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Low Quality, Low Returns, Low Adoption

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Low Quality, Low Returns, Low Adoption: Evidence from the Market for Fertilizer and Hybrid Seed in Uganda*

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To reduce poverty and food insecurity in Africa requires raising productivity in agriculture. Systematic use of fertilizer and hybrid seed is a pathway to increased productivity, but adoption of these technologies remains low. We investigate whether the quality of agricultural inputs can help explain low take-up. Testing modern products purchased in local markets, we find that 30% of nutrient is missing in fertilizer, and hybrid maize seed contains less than 50% authentic seeds. We document that such low quality results in negative average returns. If authentic technologies replaced these low-quality products, average returns for smallholder farmers would be over 50%.

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1. Introduction

Despite the fact that Africa could greatly benefit from increased use of technologies such as fertilizer and hybrid seed to promote agricultural productivity, adoption remains low, especially among smallholder farmers. In most regions of the world, yields have increased by a factor of 3–5 over the last 40–50 years, but in Sub-Saharan Africa they have remained stagnant (Evenson and Gollin, 2003). This yield gap is often explained by the lack of adoption of modern technologies in Africa (World Bank, 2007). Numerous explanations have been put forward to explain this, including lack of markets for risk, credit and land (Karlan, Osei, Osei-Akoto, Udry, 2014), lack of knowledge and behavioral constraints (Duflo, Kremer, Robinson, 2011), and uncertainty (Suri, 2009). However, evidence on the importance of each of these constraints is mixed (Foster and Rosenzweig, 2010; Jack, 2011).

We investigate a complementary explanation that takes its starting point in the technology itself: namely the quality of the technology as provided in the market. This investigation provides the first large-scale empirical assessment of the prevalence of, and economic returns to, substandard fertilizer and hybrid seed in Africa. To this end, we combine data from laboratory tests with data from researcher-managed agricultural trials. We complement the objectively measured quality data with information on farmers' beliefs about the quality of inputs in the market and their beliefs about the expected returns of using either authentic or (local) market based inputs.

We establish that low quality inputs are rife in the local retail markets we surveyed and that adoption of modern inputs with average retail quality is not profitable. Our study does not explain why the quality of agricultural inputs in local retail markets is poor, nor how it can be improved. It does, however, highlight the need to identify ways to substantially increase the quality of basic agricultural technologies available to smallholder farmers. It also stresses the importance of understanding how local input markets function in order to tackle both low adoption and low agricultural productivity. Our results are related to Suri (2009), who finds that adoption is not profitable for a large share of farmers, but also that there is substantial heterogeneity in returns. We show that one source of low returns is poor quality inputs and we also document large variation in quality across space, consistent with heterogeneity in returns.

The paper is structured as follows. In Section 2 we describe the context, our data and results on the quality available in the market. In Section 3 we estimate the returns to adoption, and in Section 4 we present results on farmers' beliefs about quality in the market and the returns to adoption. Section 5 concludes with a discussion of the implications of our results.

2. The quality of the technology

We investigate the quality of one of the most popular high-yield variety maize seed in the Ugandan market, as well as a generic nitrogen-based fertilizer (urea). Nitrogen has been shown to be the main limiting nutritional component to maize growth in Uganda (Kaizzi et al., 2012). Maize is widely grown throughout Uganda, often using traditional farmer seeds; i.e., seeds saved from the last harvest. Although declining soil fertility has been highlighted as a key concern in Sub-Saharan Africa, including Uganda (Sanchez, 2002; Nkonya, Kaizzi, Pender, 2005), only 2% of Ugandan smallholder farmers use inorganic fertilizer (Uganda Bureau of Statistics, 2006), an effective method for soil replenishment.

To measure the quality of the technologies in the market, we combine data on the nitrogen content of fertilizer from retail shops and experimental yield data from our own agricultural trials. We complement these data with household survey data to estimate the market price for maize and the labor cost of technology adoption.

At 129 randomly sampled local retail shops in two of the main maize-growing regions of Uganda, we purchased 369 samples of urea fertilizer ('retail fertilizer'), and at 30 such shops we purchased 30 samples of branded hybrid seed of the predetermined type ('retail hybrid seed'), using a covert shopper approach (see online appendix for details). We also purchased urea and hybrid seed in bulk directly from one of the main wholesalers for urea ('authentic fertilizer') and the seed company producing the branded seed ('authentic hybrid seed'). Finally, we purchased traditional farmer seed from a random sample of 80 small-scale maize farmers living around the trading centers where hybrid seed were purchased.

Each retail fertilizer sample was tested three times for the content of nitrogen (N) using the Kjeldahl method (Anderson and Ingram, 1993) at the Kawanda Agricultural Research Institute laboratory. We used the mean of these tests to determine the quality of a sample. Authentic urea should contain 46 percent nitrogen (%N) and we confirmed this to be the case in our "authentic" sample.

Researcher-managed agricultural trials at five of the National Agricultural Research Laboratories' research stations across Uganda were used to determine the yield responses of fertilizer and to estimate the quality of hybrid seed sold in retail markets. Authentic urea was diluted by proportionately adding acid-washed sand to get urea samples with 75% of stated N (approximately 34%N), 50% of stated N (approximately 23%N), and 25% of stated N (approximately 11%N). Together with authentic urea (46%N) and no urea, this yields five fertilizer treatments (N = 46%; N=34%; N=23%; N=11%; N =0%). We combined the five fertilizer treatments with the three seed treatments (authentic hybrid seed, retail hybrid seed, and farmer seed) to yield 15 possible seed-fertilizer quality combinations that were randomly assigned six 30m plots each at each of the five experimental sites. In total, each treatment combination was grown 30 times and yield data was collected from 450 plots.

