Is the Price Right?
Returns to Input Adoption in Uganda

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We estimate the profitability of fertilizer and hybrid seed use in Uganda, inputs widely promoted to enhance smallholder farmers' productivity, but that have low rates of adoption. Past studies that evaluate the returns to agronomic inputs generally assume a fixed output price and do not account for the high output price volatility that farmers face. Using unique historical output price data, we show that adoption of fertilizer is more profitable than hybrid seed, and that price volatility alone cannot explain the low levels of adoption. When we consider input quality and poor weather conditions returns can become negative even at median prices. Risk aversion further exacerbates low adoption in some markets.

JEL classification: Q12, Q16, D13
Key words: input adoption, price volatility, yields, returns, Uganda

1. Introduction

Agricultural income is key to the living standards of the vast majority of Ugandans. The bulk of the impressive progress in reducing the poverty rate from 31.1 percent of the population in 2005/06 percent to 21.7 in 2012/13 is attributable to the high growth in household agricultural income, at approximately 6 percent per year (World Bank, 2016).[2] However, only a minor share of this growth can be explained by changes in the nature of agricultural production or an increase in the adoption of better technology in agricultural production (Barrett et al. 2017, World Bank 2016). Rather, it was good fortune in the form of favorable rainfall and positive trends in commodity prices, as well as key policies advanced by the government that opened new markets, such as the stabilization of the conflict in the Northern region and infrastructure investments. In fact, only 40 percent of agricultural households have ever used improved agricultural inputs and there was little progress in their adoption between 2005/6 and 2012/13.

A considerable number of studies focus on ways to encourage adoption and alleviate constraints to adoption. The recent literature focuses both on financial constraints, such as credit and insurance, and

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[2] Official poverty numbers estimated by the Uganda Bureau of Statistics (UBOS), using the Uganda National Household Survey (UNHS) 2005/06-2012/13.

non-financial constraints, such as information and training. Binding credit constraints and limited insurance markets have been shown to negatively affect adoption (Rosenzweig and Binswanger 1993, Croppenstedt et al. 2003, Gine and Klonner 2008, Dercon and Christiansen 2011). Dercon and Christiansen (2011) show that the combination of credit constraints, failing harvests, and lack of insurance contribute to farmers remaining in low-risk low-return agricultural practices in Ethiopia. Duflo et al. (2011) show that offering time-limited discounts for fertilizer just after harvest, when farmers are cash rich, significantly increases the adoption of fertilizer. Similarly, Axmann et al. (2019) show that offering farmers certified hybrid maize seeds for purchase at precisely the time when they are least constrained, right after post-harvest sales, increases adoption by 8 percentage points.

Lack of information regarding new technologies also negatively affects adoption, and extension workers are critical in this regard. Anderson et al. (2007), Birkhaeuser, Evenson, and Feder (1991) and Evenson and Mwabu (2002) provide a review of the impact of access to extension training on production and adoption. Scaling extension operations can be difficult as extension officers can only visit a limited number of farmers. Recent research, therefore, attempts to augment and enhance training through the use of local social networks (Kondylis et al. 2014, Vasilaky and Leonard 2018, Mobarak and Yishay 2017) and low cost technologies like video and SMS (Aker and Fafchamps 2015, Campenhout et al. 2017).

Despite the progress made in training farmers on input adoption the latter research does not consider the eventual price that farmers face when they sell their output and to what degree that affects their returns. If farmers perceive a substantial amount of price dispersion this can negatively affect their agricultural investments and profits. Reducing this price dispersion that farmers face can, therefore, improve producer welfare by allowing farmers to negotiate better farm-gate prices (Svensson and Yanagizawa 2009). There is considerable evidence that information technology interventions, which can improve access to price information, are effective in this regard (Brynjolfsson and Smith 2010, Savva et al. 2016, Nsabimana). However, the use of such technologies to narrow price dispersion is far from perfect. For example, Krell et al. (2020) show that the majority small holder farmers in their sample from Kenya own a mobile phone but only 25% use their phone to acquire agricultural information. Aker and Fafchamps (2015) show that even though mobile phone coverage is associated with a reduction in price dispersion for consumers, the latter is not always true for producers. They find that increased access to price information reduces price dispersion for perishable crops, but has no effect on price dispersion for non-perishable crops. Thus, even with effective technology interventions price dispersion in output markets can remain.

Our contribution to this literature is to both document and demonstrate the potential consequences of price dispersion on the returns to input adoption.[3] With over 500 million small holder farmers worldwide the implications of input adoption are far reaching (Lowder et al. 2016). Bold et al. (2017) consider net returns, but only use one median output price estimated from a one-period survey conducted in 2013

[3] The first studies on technology adoption, developed within the agricultural economics literature in the developed world, considered output price uncertainty and variability (Kim et al. 1992) as one of the main determinants of adoption. Farm size (Just and Zilberman 1983, Hennessy 1997), complementarities in adopting multiple technologies (Dorfman 1996), and the substitution between on and off farm labor (Dorfman 1996, Diiro and Sam 2015) are other the major predictors of adoption among farmers. Foster and Rosenzweig (2010) provide a comprehensive overview of this literature.

with 312 farmers. While their results are informative in revealing the pervasive presence of low quality inputs, they cannot speak to whether there is a range of output prices for which adoption of even mediocre inputs would still be more profitable than using no inputs at all. Harou et al. (2017) study the returns to fertilizer use in Malawi, focusing on the variation in soil quality, rainfall and temperature. Just as Bold et at. (2017), Harou et al. (2017) also do not investigate the variability of prices over time. Overall, they find that the probability of returns to fertilizer is largely positive even if they increase fertilizer prices by 100% or decrease output prices by 50%. Carter et al. (2015) also study the returns to fertilizer in Kenya while accounting for soil quality, measured at the plot level. They find that the returns to fertilizer are low - 8 to 24 kg of maize per kg of nitrogen applied. However, once they control for fertilizer quality, the returns substantially increase, highlighting the importance of input quality.

First, our results suggest that increased input use, given high-quality inputs, could have the potential to drive productivity growth and render positive financial returns among smallholder farmers, despite the substantial output price volatility that characterizes the country. The economic return to fertilizer is positive (across the entire price range) for beans, maize and matooke and positive for the top 75 percent of prices for coffee. Median returns are 180 percent, 74 percent, 133 percent and 39 percent respectively. The returns to improved seed are less promising. For maize, improved seed increases gains only for the top 50 percent of the price distribution, and results in negative financial returns for the bottom 50 percent. In the case of beans, the returns are positive across the entire price distribution observed for the 12-year period and close to 80 percent at the median. However, the cost of using hybrid seeds often makes the return to using both fertilizer and hybrid seeds lower than that of using only fertilizer.

The latter results assume that farmers have access to high quality inputs. However, recent studies show that input quality and perceptions of input quality can vary considerably across markets (Bold et al. 2017, Michelson et al. 2021), and enforcing quality assurance is both a primary recommendation and current objective (IFDC 2015, 2018) in Uganda's input markets. Once we consider the low quality of inputs that can be found in input markets in the country, the financial returns for maize, the one crop for which this issue has been carefully documented, often become negative. Sub-standard quality of inputs reduces the yield gain from using hybrid seeds and nitrogen to 75-87 percent of what is expected. As a result, the sizable positive returns to using nitrogen fertilizer and hybrid seeds for maize decline considerably and even become negative for a considerable portion of the price range. The rate of return on using both fertilizer and hybrid seeds is only positive when maize prices are in the top third of the distribution. Finally, using Monte Carlo simulations, we also explore the role of farmers' risk-aversion in input adoption across all regional markets that vary in their price volatility. Considering the level of risk-aversion documented in the literature for Ugandan farmers, we observe that while risk-aversion does discourage adoption, particularly in markets with higher volatility, it alone is not enough to completely discourage adoption.

This article contributes to the literature on agricultural input adoption in much of the developing world. To our knowledge, this is the first study that incorporates over a decade of crop specific regional output prices in considering farmers' decisions to adopt inputs. While previous studies suggest that returns to improved inputs are positive, the latter often assume one output price in their calculations. In addition, we calculate returns for Uganda's four major commodities under the assumption of high and low quality inputs. If farmers believe that only low quality inputs are what are available then they are unlikely to adopt. Further, using Monte Carlo simulations we show that risk aversion can further discourage adoption in some markets. Our paper highlights the fact that exogenous factors such as commodity prices and the quality of available inputs can severely limit the impacts of programs aimed at encouraging farmers to adopt inputs.

The paper proceeds as follows. Section 2 describes the trends and spatial patterns of input use in Uganda. Section 3 describes the data and the methodology. The estimated returns to the use of fertilizer and hybrid seeds are presented in Section 4, while Section 5 explores the role of risk aversion. Section 6 concludes and offers policy recommendations.

2. Trends and spatial patterns of input use

We first explore the trends in input use in Uganda. We use the Uganda National Panel Survey (UNPS) from 2005/6 to 2013/14, a nationally representative survey of about 3,000 households across Uganda. It is part of the Living Standards Measurement Study (LSMS) and Integrated Surveys on Agriculture (ISA); a program that supports the design and implementation of household surveys such as the Uganda National Panel Survey (UNPS), and ensures comparability with other surveys being carried out under the same initiative in Sub-Saharan Africa.

The UNPS contains information on household characteristics, household consumption and income from a variety of income sources. It also contains a rich agricultural module. Five rounds of the UNPS are used in this analysis comprised of data collected in 2005/6, 2009/10, 2010/11, 2011/12 and 2013/14 (see Table 1).[4] For summary statistics, we use the sample of households engaged in agriculture weighted with cross sectional household weights.

Table 1. Attrition in the UNPS by wave

	Sample	Original sample retention	Split-off HHs	Total
2005/06	3,123	100	0	3,123
2009/10	2,607	83.5	367	2,974
2010/11	2,564	82.1	305	2,869
2011/12	2,356	75.4	479	2,835
2013/14	1,320	42.2	1,799	3,119

Source: Uganda Bureau of Statistics (2013)

For the most part, crops produced for household and national consumption dominate crop income. Maize, beans, matooke and cassava are the four most important crops as a share of total crop income for Ugandan smallholder farmers. Table 2 provides a description of the type of crops grown by the households for two of the latter years of the analysis. Maize and beans are universally prevalent—comprising 10 percent or more of crop incomes in all regions in both years. Matooke is present in all regions except the

[4] In some graphs referred as 2005, 2009, 2010, 2011 and 2013.

