4.89	0.263	1.85
Farmer characteristics								
Female head of household	-0.019	-1.97	0.000	-0.02	-0.018	-1.88	-0.015	-0.55
Age of household head	-0.034	-0.71	0.043	0.58	-0.031	-0.66	-0.008	-0.07
Weather effects								
Difference from average rainfall (mm)	-0.056	-0.123	-0.175	-0.50	-0.060	-0.29	-0.047	-0.09
Late start for season 1 rains (weeks)	-0.040	-0.068	-0.080	-3.49	-0.040	-3.34	-0.066	-1.81
Late start for season 2 rains (weeks)	-0.035	-0.052	-0.063	-1.38	-0.034	-1.10	-0.139	-1.48

Annex Table 3: Tests related to the instrumental variables, alternative model

Excluded instruments	
Combined instruments	F(1, 1391)=13.11[1]
Fertilizer use	F(3, 1390)=3.93[1]
Hired labor	F(3, 1390)=25.86[1]
--Improved seeds	F(3, 1390)=13.11[1]
Under-identification test	
Combined instruments	Anderson LM χ2(1)=4.23[2]
Fertilizer use	Angrist-Pischke χ2(1)=4.61[2]
Hired labor	Angrist-Pischke χ2(1)=58.21[1]
--Improved seeds	Angrist-Pischke χ2(1)=12.84[1]
Weak identification test	
Combined instruments	Cragg-Donald Wald F statistic =1.40
Fertilizer use	Angrist-Pischke F(1, 1390)=4.57
Hired labor	Angrist-Pischke F(1, 1390)=57.63[a]
--Improved seeds	Angrist-Pischke F(1, 1390)=12.84[c]
Weak instruments robust inference tests	
Combined instruments	Anderson-Rubin Wald χ2(3)=36.41[1]
Combined instruments	Anderson-Rubin Wald F(3, 1391)=12.01[1]
Combined instruments	Stock-Wright LM S χ2(3)=35.49[1]

Note: The superscripts 1 and 2 indicate significance at the 0.01, and 0.05 thresholds. [a]Exceeds Stock-Yogo (2005) 0.10 critical value threshold (for a single endogenous regressor) of 16.38. [c]Exceeds Stock-Yogo (2005) 0.15 critical value threshold (when two endogenous regressors are exactly identified) of 8.96. The combined instrument test is the Agrist-Pischke multivariate F test. See Baum, Schaffer and Stillman (2007) for more on the estimation and interpretation of the tests reported in this table.