The crop management and data collection protocol (see online appendix for details) followed the methodology outlined in Kaizzi et al. (2012). All five sites were managed by the research team, and the staff assigned to implement the trial protocol were blinded to the treatment status of the plots. We planted two maize seeds per hill with a spacing of 30×75 cm between hills, for a total of 105 hills per plot. We applied fertilizer at 108 kilograms per hectare (which corresponds to the official recommendation of 50kg N/ha for authentic urea) in two splits: half at planting by broadcasting and immediately incorporating into the soil and half later at tasselling top dress. In harvesting, we excluded the outer perimeter of the plot, and we oven-dried the grains to correct for moisture.

As reported in Table 1, and illustrated in Figure 1, on average, retail fertilizer contained 31% less nutrient than authentic fertilizer, or 31.8% N per kilogram (95% CI: 31.1-32.6). Nitrogen content in the lowest decile in the sample ranged from 8.6 to 24.6 percentage points; i.e., roughly one in ten samples contained less than half the nitrogen found in authentic fertilizer. Only about 1% of the tested fertilizer samples had a shortfall of less than 10% shortfall in nutrients; i.e. %N $\geq$ 41.4). Figure 2 shows that while there was substantial variation in quality across samples, prices were homogenous.

To assess the quality of retail hybrid seed, we focus on their yield response, since this is what ultimately matters to farmers. Intuitively, we infer quality by assuming the following: if a bag of farmer seed yields X tons of maize, a bag of authentic hybrid seed yields Y tons of maize and a bag of retail hybrid seed yields $\alpha X + (1 - \alpha)Y$ tons of maize, then the bag of retail hybrid seed is of the same quality as a bag of authentic hybrid seed that is diluted with α% farmer seed.

More formally, we first match the experimental yield data for the three types of seed by site, block and nitrogen content of the fertilizer applied. Then we construct a new variable in each of these strata, which is the weighted sum of the average maize yield on the plots growing farmer seed in stratum s and the average maize yield on the plots growing authentic hybrid seed in stratum s: $Yield_{s,mix} = \alpha Yield_{s,farmer} + (1-\alpha)Yield_{s,authentic}$. Third, we calculate the first four central moments of this new variable and of the distribution of yields on plots growing retail hybrid seed – the latter also averaged over the plots in each stratum. Finally, we infer the most likely level of dilution by finding α that minimizes the squared weighted difference between the simulated moments and the data moments (see online appendix for details).

The results of the estimation are presented in Table 2. The simulated method of moments estimate for α is 0.55 (95% CI: 0.33-0.77). From this we conclude that the average quality of a bag of retail hybrid seed is roughly the same as the quality of a bag mixed 50-50 with farmer seed and authentic hybrid seed. Figure 3 plots the cumulative distribution function (CDF) of retail hybrid seeds and of the distribution generated by mixing farmer (55%) and authentic hybrid seeds (45%). The two curves lie almost on top of each other and a Kolmogorov-Smirnov test confirms that we cannot reject the null hypothesis that the two distributions are equal (p-value=0.58).

Figure 4 links quality of the inputs to yields, and shows that shortfalls in quality reduce yields substantially. For example for authentic hybrid seed, average yield is 29% higher if authentic fertilizer (46%N) rather than fertilizer with 23%N is used. Columns (1)-(3) in Table 3 report estimates of linear regressions of yield on nitrogen content (%N) when planting either farmer seed, retail hybrid seed, or authentic hybrid seed. A reduction of nitrogen by 1 percentage point when planting traditional farmer seed leads to a significant yield loss of 49 kilograms per hectare (P<0.001, *t* test). The loss due to poor quality is even higher when planting retail hybrid seed (57 kg/ha, P<0.001, *t* test) and the highest when planting authentic hybrid seed (65 kg/ha, P<0.001, *t* test).

3. The economic returns to technology

Having established that modern technologies available in local retail markets are of poor and heterogeneous quality, we examine how quality affects the economic returns to adoption of retail hybrid seed and retail fertilizer. The unit of observation for these calculations is a retail fertilizer sample (see online appendix for details). The net return of a fertilizer sample *j* with nitrogen content n_j %N applied to retail hybrid seed is the difference between the revenue from planting retail hybrid seed with retail fertilizer – less the direct and additional labor costs associated with the inputs – and the revenue from planting traditional seed with no fertilizer. The rate of return of adopting fertilizer and hybrid seed is given by dividing the net return by the total cost of adoption. A fertilizer sample is deemed profitable if its rate of return is greater zero.

Predicted yield for a given seed type and fertilizer quality can be derived from Table 3. Specifically, let s_k denote seed type, with s_1 being farmer seed, s_2 being retail hybrid seed, and s_3 being authentic hybrid seed. The predicted yield of a fertilizer sample with nitrogen content n_j %N using seed type s_k is $\hat{y}(n_j, s_k) = \hat{\alpha}_k + \hat{\beta}_k \times n_j$ where the subscript *k* on the estimated coefficients refers to the column number in Table 3. To calculate the net return for authentic inputs, we replace n_j with $n = 46$ and s_2 with s_3 in the predicted yield equation. The price of maize and the labor costs are estimated from the household survey. Costs of inputs were collected during the quality assessment survey.

Low quality of inputs in the market reduces the economic returns to adoption substantially. As Table 4, Panel A, shows, using retail fertilizer and retail hybrid seed yields a negative rate of return (*r*) on average (mean *r* = –12.2% and median *r* = –8.6%). In contrast, if authentic fertilizer was sold in local retail stores, the mean and median rate of return would be over 50%. Overall, more than 80% of the fertilizer samples bought in local markets were not profitable. If instead technologies were authentic, the rate of return would be large and positive, and all samples would yield a rate of return above 30%.

For adoption of urea fertilizers only (i.e. applied to farmer seed), the mean and median return is positive, but low (mean *r* = 6.8% and median *r* = 11.7% in Panel B). Market fertilizer not only pays low average returns, over a third of samples have negative rates of return and a further third yield rates of return between zero and ten percent. A mere 7.3% of samples yield a return above 30%. Authentic fertilizer, on the other hand, would be highly profitable: assuming a nitrogen content of 46%, all the samples yield a rate of return above 30%.