Northern region, and cassava is grown in all regions except the Western region. Coffee is less ubiquitous than the latter crops, but, nevertheless prevalent in most regions. Commercial sunflower production has increased in importance in recent years, particularly in the north, but it is still a relatively small share of crop income and is not considered further. Although food crops dominate crop income, crop sales are becoming increasingly important. The share of household income coming from crop sales has increased considerably, particularly for the bottom 40 percent: from 60 percent in 2005/06 to 72 percent in 2011/12 (Figure 1.1).

Input use in Uganda is low relative to other African countries for which comparable LSMS-ISA data are available. Previous studies such as Sheahan and Barrett (2017), and Binswanger and Savastano (2014) also utilize the UNPS to quantify input use. Sheahan and Barrett (2017) provide a broad overview of input use in six Sub-Saharan African countries using the 2010 wave of the UNPS. Their work highlights the relatively low input use in Uganda compared to Ethiopia, Malawi, Niger, Nigeria, and Tanzania, and show that the average amount of inorganic fertilizer applied per hectare of 0.7 kilograms for Uganda is substantially lower than the cross-country average of 56 kilograms per hectare.

In addition to low levels of inputs, there has been little increase (or change) in the use of improved agricultural inputs in Uganda over time. Figure 1.2 details the national trends in input use over time for households engaged in agriculture.[5] While the observed fertilizer use rate in 2013/14 (at 6 percent) was slightly higher than that for previous years, it has remained constant at about 5 percent throughout 2005/06-2013/14. Pesticide use has been higher than that of fertilizer use, but the increase in use recorded in 2009/10 and 2010/11 eventually dissipated, and only 15 percent of households were applying pesticides in 2013/14. In contrast, the proportion of households purchasing improved seed has been much higher, ranging between 17 and 24 percent. Improved seeds and planting materials are used for certain crops such as maize and cassava, and to a lesser extent beans and matooke (Figure 1.3).

Input adoption varies in Uganda by region and level of income, as also highlighted by Suri (2011). Overall, poorer households have lower input use rates, particularly when considering fertilizer and pesticide (Figure 2), while improved (hybrid) seed use rates are substantially higher. The Western region lags in the use of all agricultural inputs. Joint adoption of inputs, such as inorganic fertilizer and improved seeds, remains very low, at an average of 3 percent over the period analyzed. This is probably one of the largest limiting factors to the productive use of inputs over the long run, as adoption of improved seeds without fertilizer use depletes soils and reduces the efficacy of improved seeds alone. These trends are consistent with the findings of earlier studies that show how the adoption of these complementary inputs is incomplete for Uganda (Nkonya et al. 2005 and Sserunkuuma 2005).

Table 2. Share of crop income coming from each crop for selected waves

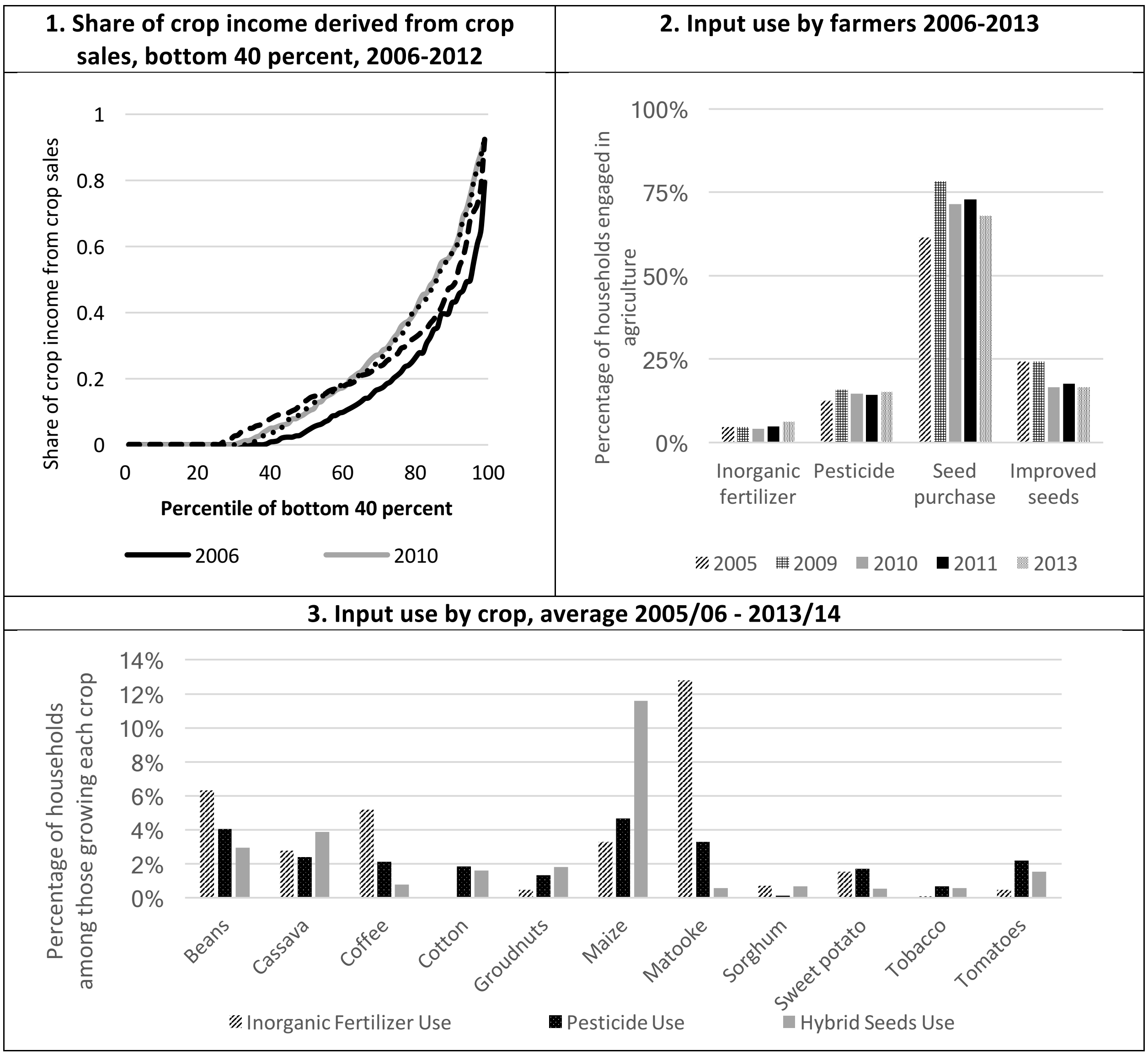
	2010/11					2011/12				
	National	Central	Eastern	Northern	Western	National	Central	Eastern	Northern	Western
Beans	0.17	0.16	0.10	0.16	0.25	0.16	0.18	0.11	0.13	0.21
Maize	0.12	0.12	0.17	0.12	0.07	0.17	0.15	0.25	0.16	0.10
Matooke	0.16	0.24	0.11	0.02	0.30	0.16	0.25	0.08	0.02	0.34

[5] The percent of households engaged in agriculture ranged between 75 and 82 percent throughout the 2005/06 - 2013/14 period.

Cassava	0.11	0.12	0.16	0.13	0.03	0.11	0.09	0.15	0.14	0.04
Sweet Potatoes	0.10	0.12	0.10	0.09	0.07	0.09	0.15	0.11	0.06	0.06
Groundnuts	0.07	0.04	0.10	0.07	0.07	0.06	0.02	0.08	0.06	0.05
Coffee All	0.05	0.08	0.06	0.01	0.05	0.04	0.08	0.03	0.01	0.05
Sorghum	0.04	0.00	0.04	0.09	0.02	0.04	0.00	0.03	0.09	0.02
Finger Millet	0.03	0.01	0.05	0.03	0.02	0.03	0.01	0.06	0.04	0.02
Simsim	0.03	0.00	0.01	0.08	0.00	0.02	0.00	0.01	0.06	0.00
Sunflower	0.01	0.00	0.00	0.04	0.00	0.02	0.00	0.00	0.05	0.00

Source: Author's calculations using RIGA 2010/11-2011/12. Note: red indicates a share 10 percent and higher in a given region, green indicates a share between 3 and 10 percent in a given region.

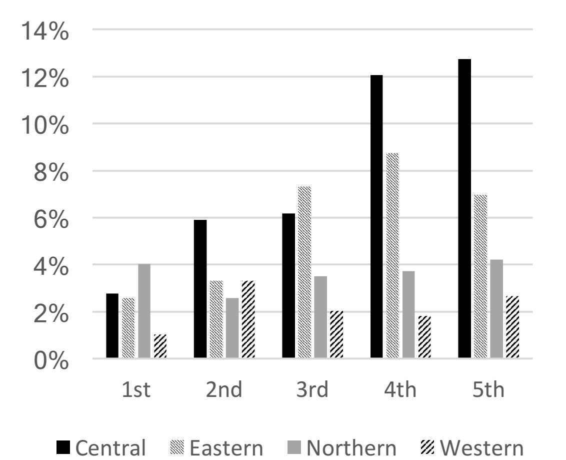
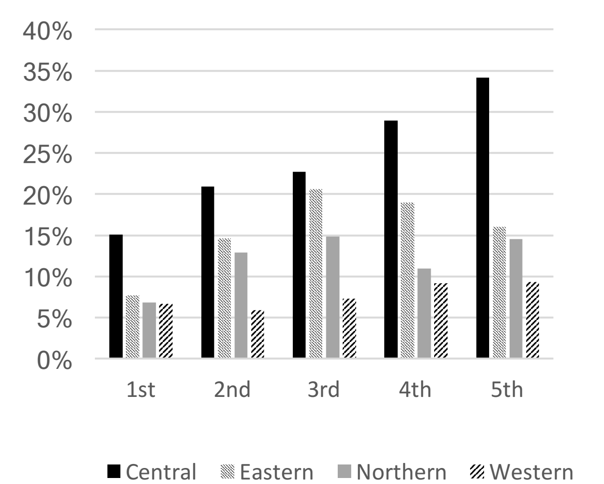
Figure 1. Crop sales and input use for households engaged in agriculture