4. Farmers' expectations

Can poor quality of fertilizer and seeds and low rates of return help explain why farmers do not adopt modern inputs?

For substandard quality to hinder adoption, it ought to be the case that (i) farmers expect that technologies available in the market are of poor quality, and (ii) that farmers expect that there is a positive relationship between quality of inputs and yields. We turn to these issues next.

A farmer (household) survey was administered to a sample of farmers at the end of the second season of 2013. For each trading center visited as part of the 2014 fertilizer study, 10 farmers within a 5-kilometer radius from the trading center and 10 farmers in 5–10 kilometer distance from the trading center were surveyed, using a two-stage sampling strategy. The objective of the survey was to collect detailed information from small-scale maize farmers on their agricultural practices, including input use and market interactions, and their expectations about the quality of and economic return to fertilizers. In total, information was collected from 312 small-scale farmers.[1]

The subjective expectations module was designed to elicit a farmer's probability distribution over the following events: (i) the yield and value of output generated by growing maize on their land either without using fertilizer, or applying the recommended amount of urea using fertilizer either bought from the nearest shop or with the best official quality; and (ii) the nutrient content of fertilizer purchased from the nearest retail shop.[2]

The protocol for eliciting the probability distributions was as follows. For the maize yield and value of output, farmers were first asked to give an estimate of the range of the distribution. The enumerator then calculated three evenly spaced mass points between the minimum and the maximum stated by the farmer. For fertilizer quality, the enumerator specified that the distribution ranged from 0-100%, where 100% corresponded to the nutrient content of authentic fertilizer, with 5 evenly spaced mass points.

For each elicitation, farmers were given 10 beans and instructed to place the beans on a plate describing the chance that the event in question would be lower or equal than this number. Enumerators were asked to check farmers' understanding in the sense that the number of beans for the minimum value should always be zero, the number of beans for the maximum value should always be 10 and to prompt respondents to ensure that answers are non-decreasing.

Table 5 and Figure 5 show that farmers are aware that fertilizer bought from shops near them are substandard. Figure 5 shows the histogram of farmers' beliefs about the nitrogen content of fertilizer in their nearest retail shop. On average, farmers expect fertilizer bought in the market place to contain 38% less nutrient, equivalent to a nitrogen shortfall of 17.6 percentage points

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[1] The FAO and the International Fund for Agricultural Development (IFAD, 2008) define small scale farmers as farmers with farms of two hectares or less (5 acres or less). We follow this definition here.

[2] See Delavande, Giné, and McKenzie (2009) for a review and analysis of subjective expectations data from developing countries. They conclude that people generally understand and answer probabilistic questions and that the expectations are useful predictors of future behavior and economic decisions.

(Table 5). Every third farmer believes the content is less than half of the stated amount, and only one percent believes UREA in the market place contains the nitrogen amount of authentic fertilizers. Thus, farmers expect substandard quality of fertilizers in the market and their expectations are on average in line with the results we obtained from the fertilizer samples tested (see Table 1).

Farmers are also aware that using fertilizer increases yields, but that the increase depends on whether fertilizer is authentic or sourced from the market. A farmer planting his own seeds expects to harvest 1.47 MT maize per hectare without fertilizer (median 0.98 MT/ha), 2.53 MT/ha with market quality fertilizer (median 1.6 MT/ha), and 5.23 MT/ha with authentic fertilizer (median 2.24 MT/ha). Figure 6 shows that the CDF of farmers' expectations of yields using authentic fertilizers is strongly shifted to the right of the CDF of farmers' expectations of yields using market quality fertilizer, which in turn lies to the right of the CDF without fertilizers. A Kolmogorov-Smirnov test rejects the equality of the three distributions at the 1% level.

That farmers know that lower quality translates into lower yields is shown parametrically in Table 3, column (4). Here, we report a linear regression of a farmer’s expectation of yields on her expectation of nitrogen content (%N) in fertilizers bought in the nearest shop, where the latter has been rescaled to range from 0 to 46%. The coefficient on the expected nitrogen content in market fertilizers implies that farmers expect yields to increase in quality, consistent with the results from the experimental plots (Table 3, column (1)). A 1% increase in nitrogen content is associated with a 61 kilograms/ha increase in expected yield.

We have so far shown that farmers know that fertilizer in the market is low quality and that it produces less maize. If, in addition, farmers expect to make a profit using authentic technologies and a loss using market quality technology, then input quality is potentially a binding constraint on technology adoption. We now calculate a farmer’s profit for the quality of fertilizer and yield she expects.

We assume that farmers are risk-neutral and can borrow.[3] We write the expected net return for a farmer i who holds l_i hectares of land, uses farmer seeds and expects market fertilizer to contain n_i percent nitrogen as:

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[3] The assumption of risk-neutrality is a strong one. Karlan et al (2014), for example, show that uninsured risk constrains investment on inputs such as fertilizers using data from a field trial in Ghana. It is important to note that since our data show substantial heterogeneity in quality, and no correlation between quality and price, risk-aversion

$$E[p^m(n_i, l_i)y(n_i, l_i)] - (c^f + c^l)l_i - E[p^m(0, l_i)y(0, l_i)] \,, \tag{1}$$

where p^m denotes the market price of maize (per MT), c^f is the cost of fertilizer per hectare, and c^l is the estimated additional labor cost per hectare of land. $E[p^m(n_i, l_i)y(n_i, l_i)]$ and $E[p^m(0, l_i)y(0, l_i)]$ are expected gross revenue when using fertilizer from the nearest retail shop and not using fertilizer. To calculate the net return from adopting authentic fertilizer, expected gross revenue using fertilizers from the nearest retail shop is replaced with expected gross revenue using authentic fertilizers, $E[p^m(46, l_i)y(46, l_i)]$. The expected gross revenues are derived from the subjective expectations module, which asked farmers to estimate the probability distribution of yields and value of output on the farmer's land using no fertilizer and using fertilizer either bought in the nearest shop or of authentic quality.

We estimate the expected rate of return by diving net returns (1) by costs $(c^f + c^l)l_i$ and record the share of farmers for whom the expected rate of return is positive conditional on using either fertilizer in the market or authentic fertilizer. Table 6 reports the results.

For fertilizers bought in the market place, both the mean and median expected rate of return are negative and 73.5% of farmers would not find adoption of fertilizers available in the nearest retail shop profitable. If farmers instead had access to authentic fertilizer, both the mean and median returns are positive and more than half the farmers expect adoption to be profitable.

Our return calculations imply that the quality of inputs may play an important role when a farmer decides whether to adopt or not. Adopting authentic instead of market fertilizer, the share of farmers who expect to make a profit doubles (an increase of 26.5 percentage points).

5. Discussion

Our findings establish that poor quality inputs appear to be the norm in the local retail markets we surveyed, and that adoption of modern inputs with average retail quality is not profitable. The rate of return of using authentic fertilizer and hybrid seed is large, however. Together these results suggest that one reason smallholder farmers do not adopt fertilizer and hybrid seed is that the technologies available in local markets are simply not profitable, and this ultimately hampers agricultural productivity.

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would decrease the willingness to adopt the technology. In this sense, our estimates may be interpreted as providing lower-bounds on the importance of substandard quality for adoption.

Our findings imply interesting avenues for future research. First, low quality could be due to a multitude of factors, including adulteration, poor storage and inappropriate handling procedures. Moreover, quality deterioration could manifest at different points in the supply chain. Anecdotal evidence and news reports suggest that adulteration, by bulking out fertilizer or dyeing simple grain to look like hybrid seeds, is common, but more research is needed to determine if this is indeed the case. While the exact reasons may be irrelevant for a farmer's decision to adopt, understanding the determinants of quality is important for policy.

Second, while our study does not explain why the quality of agricultural inputs in local retail markets is poor, or how the problem should be tackled, it does suggest that the market is partly characterized by a low-quality, low-trust, low-adoption equilibrium. Specifically, the data show not only low average quality but substantial heterogeneity in quality which is not correlated with price. This suggests that the ability to infer quality may be severely limited, since we would otherwise expect prices to adjust. Fertilizer and hybrid seed are experience goods; i.e., consumers do not observe the quality of the inputs before purchase, and in markets for such goods a seller's incentive to provide high-quality products crucially hinges on consumers' ability to learn about quality (Shapiro, 1982; Mailath and Samuelson, 2001). Our data reveal, for a given quality, large variation in yields (across both the experimental plots and across farmers' beliefs about expected yields), and this uncertainty may severely affect farmers' ability to learn about quality. The difficulty in learning about quality, in turn, can help explain why retailers sell low quality inputs and why farmers' do not use them. In order to understand low adoption, we believe, it is important to investigate this issue further.

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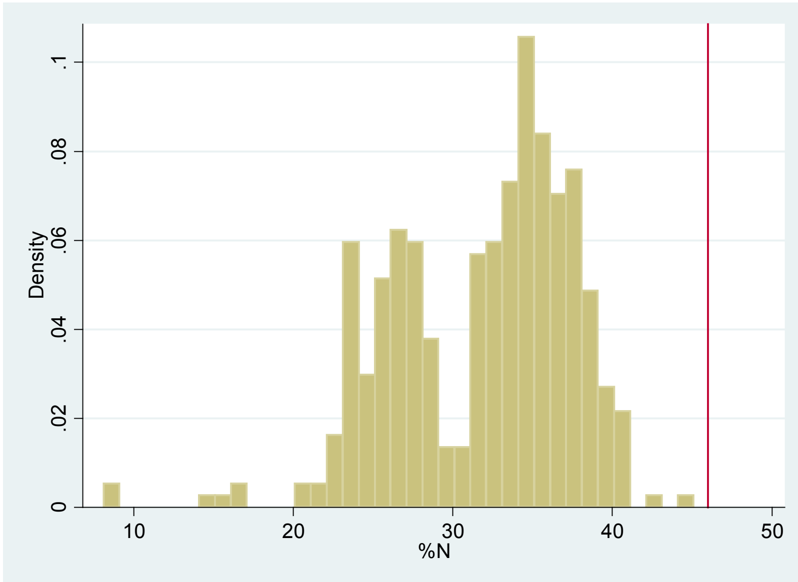
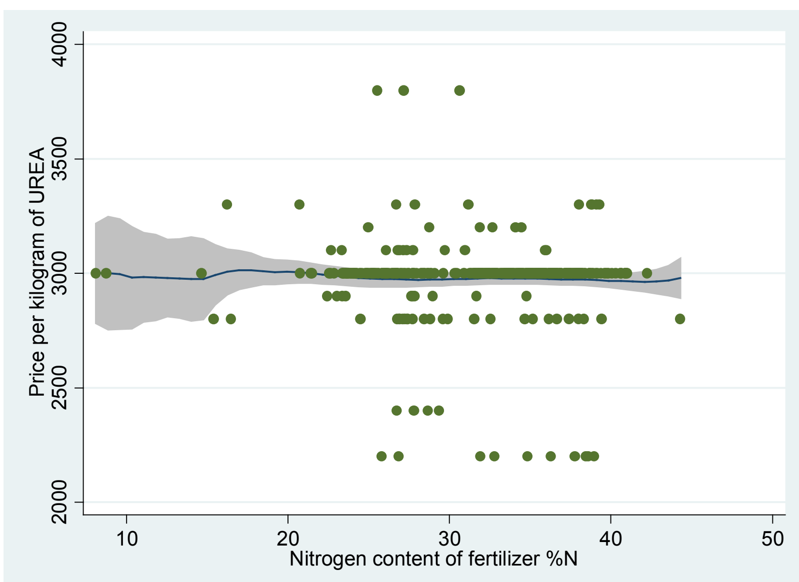
Figure 1. The distribution of nitrogen content in fertilizer