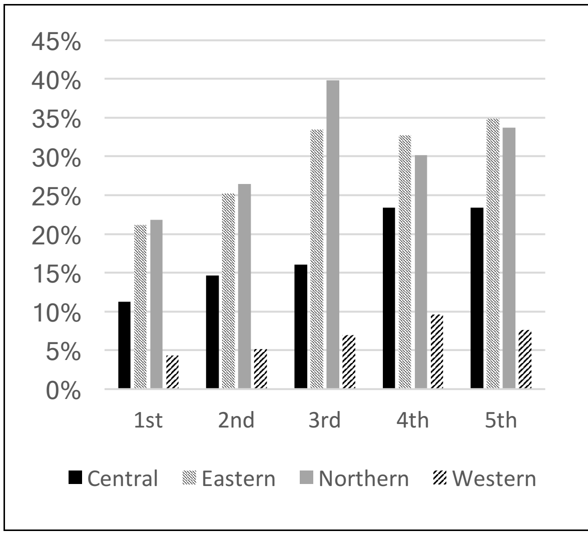


Source: 1-3: Author's calculations using UNPS 2005/06-2013/14.

Despite the low trends in input use, agricultural studies show that the yield potential to using inputs in Uganda is high. Binswanger and Savastano (2014) provide a measure of the agricultural potential of Uganda compared to other LSMS-ISA countries, using the 2005/06 and 2009/10 LSMS-ISA waves. They develop a measure of agro-ecological potential (AEP) using international crop prices, the share of land under each crop, and the potential of the crop in that area under optimal agricultural production practices, including use of improved varieties, fertilizer application adequate disease and weed control, adequate fallows and some mechanization. The AEP is based on attainable crop yields across all agricultural zones using data from the International Institute for Systems Analysis and the Food and Agriculture Organization for medium input levels (Tóth et al., 2012). Uganda has the highest AEP (and the 4th highest AEP per capita) compared to all other countries at $1,878 per hectare, twice as high as the second runner up, Malawi, at $999 per hectare.

Figure 2. Poorer households in poorer regions are less likely to use inputs

1. Inorganic Fertilizer Use by Consumption Quintile, 2005/06 -2013/14	**2. Pesticide Use by Consumption Quintile, 2005/06 – 2013/14**
	
3. Improved Seed Use by Consumption Quintile, 2005/06 – 2013/14	



Source: Author’s calculations using UNPS 2005/06-2013/14

Likewise, McCarthur and McCord (2017) predict high potential returns to input use under the assumption that inputs are of high quality. In a cross-country panel study, they estimate a production function where fertilizer use at the household level is instrumented for by variance in distance to fertilizer production. Overall, they find that a 1 kg/ha increase in fertilizer results in 8 kg/ha increase in cereal yields between the years. That said, even though there is a potential for high yields, neither study considers prices or farmers’ economics returns.

3. Methodology

We focus on the estimation of the profitability of the use of two agricultural inputs, inorganic fertilizer and improved seeds for four of the *main crops* in Uganda: maize, beans, coffee and matooke (as described in Table 2).[6] First, we estimate the yields for each crop, under optimal conditions, using the best available information on the yield return to inputs from experimental fields as reported by agronomic research. We then estimate the financial returns by considering output price data from different local markets in Uganda over a little more than a decade.

3.1 Estimating yield gains from the use of authentic inputs

We calculate the returns per hectare to using fertilizer and hybrid or improved seed using the following formula:

$$\frac{\Delta y * p^{q} - l^{fs} * (c_f + c_s)}{l^{fs} * (c_f + c_s)}$$

[6] As mentioned above, we did not find experimental field trials for hybrid seeds use in matooke and coffee. Similarly, we could not find experimental evidence on the use of pesticide in Uganda or similar countries with detailed data on application rates and costs.

where Δy is the change in yield per hectare as compared to control plots, p^q, is the farm gate output price of the commodity for the qth price quintile, c_f is fertilizer cost or total fertilizer used per hectare times its cost, and c_s is seed cost or total seed used per hectare times its cost, $l^{fs}$is an additional labor factor that is 1.47 whenever hybrid varieties are used, and accounts for the extra labor that is needed for more intensive application of fertilizer with hybrid varieties .[7]

The change in yields, Δy, arising from input use, is taken from different agricultural field studies in Uganda, and the calculations for each crop are listed in the Appendix. Returns to nitrogen for maize were taken from Bold et al. (2017).[8] Returns to the remaining crops were taken from the following agronomic studies in Uganda: Asten et al. (2019) for the returns to nitrogen application for Robusta coffee; Kaizzi et al. (2012b) for the returns to nitrogen in beans; and Nyomibi et al. (2010) for the returns to NPK for matooke. For both beans and matooke the latter estimates necessary to calculate Δy were pulled from the Optimized Fertilizer Recommendations in Africa (OFRA) Response Function Database developed by agronomists with "over 5,800 geo-referenced response functions for food crops determined from past and OFRA-related research with 49% from the latter" (Wortmann 2017). Our objective is to use response functions that were developed by experimental agronomic studies aimed at testing input use only. The estimates in OFRA come from fitting an asymptotic quadratic–plateau function, which gives an exponential rise to maximum yield. The asymptotic function for nitrogen, for example, is $a - bc^N$, where a, b, and c are estimated as N varies across field tests.

Total fertilizer cost, c_f, depends on the amount (kgs) of fertilizer applied per hectare and the cost per kg of fertilizer. Total seed cost, c_s, depends on the seed application rate per hectare and the cost of seed. Because input prices have been fairly stable between 2005/06 and 2013/14, as shown in Figure 3.4.4, we use the single price for fertilizer and seed that is stated in each study, which we cross checked via local distributors in Uganda.[9] Fertilizer application rates vary based on the study used for each crop and are listed in the Appendix. For beans and matooke we use 45 kilograms of fertilizer per hectare, the middle fertilizer value explored in the studies mentioned above. Conversely, for maize and coffee, the corresponding studies only provide average returns for one set of input values, which correspond to official recommendations for authentic urea. Seed application rates per hectare were calculated from the study's targeted plant growth per meter squared and estimated using the seed's weight.[10] We assume that traditional seed prices cost approximately one-third of improved or hybrid seed.[11] However, in some

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[7] Costs are 32% more for applying fertilizer (Bold et al 2017), so 32% of the total input expenses, per hectare , implies that $l^{fs} = 0.32 * (c_f + c_s + l^{fs})$ or $l^{fs} = 0.47 * (c_f + c_s)$.

[8] In the Appendix we compare Bold et al. (2017)'s returns to fertilizer use to a purely agronomic study, Kaizzi et al. (2012a). We show that the results between the two studies do not differ greatly in terms of yield responses with and without nitrogen application. One of the benefits of the Bold et al. (2017) study is that it also considers the returns should fertilizer quality be diminished.

[9] We only include fertilizer and pesticide, because there was no information on the quantity of hybrid seeds used.

[10] For example, if the targeted plant growth was 11 plants per square meter, then that is 11 seeds per square meter multiplied by the weight of the seed to estimate how many kilograms of seed were used per hectare. For example, a 100 seed bag of K132 beans is 35 grams.

[11] Note that only the Bold et al (2017) study applies hybrid seed, while all other studies use improved seed, including the households in the LSMS.

cases, traditional seed may very well be free.[12] Coffee and matooke do not require seeds after the tree has already been planted, and, therefore, do not incur in a variable cost. Since the various studies took place in different years, we deflate all prices using the 2005 CPI.

3.2 Estimating financial returns

There is considerable variation in the output prices of the crops considered in this study. Price variation is particularly relevant for the adoption of inputs, as fluctuations in wholesale prices are often passed on to producers who then receive a smaller market share, particularly at the farm-gate when they sell their crops (Fafchamps and Hill 2005). Figure 3 details the volatility in the real wholesale price of maize, beans and matooke from 2000 to 2012 using data on wholesale prices collected by the Uganda Bureau of Statistics (UBOS) in 8 markets as part of price data collection for the consumer price index (CPI). The graphs show the distribution of prices using data only from months in which farmers typically sell (namely November to February and June to August, as reported in the UNPS survey). Matooke prices, for example, can range from 150 shs/kg to 650 shs/kg. This can generate a wide range of returns for a farmer, and our interest is knowing how often returns remain positive.

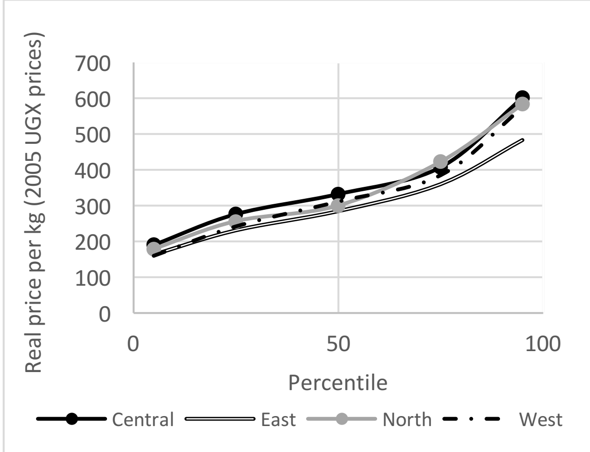
For each region (North, East, South, West), we calculate output prices, p^q, for five quantiles (q = 5, 25, 50, 75, 95) using monthly wholesale price data between 2000 and 2012. We then account for the fact that farm gate prices (what farmers receive for their output) are lower than the international retail price in our data by scaling the output price by a factor between 0.6 and 0.8, except for coffee.[13] With coffee, our price data for unmilled coffee was on par with farm gate prices, and, therefore, not deflated. Similarly, coffee prices are not disaggregated at the regional level and at each point in time, they represent national averages.