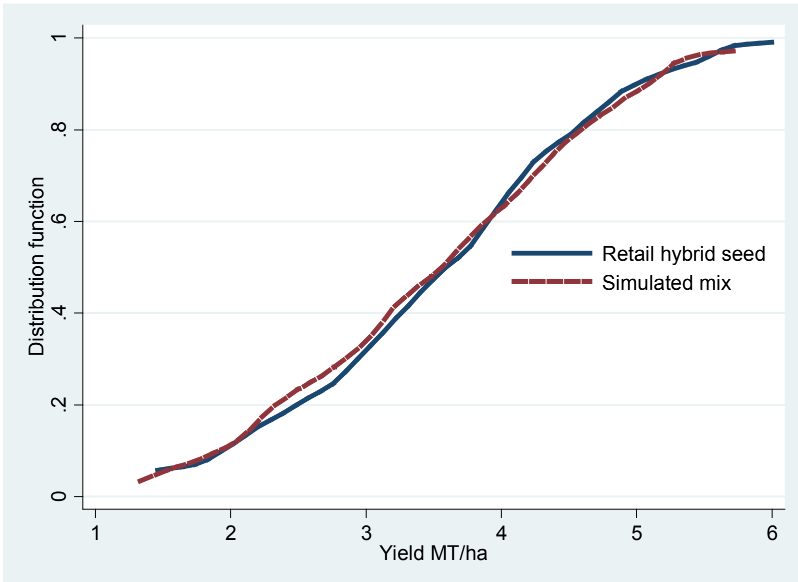
Note: The bars present the percentage of the 369 fertilizer samples with nitrogen content equal to the values shown on the X-axis. The line indicates the amount of nitrogen that should be contained in a bag of fertilizer according to the information written on the package.

Figure 2. The relationship between price and quality of fertilizer



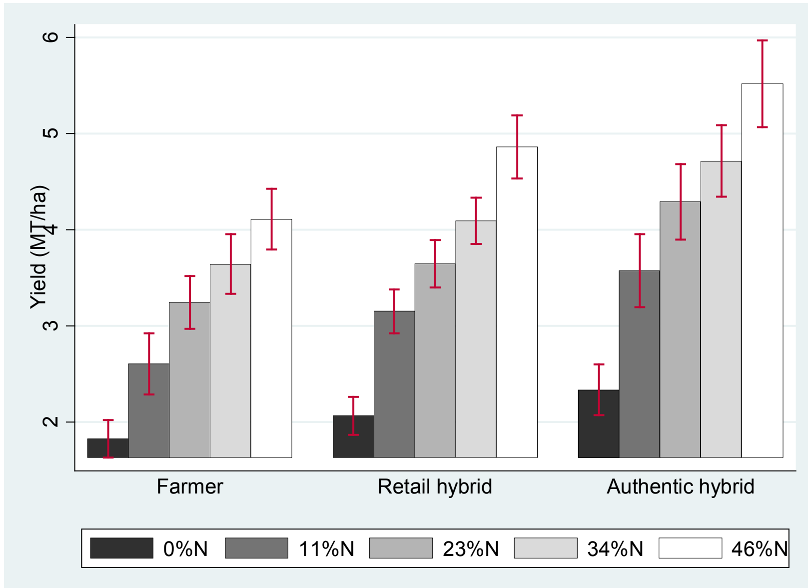
Note: The dots show the combination of nitrogen content and price per kilogram of urea for each of the 369 fertilizer samples. The line is a local polynomial regression fitted to this data and the grey shaded area represents the 95% confidence interval.

Figure 3. The yield distribution of retail hybrid seed and the simulated yield distribution of mixing farmer and authentic hybrid seed.



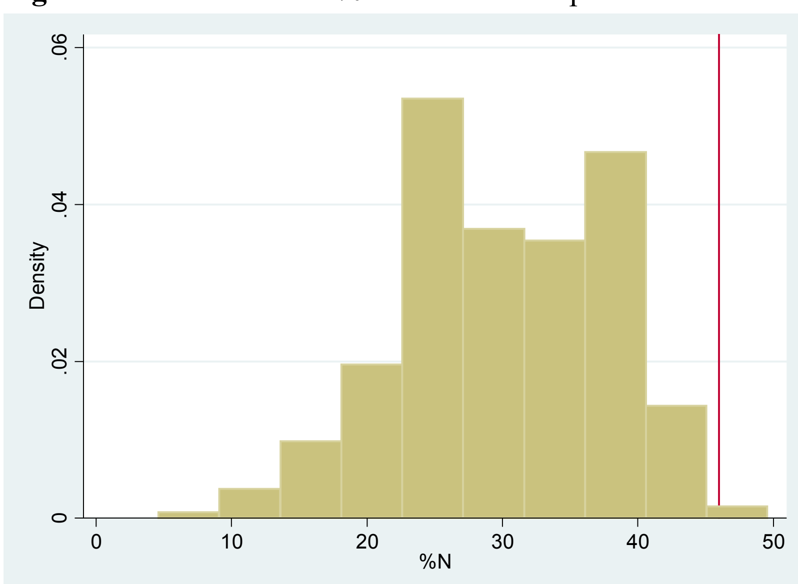
Note: The solid line represents the cumulative distribution of maize yields observed on the experimental plots when growing hybrid seed purchased from retailers. The dashed line represents the cumulative distribution of the simulated maize yield obtained when mixing farmer seed and authentic hybrid seed with the ratio 0.55:0.45.

Figure 4. The yield return to nitrogen content in fertilizer



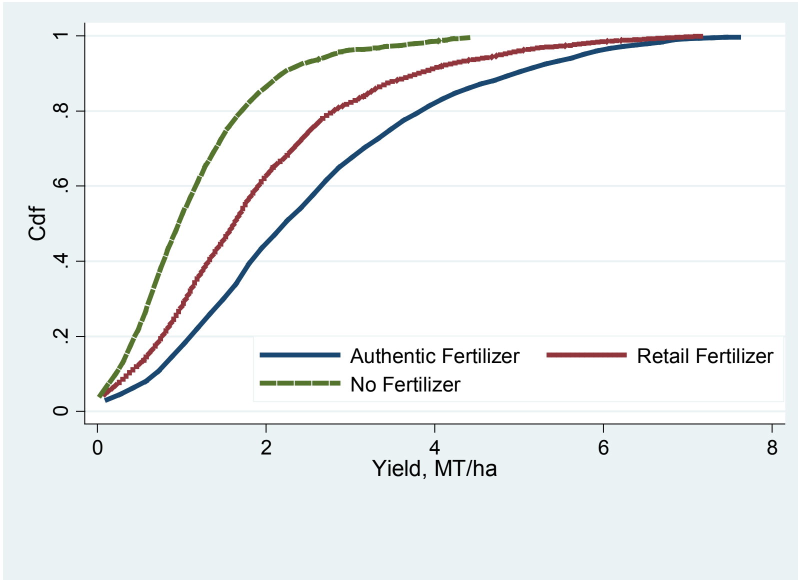
Note: The bars present maize yield in MT/ha growing farmer seed (leftmost panel), retail hybrid seed (middle panel) and authentic hybrid seed (rightmost panel) after applying fertilizer with 0%N, 11%N, 23%N, 34%N or 46%N. The error bars represent the 95-percent confidence interval. The unit of observation is an experimental plot.

Figure 5. Farmer beliefs: %N in nearest shop



Note: The bars present the percentage of the 312 farmers' beliefs about nitrogen content equal to the values shown on the X-axis. The line indicates the amount of nitrogen that should be contained in a bag of fertilizer according to the information written on the package.

Figure 6. Farmer expectations: Cumulative distribution of maize yield



Note: The dashed line represents the cumulative distribution of expected yields when not using fertilizer. The dotted line represents the cumulative distribution of expected yields when using retail fertilizer. The solid line represents the cumulative distribution of expected yields when using authentic fertilizer. Data from the farmer survey.

Table 1. %N in retail fertilizers (UREA)

	Mean	Standard deviation	Minimum	Maximum	Observations
%N	31.8	5.6	8.1	44.3	369

Note: The values provide summary statistics of the nitrogen content of the 369 fertilizer samples purchased in the covert shopper exercise and analyzed in the laboratory.

Table 2. Estimates of quality of retail hybrid seed based on its yield.

	Retail hybrid seeds	Mix of authentic and farmer seeds
	(1)	(2)
α		0.55
		(0.111)
Mean	3.563	3.566
Variance	1.172	1.264
Skewness	-0.058	-0.069
Kurtosis	2.437	2.123
Weighted sum of squared deviations		0.004

Note: The unit of observation is a stratum, which contains the plots that are on the same site and block and have fertilizer with the same level of nitrogen applied to them. Column (1) contains the first four moments from the observed distribution of yields (MT/ha) planting retail hybrid seed averaged at the stratum level. Column (2) presents the estimate of α that minimizes the squared weighted distance between the first four moments of this distribution and a simulated distribution of yields constructed by combining the maize yield from plots growing farmer seed and the maize yield from plots growing authentic hybrid seed in each stratum using the ratio α: 1-α. The first four moments of this simulated distribution are also reported. Standard errors in parentheses are bootstrapped drawing 1,000 samples from the yield distribution.

Table 3. Yield return (MT/ha) to increasing quality of fertilizers

Source:	Experimental sites			Farmer survey
	(1)	(2)	(3)	(4)
%N	0.049***	0.057***	0.065***	
	(0.004)	(0.004)	(0.005)	
Expected %N				0.060**
				(0.024)
Constant	1.973***	2.268***	2.600***	0.82
	(0.095)	(0.087)	(0.126)	(0.56)
Observations	150	150	150	292
R-squared	0.52	0.65	0.52	0.02
Seeds	Farmer	Hybrid market	Hybrid authentic	Farmer
Unit of Analysis	Plots	Plots	Plots	Farmers

Note: Values shown are coefficients from ordinary least squares regression. Each column represents a different regression. The dependent variable in columns (1)-(3) is maize yield on experimental plots. The independent variable is content of nitrogen (%N) in the fertilizer applied to the experimental plot. The dependent variable in column (4) is expected maize yield based on farmer survey data and the independent variable is expected content of nitrogen (%N) in the nearest retail shop. Robust standard errors in parentheses. *** 1% , ** 5% , * 10% significance.

Table 4. Economic returns to fertilizer and hybrid seeds adoption

Source:	Technologies available in the market	Authentic technologies
	(i)	(ii)
Panel A: Adoption of UREA fertilizers and hybrid seeds		
Mean rate of return	-12.2%	51.3%
Median rate of return	-8.6%	51.0%
Fertilizer samples yielding positive net-return	18.4%	100.0%
Fertilizer samples yielding rate of return > 10%	1.4%	100.0%
Fertilizer samples yielding rate of return > 20%	0.0%	100.0%
Fertilizer samples yielding rate of return > 30%	0.0%	100.0%
Panel B: Adoption of UREA fertilizers		
Mean rate of return	6.8%	54.2%
Median rate of return	11.7%	53.6%
Fertilizer samples yielding positive net-return	65.3%	100.0%
Fertilizer samples yielding rate of return > 10%	52.6%	100.0%
Fertilizer samples yielding rate of return > 20%	26.3%	100.0%
Fertilizer samples yielding rate of return > 30%	7.3%	100.0%

Note: Values present the average and median rate of return for adopting fertilizer and hybrid seed as opposed to traditional methods. The unit of observation is a fertilizer sample. The rate of return is calculated by dividing the net return to adopting the technology by the cost of adoption, which includes both the direct cost of the inputs as well as the additional labor cost. We also report the percentage of samples that pay rates of return higher than a certain threshold. Column (1) presents the rate of return of technologies available in the market and column (2) presents the rate of return if technologies were authentic.