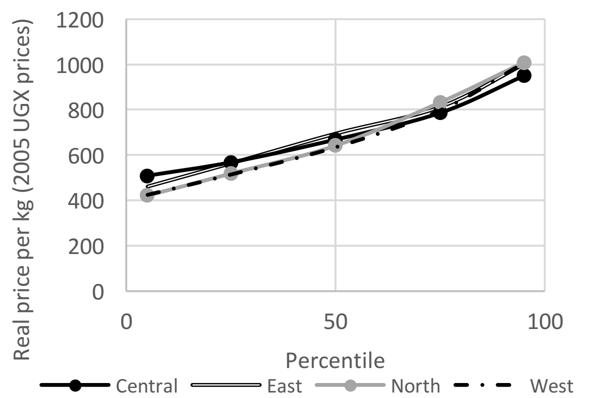
Figure 3. Distribution of real crop prices

1. Maize crop prices (2000 - 2012)	2. Bean crop prices (2000 - 2012)

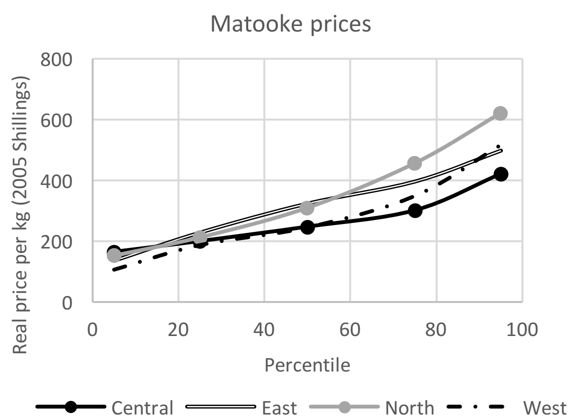
[12] The returns can vary based on our assumptions relating to traditional seed costs. There is inadequate data as to whether farmers are purchasing traditional seed and at what price. Here we assume a traditional seed price that is 30% of hybrid or improved seed prices. For matooke and coffee we do not consider seed costs, assuming that trees have already been planted in the past.

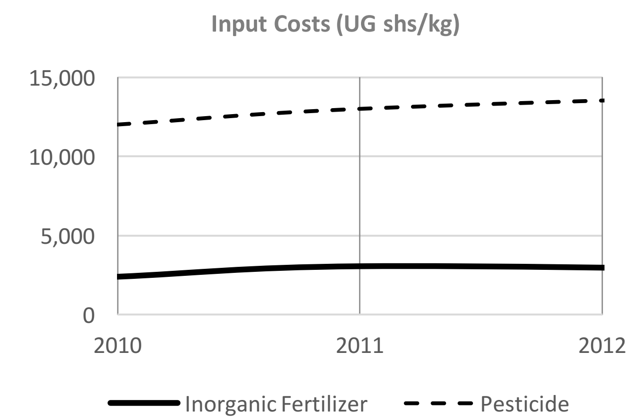
[13] The deflation factor was determined by comparing the international price to the farm gate price reported by farmers in the LSMS.





3. Matooke crop prices (2000 - 2012)	4. Input prices (fertilizer and pesticide, UG shs per kg.)





Source: Staff calculations using wholesale prices from UBOS, 2000 - 2012 and UNPS 2005/06-2013/14. Prices are averaged across the 1st and 2nd season.

4. The net financial return to the use of inputs

Using the range of output prices shown in Figure 3, we first calculate the returns to applying nitrogen (inorganic fertilizer) and using hybrid seeds for the main maize growing region, the Eastern region (as shown in Table 2).

Figure 4.1 plots the distribution of the net financial return per hectare across the range of maize prices, while assuming input prices constant. The estimates show that when crop prices are at their lowest, returns to fertilizer use are almost 0 (bottom 5 percent of prices) and at median prices returns are 74 percent. At the highest crop prices (top 5 percent of prices), returns are a substantial 196 percent. Thus, overall, fertilizer use results in positive returns along the entire range of maize prices observed between 2000 and 2012.

The use of hybrid seeds alone is not as profitable. The return to using hybrid seeds alone is negative except when output prices are very high, as the cost often exceeds the extra revenue gained from using them. The returns are positive for the top 50 percent of maize prices, but at median prices the rate of return to using hybrid seeds is zero. Yield gains are highest for fertilizer alone and using hybrid seeds and nitrogen together results in slightly lower returns.

We obtain similar results when calculating the returns to fertilizer and hybrid seeds for maize in the other three regions of Uganda where maize is also popular but not as important in terms of crop income as in the Eastern region. In all regions (Central, Northern and Western) the financial returns to fertilizer are positive throughout the price distribution, and slightly higher than in the Eastern region. In the case of seeds, the returns become positive after the 25th percentile for the Central region and after the 50th percentile for the Northern and Western regions. Thus, the return to both inputs in these regions has the same pattern but is slightly lower when compared to the Eastern region, as seen in Figure 4.2.

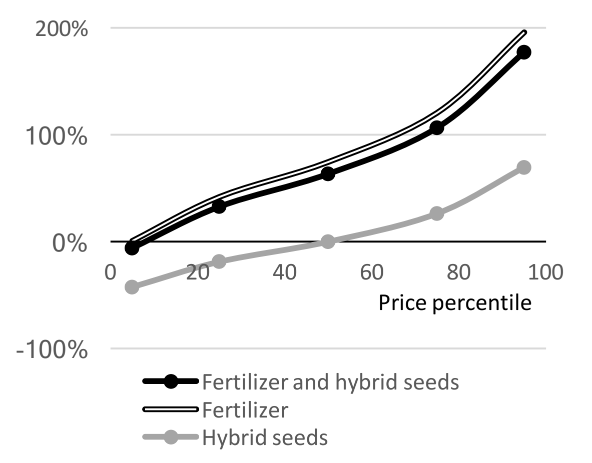
Secondly, we calculate the returns to using fertilizer and hybrid seeds for beans, this time focusing on the Western region for which this crop represents the highest percentage of crop income (Table 2). There are positive and large returns for both fertilizer and improved seeds across the entire range of bean prices. Even in the case of very low prices (at the 5th percentile), the returns are large, close to 90 and 21 percent, respectively. However, similar to maize the returns to investing in hybrid seeds and fertilizer together are lower than investing in just fertilizer alone.[14] The median return for fertilizer is 182 percent, while that for using both inputs is 138 percent (see Figure 4.3), explained once more by the elevated cost of hybrid seeds.

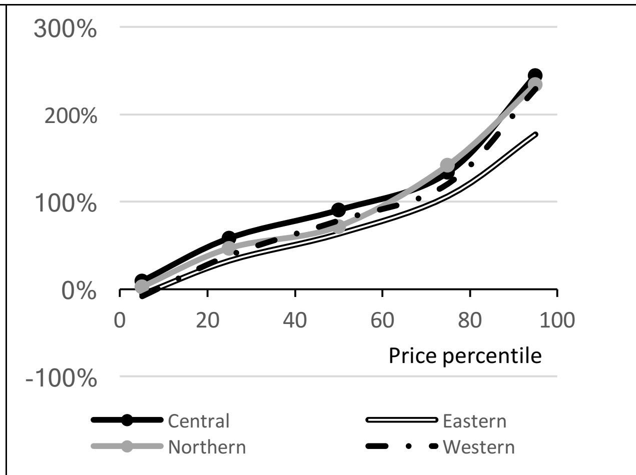
As for the other three regions (Central, Northern and Eastern), we find that while the returns to fertilizer and hybrid seeds for beans in the Northern region are very similar to those observed in the Western region, they are slightly higher in the Central and Eastern region. Once more, a similar pattern emerges across all four regions of Uganda (see Figure 4.4).

Figure 4. The returns to nitrogen fertilizer use are high across a range of prices, but not so for hybrid seeds

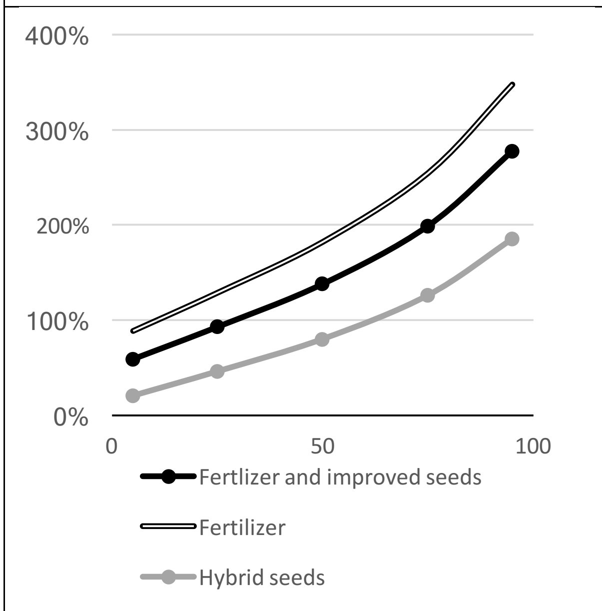
1. Rate of return to fertilizer and hybrid seeds for Maize in the Eastern Region	2. Rate of return to fertilizer and hybrid seeds for Maize across regions

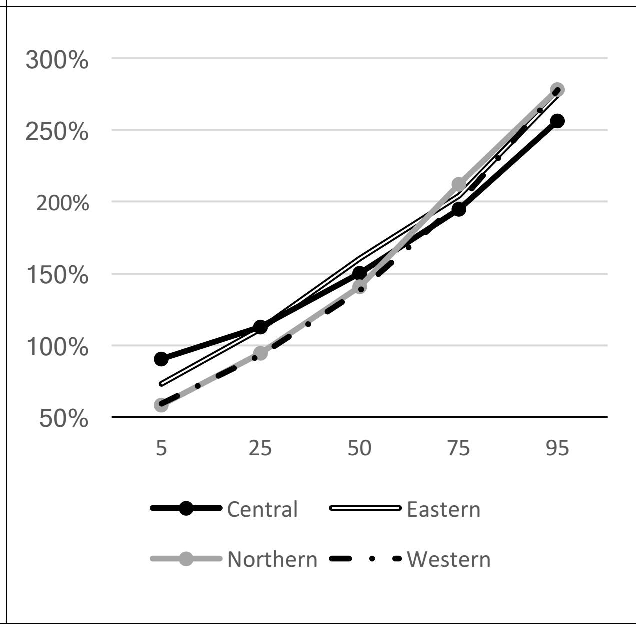
[14] These returns are also specific to the particular seed used and region, the Western region. For beans we used the returns from K132 and Kanyebwa seeds from Kaizzi et al. (2012).