Table 5. Farmer beliefs: %N in nearest shop

	Mean	Std	Min	Max	Obs
%N	28.4	8.0	4.6	46	295

Note: The values provide summary statistics of the expected nitrogen content in the nearest retail shop from the farmer survey.

Table 6. Expected economic returns to fertilizer adoption

Source:	Market fertilizer	Authentic fertilizer
Mean expected rate of return	-0.2%	67.4%
Median expected rate of return	-52.2%	10.5%
Farmers with expected positive net-return	26.5%	53.0%
Farmers with expected rate of return > 10%	24.4%	50.9%
Farmers with expected rate of return > 20%	22.7%	46.3%
Farmers with expected rate of return > 30%	21.3%	41.1%

Note: Values present the average and median expected rate of return for adopting fertilizer as opposed to traditional methods. The unit of observation is a farmer. The rate of return is calculated by dividing the net return to adopting fertilizer by the cost of adoption, which includes both the direct cost of the fertilizers as well as the additional labor cost. Column (1) presents the rate of return of technologies available in the market and column (2) presents the rate of return if technologies were authentic.

Online appendix

Measuring the quality of fertilizers and seed

The purchases of urea were done in connection with the first planting seasons of 2013 and 2014. We conducted the sampling of retail shops in two steps: first, in each year we randomly selected districts from two of the main maize-growing regions (eastern and western regions), and second, in each district we enumerated all trading centers and randomly selected a total of 20 trading centers. We then sampled up to three retail shops in each trading center. In total, 96 agro-input retailers were sampled, 50 in 2013 and the remainder in 2014. In addition, 33 retailers operating in the main agro-inputs market in Kampala ("Container village") were randomly selected and visited in 2014, yielding a total sample of 129 retail stores.

We sent covert shoppers to purchase the samples we tested. We trained a set of enumerators with knowledge of the local area and language, and gave them a prepared script for how to buy the inputs. These covert shoppers were impersonating poor farmers from the area, with clothing and accessories chosen accordingly, with the objective of mimicking the purchase of a farmer wanting to begin using fertilizer. We deemed the design appropriate for this purpose, as agro-input retailers in the trading centers, and in Container village, serve large potential customer bases.

Between 1–6 bags of 1–2 kilograms each were purchased from each retailer outside of the main agro-inputs market in Kampala. For the random subset of retailers where multiple purchases were done, two covert shoppers were used, buying on up to three different days, with at least two weeks between purchases. In the main agro-inputs market in Kampala, it is common to buy fertilizer in larger quantities. For that reason, two 50-kilogram bags were purchased by two different buyers from each of the retailers sampled in Container village. In total, 369 samples were purchased.

After the purchase was completed, and once out of sight of the shop, the surveyor recorded the price of the sample. The samples were then transferred to Kampala. Each sample was tested three times for the content of nitrogen (N) using the Kjeldahl method (Anderson and

Ingram, 1993) at the Kawanda Agricultural Research Institute laboratory. We use the mean of these tests to determine the quality of a sample. Authentic urea should contain 46% nitrogen.

The purchase of retail hybrid seed followed a similar design. Close to the planting season in 2014, we identified the 15 closest trading centers surrounding the five research stations. We enumerated stores in each trading center and randomly selected 30. According to the script, the covert shoppers bought 2–6 kilograms of the same branded seed type as the authentic hybrid seed. If the retailer did not carry that particular hybrid seed, the shopper did not buy, and the team selected a replacement shop.

For farmer seed, we enumerated the villages in a 20-kilometer radius around the research stations and randomly picked 6–9 villages per site. In each village covert shoppers (farmers) bought approximately 3 kilograms of farmer seeds from two farmers.

We complement these data with household survey data to estimate market prices for maize and the labor costs of technology adoption. Specifically, we administered a farmer (household) survey to a sample of farmers at the end of the second season of 2013. For each trading center visited as part of the 2014 fertilizer study, 10 farmers within a 5-kilometer radius from the trading center and 10 farmers in 5–10 kilometer distance from the trading center were surveyed, using a two-stage sampling strategy. The sampled farmers were asked for informed consent to participate in the survey. The respondent was the head of household if available at the time of the interview or the closest family member of the household head. If neither could be found, or the household refused to participate, a replacement household was chosen. The objective of the survey was to collect detailed information from small-scale maize farmers on their agricultural practices, including input use and market interactions, and their expectations about the quality of and economic return to fertilizers. In total, information was collected from 312 small-scale farmers.

Crop management and data collection protocol

The crop management and data collection protocol followed the methodology outlined in Kaizzi et al. (2012). All five sites were managed by the research team and the staff assigned to implement the trial protocol were blinded to treatment status of the plots. At each site the field was ploughed and harrowed. Composite soil samples were taken and analyzed for pH, organic matter, total N, extractable P, and exchangeable bases (K, Ca, Mg, Na and texture) to ensure that the soil, as in most of Uganda, was depleted with N. In each plot, 7 rows of seed were planted, with a spacing of 75 cm between rows. In each row two maize seeds were planted per hill with a spacing of 30 cm between hills, for a total of 105 hills per plot. Fertilizer was applied at 108 kilograms per hectare (which corresponds to the official recommendation of 50kg N/ha) in two splits: 54 kg/ha at planting by broadcasting and immediately incorporating into the soil and later at tasselling top dress with the remaining 54kg/ha. At 2–3 weeks after emergence, the plants were counted, weeded, and thinned to one plant per hill. The harvest was done excluding the outer perimeter of the plot and the grains were oven dried to correct for moisture.