3. Rate of return to fertilizer and hybrid seeds for Beans in the Western region	**4. Rate of return to fertilizer and hybrid seeds for Beans across regions**



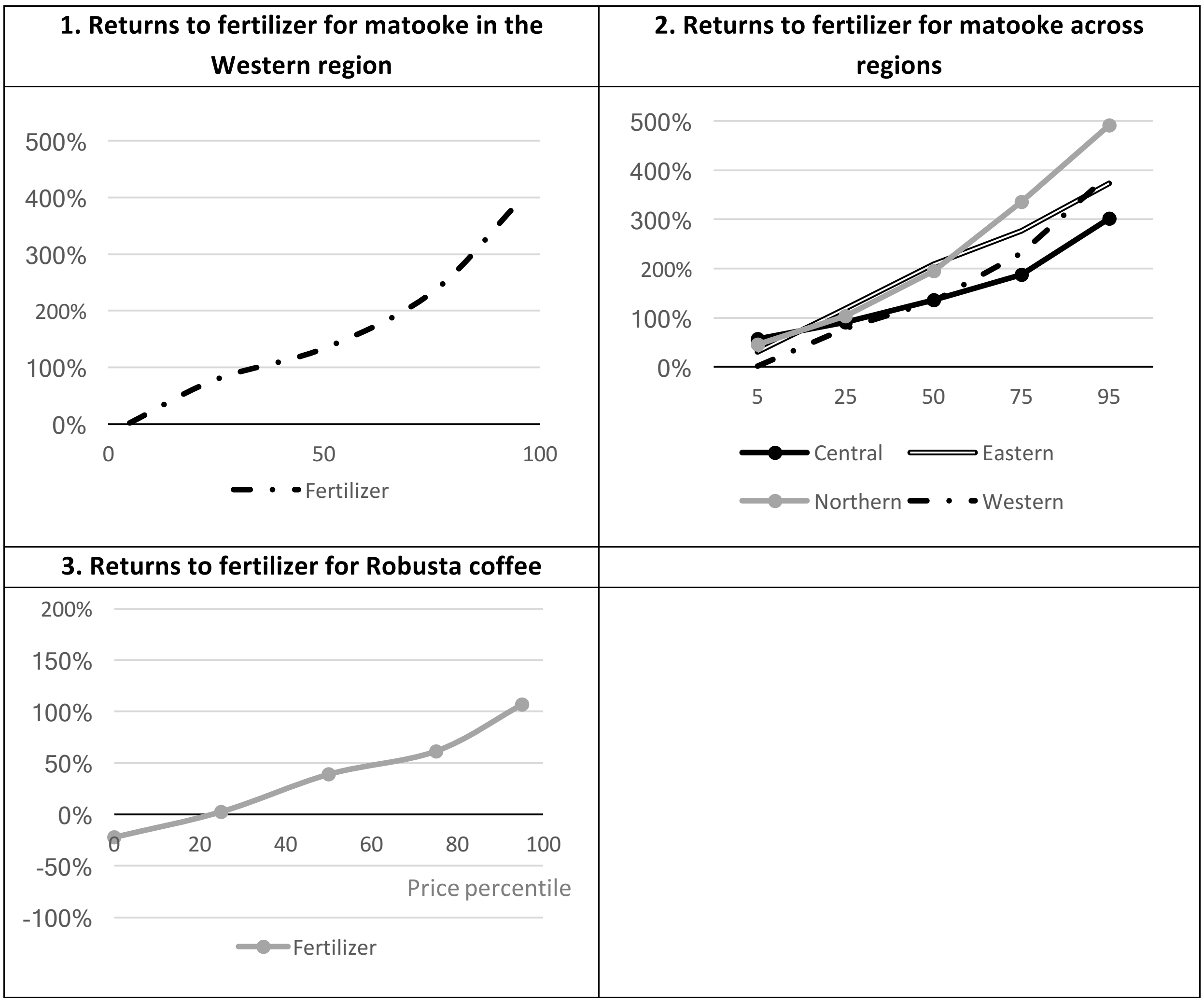


Source: Staff calculations using yield responsiveness and cost of inputs estimated in Bold et al. (2017) and wholesale prices from UBOS, 2000 - 2012.

We now turn to the returns to fertilizer for two other crops that have been traditionally important in Uganda: matooke and coffee, which are tree-based crops. We focus on the Central region for matooke, and the national average for coffee. The returns to applying fertilizer in matooke crops are positive through the entire price range, with a median return of 133 percent, similar to the returns observed for the same input on bean crops (see Figure 5.1). When compared to the other regions, we observe higher returns across the board for the Northern and Eastern regions, with mean returns close to 200 percent in both cases. As for the Central region, it presents higher returns compared to the Western region for the lower half of the distribution but that is reversed for the top 50 percent (see Figure 5.2). In the case of coffee, national returns are positive only for the top 75 percent of prices, and the median return is 39 percent.[15]

Overall, our results demonstrate that the returns to fertilizer use alone are positive for all crops, at least for the top 75 percent of prices, and using fertilizer alone is generally more profitable than the combined use of fertilizer and improved seeds, or improved seeds alone. These findings stand in contrast to the observed trends in Uganda. As shown in Figure 1, hybrid seed use was around 20 percent between 2005 and 2013, while fertilizer use never reached 10 percent in the same period. A greater percentage, although still small, of farmers are adopting improved seeds alone, but fewer are adopting fertilizer alone despite the size of the returns (Figure 1.2). This is one of our main findings– despite its profitability fertilizer is rarely adopted, particularly in comparison to hybrid seeds.

Figure 5. Returns to fertilizer for matoke and coffee

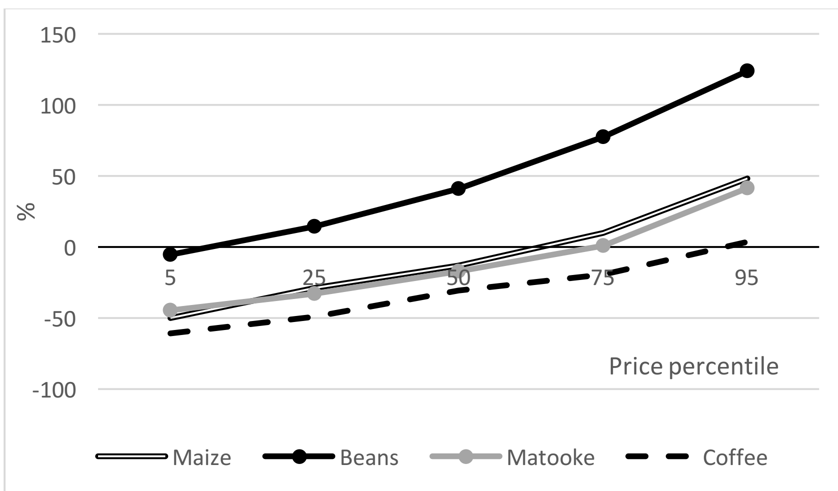


[15] Yield increases are taken from Nyombi et al. (2010) for matooke and van Asten et al. (2017) for coffee. In neither study were returns to improved planting materials for matooke or coffee, for example, considered.

Source: 1: see Figure 3.5, 2-4: staff calculations using yield responsiveness and cost of inputs estimated in the OFRA Response Function Database (2017) from the University of Nebraska. Wholesale prices from UBOS, 2000 - 2012.

The latter returns assume normal weather conditions, and under poorer weather conditions the financial returns likely disappear. If the yield gain is halved under bad weather conditions as some studies suggest (Dercon and Christiaensen 2011, Rosenzweig and Udry 2017), the financial returns become negative for all coffee prices and all but the top 25 percent of maize and matooke prices. In contrast, the return to fertilizer use on beans remains positive across the full range of prices (see Figure 6). The expected return for fertilizer use will depend on the full distribution of possible returns under all weather and price outcomes, which is not possible to estimate with the available data. However, if farmers are risk averse as studies suggest (Binswanger 1980, Brauw and Eozenou 2014), then a large expected return may be needed in order to offset the disutility from negative returns. Indeed, coffee farmers have been shown to reduce input use in Uganda as a result of expected risk in prices and weather (Hill 2010). We explore the consequences of risk aversion in Section 5.

Figure 6. Predicted returns to fertilizer use under bad weather conditions



Source: Staff calculations using yield responsiveness and cost of inputs estimated in the OFRA Response Function Database (2017) from the University of Nebraska and in Bold et al. (2017) and wholesale prices from UBOS, 2000 - 2012.

4.1. Quality of input use

It is often noted that experimental yields from controlled agronomic studies are high but rarely observed on an average farmer's plot. This can be explained by differences in soil and environmental conditions across farmers (Suri 2011, Harou et al. 2017), variation in crop management practices (Esilaba et al. 2005, Ngome et al. 2011, and Sileshi et al. 2010). In addition, variation in access to high quality inputs can also impact yields.

The quality of inputs available to farmers are not always the same as those used in agronomic studies. For example, Ashour et al. 2019 test the quality of herbicides – the most prevalent input in their sample- in Uganda using 483 samples from 120 different markets and find that "15 per cent of the active ingredient is missing in herbicide samples, and 31 per cent of samples contain less than 75 of the advertised concentration of glyphosate and another 40 per cent of samples contain between 75 and 99 per cent of the advertised concentration of glyphosate." Similarly, in Bold et al. (2017), for 369 samples of fertilizer purchased from 129 retail shops in Uganda by a mystery shopper, no samples were found to contain the required nitrogen content. The average nitrogen content was 30 percent lower than what it should be. They also find that the average quality of hybrid seeds purchased at 30 retail shops was below international standards and estimated them to be equivalent to a mix of 50 percent hybrid seeds purchased directly from the seed dealer and 50 percent traditional seeds purchased from farmers. In a similar study, Tjernstrom et al. (2017) find that 77% of seeds in their samples from 167 stores in western Kenya (Kisumu, Kisii, Kakamega, and Eldore) germinate, compared to the regulatory threshold of 95% germination for certified seed. Overall, Bold et al. (2017) show that sub-standard qualities of inputs that have been found in Uganda's markets reduce the yield gain from using hybrid seeds and fertilizer for maize to 75-87 percent of what is expected.

In many cases, the quality of the input itself is not substandard, but the packaging is, and this can lead to perceptions of adulteration and low quality. Adulteration has been associated with bulk breaking – that is, when smallholder farmers demand quantities of fertilizer or seed that are smaller than the contents of the package. For example, fertilizer is sold in 50 kg bags, but farmers will often demand fertilizer in 1 kg, 2kg or 5kg bags. Similarly, seed companies package seed in 2kg bags while farmers often demand smaller quantities than this. When selling these smaller quantities, the input can be easily diluted and/or the label can be counterfeited. Thus, even when the quality of inputs is not substandard, non-compliance with packaging can lead to a perceived low-quality, ultimately affecting adoption by farmers. Sanabria et al. (2013) find that compliance for Urea alone in West African markets across five countries (Nigeria, Côte d'Ivoire, Senegal, Ghana, and Togo) is satisfactory, but that the majority of the problems lie with underweight fertilizer bags (from 7 percent in Togo to 41 percent in Nigeria). Mbowa et al. (2015) collect 170 samples from 22 shops across Uganda. They find that Urea and DAP content are within acceptable ranges for nitrogen content but that NPK is below the 17 percent stated nitrogen content found on bags. They also find considerable non-compliance in moisture content and bags being under weight (from 65 for non-registered to 80 percent for registered actors). Likewise, Michelson et al. (2021) find no issues with the quality of inputs in nearby Tanazia, but emphasize that packaging and physical tampering reduce the perceived value fertilizer, even if the quality of fertilizer is adequate.[16]

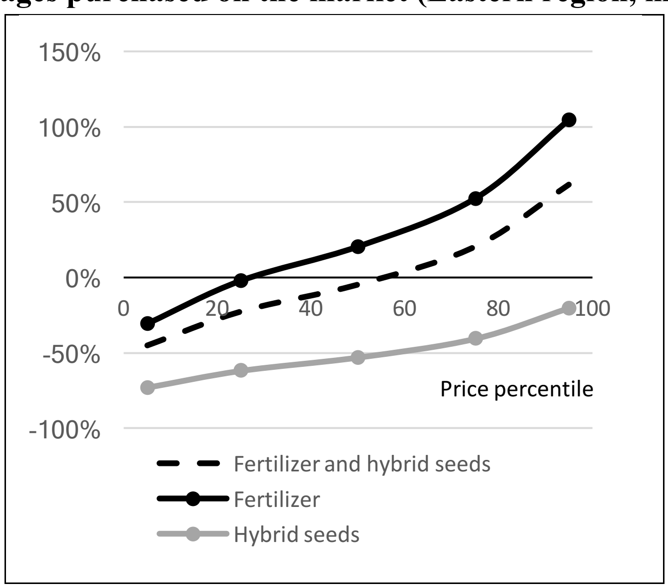
While our paper does not aim to measure the degree to which inputs are of low quality or are perceived to be low quality, both scenarios are important to consider form the standpoint of the farmer. If the farmer expects the inputs to be diluted, then his or her expected returns to inputs will be lower and he or she will be discouraged to adopt. Considering this, we recalculate the returns to using fertilizer and hybrid seeds for maize assuming lower yields associated with lower quality inputs (assumptions can be found in

[16] For example, fertilizers purchased in the market often contain large hard caked clumps, colored pebbles or foreign material, and may exhibit some discoloration. However, the actual nitrogen content, which should be around 46% for Urea, is intact.

the Appendix). The sizable positive returns that we estimated earlier disappear and even become negative at many prices. The rate of return to fertilizer at median prices in Eastern Uganda falls from 74 percent, when authentic fertilizer is used, to 20 percent, when fertilizer purchased on the market is used (Figure 7). Thus, the rate of return on fertilizer is only positive when maize prices are in the top two-thirds of the distribution. Similarly, positive rates of return for adopting both fertilizer and hybrid seeds are only observed when prices are in the top half of the price distribution, when quality is taken into account. As for the returns to just using hybrid seeds, owing to yield loss, they are negative across the entire price distribution, suggesting that farmers should not adopt seeds bought in the market. This finding is interesting as adoption rates of hybrid seeds have been historically higher than they have been for fertilizer in Uganda. One possibility for this difference is in farmers' perception of input quality. As Michelson et al. (2021) demonstrate, farmers often differentiate between high and low quality fertilizer according to observable physical characteristics including clumping and caking, and the appearance of foreign materials. However, evidence of similar visual cues does not seem to exist for differentiating between authentic versus non-authentic seeds. Another possibility is that hybrid seed quality is less of a concern than fertilizer and the evidence focuses more on fertilizer. Again, this paper does not claim that either are substandard in all markets, but considers the possibility of lower quality or lower perceived quality as reported by past studies.

We do not have agronomic data on the yield response for beans, coffee and matooke under inauthentic inputs; however, given that the range of the return for authentic inputs is in line with that of maize's returns to authentic inputs, we expect a similar downward shift in the distribution of returns should input quality be suboptimal. If this were the case, using fertilizer on coffee would likely never be optimal and using fertilizer on matooke would only be optimal at higher prices, as with maize.

Figure 7. The extent and impact of poor-quality inputs (maize): returns to different input packages purchased on the market (Eastern region, maize)



Source: Figure 1: 2015 NSDS. Figures 2 and 3: Bold et al. (2017). Figure 4: Staff calculations using yield responsiveness and cost of inputs estimated in Bold et al. (2017) and wholesale maize prices from UBOS, 2000 - 2012.

5. Risk Aversion and Price Uncertainty

Thus far we have considered the returns to input use based on known agronomic yields from a variety of studies, coupled with price data reflecting the price volatility in the Ugandan retail market. An important related question is whether and to what degree risk aversion can impact a farmer's decision to adopt inputs given the price uncertainty that they face in their market. In this section, we compare a risk neutral farmer to a risk averse farmer with constant relative risk aversion when prices are uncertain. We are interested in understanding how the volatility in the price market affects whether the risk averse farmer of a certain income level would be willing to adopt hybrid seed and fertilizer in a scenario of high input quality (as in the agronomic studies referenced in this paper) and in a scenario of reduced input quality.

We set the relative risk aversion parameter at 1.32 following Tanaka and Munro (2014) and Kijima (2019), which study risk aversion among Ugandan farmers. We proxy household income with farmers' average total income using the World Bank's LSMS data described in Section 2, which, in 2005 CPI adjusted prices, is on average 500 USD per year.

We first fit the price data from each of the eight markets for which we have data from 2000-2012 to a skewed normal distribution.[17] We conduct a Monte Carlo simulation drawing 100,000 prices and calculate the net financial returns in each of these draws. Net financial returns are the added gains of jointly using hybrid seed and fertilizer less the cost of those additional inputs and the cost of applying the inputs. These returns are taken from Bold et al. (2017) and are also benchmarked against Kaizzi et al. 2012a (pg 76). The values used in this exercise are those listed in row 1 of Table 1 in the Appendix. In Figure 8a we plot the net financial returns for each market from the lowest standard deviation to the highest (lowest volatility to highest volatility). We also plot two lines: the expected value of profits, and the certainty equivalent (CE) of profits for these farmers, and include values for the risk premium (rp) in that market (expected returns less the certainty equivalent), and the standard deviation (std) of profits.

In terms of volatility, and as expected, we observe higher risk premiums for farmers in markets with higher price volatility, although at this level of risk aversion the differences are not large. In this ideal scenario of high quality inputs, farmers across all eight markets adopt inputs. For both the risk averse and the risk neutral farmer, the net financial returns from using inputs are well above zero. In fact, we calculated that only for a very high level of risk aversion, $\gamma = 13$, well above what Tanaka and Munro (2014) and Kijima (2019) estimate for rural Ugandan farmers, is when the certainty equivalent becomes negative. In terms of volatility, and as expected, we observe higher risk premiums for farmers in markets with higher price volatility.

The additional returns to combined input use in a scenario of low quality inputs (inauthentic seed and fertilizer), are depicted in Figure 8b, (row 4 of Table 1 in the Appendix lists the assumptions, and these are taken from Table 3, column 2 Bold et al. (2017))**.** In this case, for half of the markets the certainty equivalent to the risky investment in hybrid seed and fertilizer is no longer positive. Specifically, in Tororo, Lira and Soroti the expected value for the risk neutral farmer is marginally positive, but the certainty equivalent is now negative. Thus, risk aversion matters in that it can put a farmer right above or below the zero net return line, but it is not the main driver in adoption.

[17] We compare the actual price data to a truncated skewed normal distribution where the Kolmogorov Smirnov test yields a pvalue = 0.5. A truncated skewed normal provides the best fit for the price data as compared to a normal or lognormal distribution.