Measuring the quality of retail hybrid seeds

To infer the quality of retail hybrid seed, we used the experimental yield data and compared yields across the three types of seed that were purchased and planted: farmer seed, authentic hybrid seed and retail hybrid seed. The experimental yield data provides us with plot-specific yields for different combinations of seed and fertilizer quality. To determine the quality difference between authentic and retail hybrid seed, we estimate what mix of authentic hybrid and farmer seed would generate the same distribution of yields as retail hybrid seed.

Specifically, we used the entire sample of seed across all levels of fertilizer, and matched observations by site and nitrogen content of fertilizer applied. Each of these strata contains six plots, two growing farmer seed, two growing retail hybrid seed and two growing authentic hybrid seed, and we denote the average yield for each seed type across the two plots in each stratum s by $Yield_{s,seed\ type}$. We then construct a new variable that is the weighted sum of the average maize yield on the plots growing farmer seed in stratum s and the average maize yield on the plots growing authentic hybrid seed in stratum s: $Yield_{s,mix} = \alpha Yield_{s,farmer} + (1-\alpha) Yield_{s,authentic}$. We compare the distribution of this variable with the distribution of yields generated by retail hybrid seed, $Yield_{s,retail}$. We judge the two distributions to be the same if the first four central moments are equal.

To estimate α based on matching the mean (μ), variance (σ^2), skewness (γ_1) and kurtosis (γ_2) of the two distributions, we use the simulated method of moments (Gourieroux and Montfort, 1996). Specifically, we define the vector $\boldsymbol{G}(\alpha)$, which contains the difference in the first four simulated moments of the yield distribution generated by mixing farmer and authentic hybrid seed with the ratio α:1-α and the yield distribution of retail hybrid seed

$$\boldsymbol{G}(\alpha) = \begin{pmatrix} \mu_{mix}(\alpha) - \mu_{retail} \\ \sigma^2_{mix}(\alpha) - \sigma^2_{retail} \\ \gamma_{1,mix}(\alpha) - \gamma_{1,retail} \\ \gamma_{2,mix}(\alpha) - \gamma_{2,retail} \end{pmatrix}. \tag{1}$$

We then solve for α that minimizes the squared weighted sum of the moment conditions

$$\hat{\alpha} = argmin_\alpha\ \boldsymbol{G}(\alpha)'\boldsymbol{W}\boldsymbol{G}(\alpha)\,, \tag{2}$$

where the weighting matrix $\boldsymbol{W}$ is the inverse of the covariance matrix of the data moments, which is obtained by bootstrapping the yield distribution 1,000 times.

<u>Estimating the economic returns to adoption</u>

The net return (NR) of a fertilizer sample j with nitrogen content n_j %N, using retail hybrid seed, is estimated as

$$NR(n_j, s_2) = p^m\hat{y}(n_j, s_2) - c_j^f - c^s - c^l - p^m\hat{y}(0, s_1)\,, \tag{3}$$

where p^m denotes the market price of maize (per MT), c_j^f and c^s are the costs of fertilizer and seed per hectare, and c^l is the estimated additional labor cost per hectare of land. $p^m\hat{y}(n_j, s_2)$ is the predicted revenue per hectare of land, using the results in Table 3, column 2, to predict $\hat{y}(n_j, s_2)$. $p^m\hat{y}(0, s_1)$ is the revenue from traditional farming (no hybrid seed or fertilizer), where the predicted yield is estimated from Table 3, column 1. To calculate the NR for authentic inputs, we replace n_j with $n = 46$ and use the coefficients in column 3 of Table 3 to predict yields. For the net return of adopting fertilizer only, we estimate

$$NR(n_j, s_1) = p^m\hat{y}(n_j, s_1) - c_j^f - c^s - c^l - p^m\hat{y}(0, s_1)\,. \tag{4}$$

The market price for maize per hectare (p^m) is estimated from the farmer survey where we collected information on the value and amount of harvest sold in the last season. From this we derive the price each farmer received. Since the reported output price is strongly left-skewed, we used the median (UGX 600,000 or ~$240 per MT) rather than the mean price.

The price of each fertilizer sample and the average (and the median) price for the hybrid seed were collected as part of the covert shopper surveys. The costs of fertilizer and seed, c_j^f and c^s, were then calculated assuming that inputs were applied using the officially recommended amounts per hectare.

To estimate the increase in the number of days worked when using fertilizer and hybrid seed, we rely on information from the farmer survey. Specifically, we regress the number of days worked on the farm per hectare of land (days of own and hired labor) on agricultural input use (fertilizer, high yielding variety (HYV) seed, manure, pesticides, herbicides or fungicides, and rented machinery). The coefficients on fertilizer and HYV seed in such a multivariate regression model measure the conditional mean difference in labor between farmers that use fertilizer and HYV seed and farmers that do not. The estimates do not capture the causal effect of these inputs on labor, however. With that caveat in mind, we interpret the coefficients on fertilizer and HYV seed as the additional working days associated with their use. We find that modern input use (fertilizers and hybrid seed) is associated with an increased use of labor: farmers who use fertilizer increase their labor by 16.5% compared to farmers that do not use fertilizer. Farmers who also plant hybrid seed report a further 4.9% increase in working days. As in Beaman et al. (2013), the increase in labor is accounted for solely by an increase in hired labor. The unit cost of (hired) labor is also estimated using data from the farmer survey where we collected information on the wage paid for hiring labor. Since the wage distribution is strongly left-skewed, we use the median wage (UGX 6000 or ~$2.4 per day).

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