Figure 8a. Distribution of net returns (USD 2005 prices) when using hybrid seed and fertilizer for *high* quality inputs

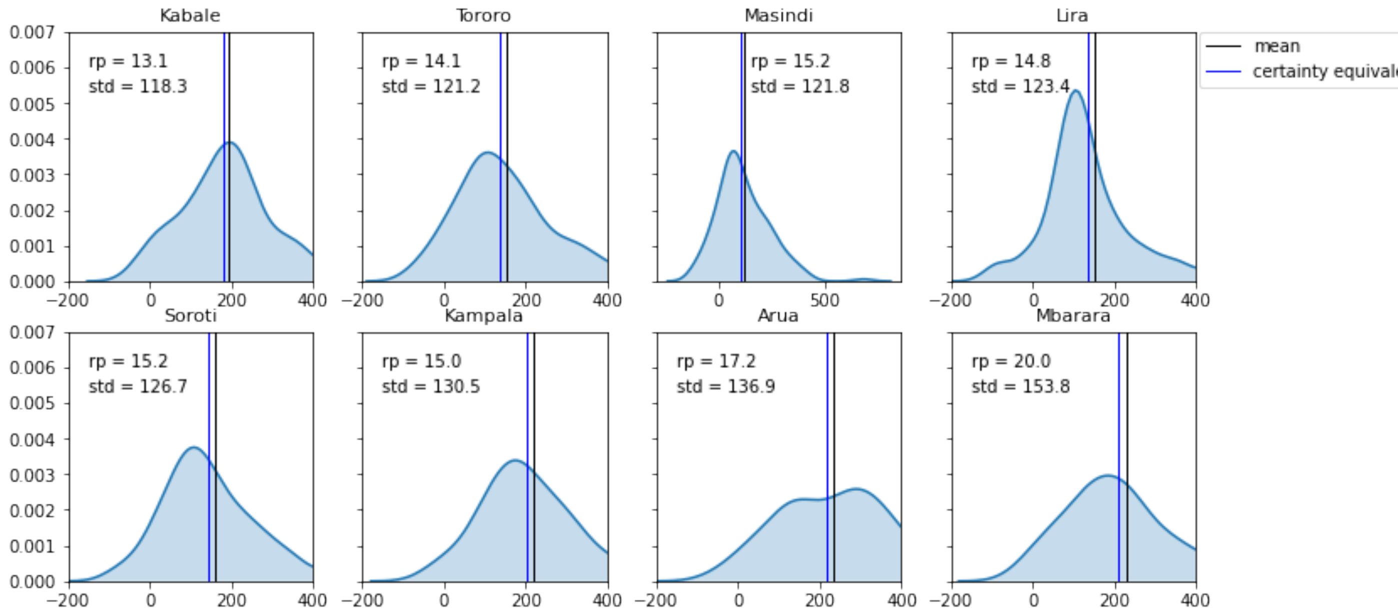
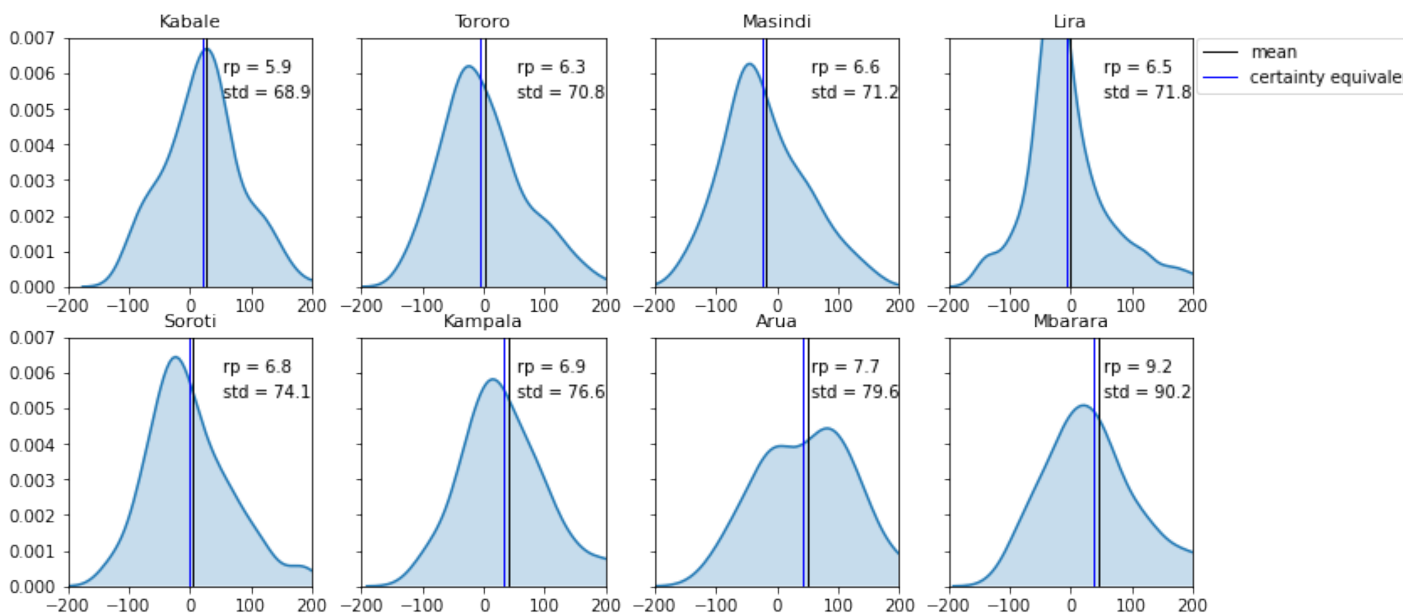


Figure 8b. Distribution of net returns (USD 2005 prices) when using hybrid seed and fertilizer for *low* quality inputs



Source: Price data taken from the World Bank. Yield and input cost estimates for maize taken from Bold et al. (2017). Rp=risk premium on investing in hybrid seed and fertilizer versus not using hybrid seed and fertilizer. It represents the mean difference between additional profits from the investment for a risk neutral farmer compared to the certainty equivalent of those profits for a risk averse farmer with constant relative risk aversion (CRRA). Std=standard deviation of the profits. The certainty equivalent of the profit data is calculated for CRRA utility where $\gamma = 1.32$ based on Tanaka and Munro (2014) and Kijima (2019).

6. Conclusions

Financial returns to input use in Uganda are considerable. Yet, despite favorable weather conditions and favorable agricultural crop prices, adoption rates of fertilizer, pesticide and hybrid seeds in Uganda have remained stubbornly low in comparison with other countries in Sub-Saharan Africa. We contribute to the literature studying this issue by taking into consideration the volatility of commodity output prices using over a decade of international output price data from Uganda. We first analyze the financial returns to using inorganic fertilizer and hybrid seeds under normal conditions, across the distribution of observed prices in Uganda, along with yield parameters identified in the agronomic literature. The main finding is that financial gains from using inputs in Uganda are substantial, despite observed output price volatility. The economic return to fertilizer is positive across the entire price distribution for beans, maize and matooke, and positive for the top 75 percent of prices for coffee. Median returns are 180 percent, 74 percent, 130 percent and 39 percent respectively. In the case of hybrid seeds, yields increased by 32 percent on average. However, the cost of using maize hybrid seeds often exceeds the extra revenue gained, reducing financial returns. As a result, the returns to fertilizer alone are generally higher than the returns to the combined use of fertilizer and hybrid seeds.

However, once the quality of inputs is considered, the returns decline substantially, becoming negative for a considerable segment of the price range. Some studies show that the quality of inputs can be substandard (Bold et al 2017; Ashour et al 2020). Given the substandard quality of inputs typically available in local markets, and measured quantitatively by several studies, the yield gain from using hybrid seeds and nitrogen falls by around 75 to 87 percent. As a result, the sizable positive financial returns observed for using authentic inputs in maize crops disappear and even become negative at many prices. The rate of return on fertilizer is only positive when maize prices are in the top two-thirds of the distribution, and the median return drops from 74 percent to 20 percent. Other studies show that farmers may expect low quality inputs even if they are not in fact of poor quality (Michelson et al. 2021). Thus, if quality of the inputs available on the local market is low, and/or if farmers believe it to be low, then there is little incentive for farmers to adopt inputs. Our simulations of risk averse farmers suggest that risk aversion discourages input adoption but does not seem to be the driving factor. In terms of volatility, and as expected, we observe higher risk premiums for farmers in markets with higher price volatility, although the differences are not large.

Our findings show that given the distribution of historical output prices there is a limit to positive returns. With high quality inputs farmers can still realize positive returns for a wide range of prices, and even more so with fertilizer. However, if farmers face suboptimal input quality then returns to fertilizer for maize are positive only for the 50th percentile of prices and higher and returns to fertilizer with hybrid seeds are positive only for the 75th percentile of prices and higher. Further, even if actual input quality is not low but farmers perceive it to be low adoption will still be impacted, particularly for inputs like fertilizer where there are visual cues that farmers use to infer quality (even if the cues are not accurate measures of quality). Similarly, if farmers face suboptimal weather then returns to fertilizer are positive only for the

75th percentile of prices and higher for maize and matooke, and in the case of coffee only for the top 5th percentile. Overall, the latter conditions can make for an unsustainable input adoption environment.

From a policy perspective these results suggest that monitoring input quality and strengthening the institutions that regulate input certification is important to increasing input adoption in Uganda. Farmers need to know that the contents of the inputs that they are buying are of sufficiently high quality. Two initiatives should be noted in this regard. Recently, the National Agricultural Advisory Services (NAADS), in conjunction with the World Bank, rolled out an e-voucher system to a small number of pilot districts in Uganda. The aim is to provide farmers with vouchers for quality-inspected inputs to increase production and productivity of the 5 priority crops (rice, beans, cassava and maize) in 42 districts in Uganda. Another potential tool is e-verification, developed by The Feed the Future Uganda Agricultural Inputs Activity in Uganda, and funded by the U.S. Agency for International Development (USAID). The tool involves labeling genuine agricultural inputs with a scratch-off label, which reveals an authentication code, can be used via SMS and is currently being piloted in Uganda. Scaling initiatives like these can help make input adoption become a profitable investment for smallholder farmers, and also make other programs that aim to alleviate other constraints, worthwhile.

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Appendix

FIGURE 1: Difference in grain yields using nitrogen

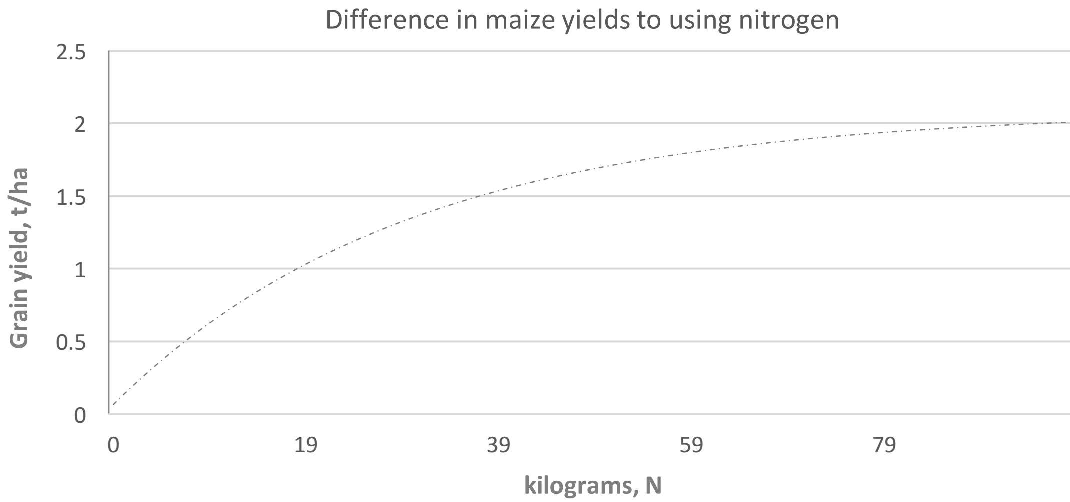

Figure 1 maps the *difference* in the response functions from the OFRA database for maize with and without fertilizer (N) applications (Wortmann 2017). The database provides the estimates of a, b, and c are as N varies across field tests from fitting an asymptotic quadratic–plateau function. The asymptotic function for nitrogen, is $a - bc^N$, where a=3.64, b=2.09, and c=0.968, and is taken from Kaizzi et al. 2012 a, pg 76. We can see that the maximum difference between output with and without nitrogen is 2.009 tons per hectare, which is on par with the difference found in Bold et al. (2017) find. See Table II, Column 1 of Bold et al. (2017). The yield without hybrid seeds or nitrogen is 1.973 tons per hectare. The return to nitrogen without hybrid seeds is 1.973 tons per hectare + 0.049x46, where 46 is the percentage nitrogen, resulting in 4.2 tons per Hecate, resulting in a difference of 2.2 tons per hectare, as compared to 2.009 tons per hectare difference in Bold et al. (2017).

Table 1: Input Values by Crop

Maize (N)	change yield kgs/ha	fertilizer price shs/kg	fertilizer amount kg/ha	seed cost shs/kg	seed amount kgs/ha	deflation output price factor
AUTHENTIC FERTILIZER N WITH AUTHENTIC HYBRID SEEDS	3617	3000	108	7000	50	0.6
AUTHENTIC FERTILIZER N	2254	3000	108	7000	50	0.6
AUTHENTIC HYBRID SEEDS	627	3000	108	7000	50	0.6
INAUTHENTIC FERTILIZER N WITH INAUTHENTIC HYBRID SEEDS	2108	3000	108	7000	50	0.6

INAUTHENTIC FERTILIZER N	1558	3000	108	7000	50	0.6
INAUTHENTIC HYBRID SEEDS	295	3000	108	7000	50	0.6

Beans (N)	change yield kgs/ha	fertilizer price shs/kg	fertilizer amount kg/ha	seed cost shs/kg	seed amount kgs/ha	deflation output price factor
AUTHENTIC FERTILIZER N WITH AUTHENTIC IMPRPOVED SEEDS	1718	3000	45	4500	85	0.7
AUTHENTIC FERTILIZER N	840	3000	45	4500	85	0.7
AUTHENTIC IMPROVED SEEDS	787	3000	45	4500	85	0.7

Matooke (NPK)	change yield kgs/ha	fertilizer price shs/kg	fertilizer amount kg/ha	seed cost shs/kg	seed amount kgs/ha	deflation output price factor
AUTHENTIC FERTILIZER NPK	1000	3000	45	0	0	0.8

Coffee (N)	change yield kgs/ha	fertilizer price shs/kg	fertilizer amount kg/ha	seed cost shs/kg	seed amount kgs/ha	deflation output price factor
AUTHENTIC FERTILIZER N	1040	3000	190	0	0	1

Table 2: Yield Calculations by Crop

Maize (N)	**change yield kgs/ha**	**Source and Calculation**
AUTHENTIC FERTILIZER N WITH AUTHENTIC HYBRID SEEDS	3617	3617 = 1000*(2.60 + 46*0.065 - 1.973), where 1.973 metric tons is the baseline (no fert, trad seed), 2.6 is the returns to hybrid seeds, and 0.065 is the return to fertilizer, where authentic urea should contain 46 percent nitrogen (%N). from Bold et. al (2017) Table 3.
AUTHENTIC FERTILIZER N	2254	2254 = 1000*(46*0.049) from Bold et. al (2017) Table 3, where authentic urea should contain 46 percent nitrogen (%N).

AUTHENTIC HYBRID SEEDS	627	627 = 1000*(2.60 - 1.973), where 1.973 metric tons is the baseline (no fert, trad seed), 2.6 is the returns to hybrid seeds from Bold et. al (2017) Table 3.
INAUTHENTIC FERTILIZERN WITH INAUTHENTIC HYBRID SEEDS	2108	2108 = 1000*(2.268 + 31.8*0.057 - 1.973), where 1.973 metric tons is the baseline (no fert, trad seed) from Bold et. al (2017) Table 3 and mean urea contains 31 percent nitrogen.
INAUTHENTIC FERTILIZER N	1558	1558 = 1000*(31.8*0.049), 0.065 is the return to fertilizer, where inauthentic urea should contain 31 percent nitrogen (%N). from Bold et. al (2017) Table 3.
INAUTHENTIC HYBRID SEEDS	295	295 = 1000*(2.268 - 1.973), where 1.973 metric tons is the baseline (no fert, trad seed), 2.268 is the returns to inauthentic hybrid seeds from Bold et. al (2017) Table 3.

Beans (N)	**change yield kgs/ha**	
AUTHENTIC FERTILIZER N WITH AUTHENTIC IMPROVED SEEDS (K132)	1718	1718 = 1000*(2.46 - 0.93*0.59^45) - 1000* (1.58- 0.84*0.88^0), where the asymptotic function for nitrogen is a-bc^N, and a, b, and c were estimated as N varies across field tests in Kaizzi et al. (2012b) and compiled into a response function database (Ofra 2017). Improved seed (K132) with fertilizer at the optimal rate of 45 kgs per hectare is represented by: 2.46-0.930666667*0.594666667^45 = 1.529 tons/ha, and the baseline with traditional seed (Kanyebwa) and no fertilizer is given by: 1.5855 - 0.844*0.88^0 = 0.74 tons/ha.
AUTHENTIC FERTILIZER N	840	840 = 1000*(1.58 - 0.844*0.88^45) - 1000* (1.58-0.844*0.8835^0), where the asymptotic function for nitrogen is a-bc^N, and a, b, and c were estimated as N varies across field tests in Kaizzi et al. (2012b) and compiled into a response function database (Ofra 2017). Authentic fertilizer at the optimal rate of 45 kgs per hectare is represented by: 1.5855 - 0.844*0.88^45 = 1.582 tons/ha, and the baseline with traditional seed (Kanyebwa) and no fertilizer is given by: 1.5855 - 0.844*0.8835^0 = 0.7415 tons/ha.
AUTHENTIC IMPROVED SEEDS (K132)	787	787 = 1000*(2.46- 0.93*0.59^0) - 1000*(1.5855 - 0.844*0.8835^0), where the asymptotic function for nitrogen is a-bc^N, and a, b, and c were estimated as N varies across field tests in Kaizzi et al. (2012b) and compiled into a response function database (Ofra 2017). Improved seed (K132) without fertilizer is represented by: 2.46- 0.9*0.59^0 = 1.529 tons/ha, and the baseline with traditional seed (Kanyebwa) and no fertilizer is given by: 1.5855 - 0.84*0.88^0 = 0.7415 tons/ha.

Matoke (NPK)	change yield kgs/ha	
AUTHENTIC FERTILIZER NPK	1000	1000 = 1000* (6 - 0-0.0001^45) - 1000*(6 - 0-0.0001^0), where the asymptotic function for nitrogen is a-bc^N, and a, b, and c were estimated as NPK varies across field tests in Nyomibi et al. (2010) and compiled into a response function database (Ofra 2017). Authentic fertilizer NPK at the optimal rate of 45 kgs per hectare is represented by: 6 - 0-0.0001^45 = 6 tons/ha, and the baseline with traditional seed (Kanyebwa) and no fertilizer is given by: 6 - 0-0.0001^0 = 5 tons/ha.

Coffee (N)	change yield kgs/ha	
AUTHENTIC FERTILIZER N	1040	1040 =1000*(2.21- 1.17). Where 2.21 is the yield with authentic N urea fertilizer and 1.17 is the control yield in Asten et al. (2019).

Example of financial returns for maize:

For each crop we calculated returns at the 5, 25, 50, 75, and 90 percentile of output prices. The return at the 50th percentile of maize prices in the East for authentic fertilizer and authentic hybrid seed after deflating to 2005 prices:

$$\frac{\Delta y * p^q - l^{fs} * (c_f + c_s)}{l^{fs} * (c_f + c_s)}$$

$$\frac{(0.6 * 284)\,{}^{shs}/_{kg} * 3{,}617\,{}^{kg}/_{ha} - 1.47(1{,}393\,{}^{shs}/_{kg} * 108\,{}^{kg}/_{ha} + (0.6 * 3{,}250)\,{}^{shs}/_{kg} * 50\,{}^{kg}/_{ha})}{1.47(1{,}393\,{}^{shs}/_{kg} * 108\,{}^{kg}/_{ha} + (0.6 * 3{,}250)\,{}^{shs}/_{kg} * 50\,{}^{kg}/_{ha})}$$

Where we know that the return of 3,617 kilograms per hectare because the return to authentic fertilizer and authentic hybrid seed from Bold et al. (2017) is (2.60 + 46*0.065) tons per hectare, and the baseline return (no fertilizer, no hybrid seed) is 1.973 tons per hectare.