Misperceived Quality: Fertilizer in Tanzania

Abstract

Fertilizer use remains below recommended rates in most of Sub-Saharan Africa, contributing to low crop yields and poverty. We explore the role of fertilizer quality. We interviewed fertilizer sellers in an important agricultural region in Tanzania and sampled their fertilizer to establish that the nutrient content of fertilizers is good, meeting industry standards. However, we find widespread farmer beliefs of fertilizer adulteration. These beliefs push down farmer willingness-to-pay for fertilizer. We find evidence of a quality inference problem: many fertilizers have degraded appearance, and farmers rely on these observable attributes to (incorrectly) assess unobservable nutrient content. Market prices reflect neither nutrient content nor degradation in appearance, even in competitive markets. Our results suggest the existence of an equilibrium where farmer beliefs about fertilizer are inconsistent with the truth, and seller incentives to invest to alter beliefs are limited, motivating future research into the origins and persistence of such an equilibrium.

JEL Codes: Q12, D82, O13

1 Introduction

Fertilizer use in Sub-Saharan Africa remains well below profit maximizing levels (Sanchez 2002, Sheahan and Barrett 2017). Tanzanian and Kenyan farmers, for example, apply only 13 kilograms of fertilizer per hectare, in contrast with Brazilian and Indian farmers, who apply 175 and 165 kilograms per hectare, respectively (World Bank 2020). While recent literature points to heterogeneity in the yield response function to fertilizer; i.e., variation due to soil and weather conditions, overall the marginal productivity of fertilizer is high (see, among others Kaliba et al. 2000, Duflo et al. 2008, Marenya and Barrett 2009, Sileshi et al. 2010, Chivenge et al. 2011, Beaman et al. 2013, Suri, 2011, Liverpool-Tassie 2017, Harou et al. 2020, Hurley et al. 2018).

What are the reasons for chronically low fertilizer use by small farmers in Sub-Saharan Africa? An extensive literature has emphasized the role of incomplete and imperfect credit, insurance and output markets and fertilizer subsidies (Croppenstedt et al. 2003, Chirwa 2005, Dercon and Christiaensen 2011, Minten et al. 2013, Karlan et al. 2014, Liverpool-Tassie 2017, Harou et al. 2020)[1], as well as farmer characteristics including risk-aversion and time preferences (Duflo et al. 2011). Researchers have also considered the role of social networks and information. Conley and Udry (2010), for instance, observe that farmers in Ghana learn about the optimal application of fertilizer on pineapple production (a new crop in the region) from their network contacts (see also Foster and Rosenzweig 1995 and Munshi 2004).

In this paper, we explore an additional important contributing cause for this under-use of fertilizer: a belief among farmers that the product available to them at local markets is of poor quality. The actual quality of fertilizer – its nutrient content – is not evident from visual observation; and in contexts of weak regulation and enforcement of product standards, opportunities might indeed exist for Akerlof's (1970) "dishonest sellers" to offer "bad wares as good wares and thereby tend to drive the good wares out of the market" (p. 495); and awareness of this possibility can decrease the demand among farmers.[2]

We selected Tanzania as the focus for our study. The share of small farmers using fertilizer is low in Tanzania: the 2014-15 Tanzanian National Panel Survey found that only 16% report using fertilizers (TNBS 2017).[3] In addition, anecdotal evidence indicates that farmers in Tanzania believe that the fertilizer available in local shops is substandard. Farmers report suspicions about fertilizer sold past its expiration date, along with concerns about purchasing urea fertilizer that has been mixed with table salt,

[1] See Li et al. (2013) and Fan et al. (2008) on fertilizer subsidies in China and India; and Scheiterle et al. (2019), Carter el al. (2014), Rickert-Gilbert et al. (2010) and Chirwa and Dorward (2013) on subsidies in Sub-Saharan Africa.

[2] Poor quality fertilizer would have direct effects on yields. Mather et al. (2016) calculate a linear maize-nitrogen response rate for Tanzania of 7.6 kilograms of maize per kilogram of nitrogen applied; 10% nitrogen missing from the fertilizer would mean a 10% loss in production.

[3] Similarly, Tanzania's 2014 Agricultural Statistics Strategic Plan mentions that the latest, 2007/08, National Sample Census of Agriculture noted that 13% of smallholder farmers use chemical fertilizer (TNBS, 2012 and 2014).

or diammonium phosphate (DAP) diluted with powdered concrete to compromise its agronomic effects.

In this paper, we use quantitative and qualitative data on a sample of farmers in the Morogoro Region in Tanzania, and a census of fertilizer sellers within the same region to establish fertilizer quality, and to measure the concerns of farmers and sellers. First, we collect rich measures of fertilizer quality for an entire region and we document descriptive patterns of quality variation. Second, we elicit buyers' willingness-to-pay for fertilizer and conduct and information treatment to assess the importance of beliefs about fertilizer quality in take up. Third, we examine seller behavior, both in terms of pricing and quality investment. We demonstrate that farmer beliefs about fertilizer quality do not reflect the truth, but seller incentives to invest to change farmer beliefs are limited.

First, to establish fertilizer quality in the market, we visited all sellers in the Morogoro Region of Tanzania. We interviewed these sellers, and collected information on their business and the local market. We then used mystery-shoppers to purchase 633 fertilizer samples from the 225 fertilizer sellers and to record prices and other features of the transaction. We focus our analysis on three of Tanzania's most prevalent and agriculturally important fertilizer types: urea, calcium ammonium nitrate (CAN) and diammonium phosphate (DAP). We tested the fertilizer in laboratories in both Kenya and the United States (a randomly selected subset were double tested in both laboratories) and confirmed that the quality of fertilizers in this market is good, meaning that the nitrogen content was in compliance with the manufacturer standard[4]: only six of 300 urea samples were out of compliance with industry standards and with a mean percent nitrogen deviation of 0.28%. We find that the mean percent deviations for the other fertilizers, CAN and DAP are also modest: 5.9% and 3.0% respectively. Additional testing at the Dar es Salaam port (where nearly all fertilizer in Tanzania enters the country) and warehouses, and interviews with sellers, confirm the quality of the fertilizer on the market in Tanzania. The finding of adequate nutrient content in marketed fertilizer, especially for urea, is consistent with recent large-scale assessments undertaken by the International Fertilizer Development Center (IFDC) across Sub-Saharan Africa (Sanabria et al. 2013, 2018A/B), and smaller scale studies undertaken by the Ugandan Ministry of Agriculture (Mbowa et al. 2015), and an International Food Policy Research Institute (IFPRI) team in Uganda (Ashour et al. 2017A). In contrast, Bold et al. (2017) finds considerable nutrient deviations in urea, with tested urea lacking, on average, 30% of its advertised nitrogen content. We discuss the breadth of results on fertilizer nutrient quality and the fact that Bold et al. (2017) uniquely find large average nitrogen deviations in Section 4.

[4]Fertilizer quality is represented by the degree to which its measured nutrient content is consistent with the manufacturer standard for each fertilizer. The Economic Community of West African States (ECOWAS) sets standards for each fertilizer sold in the region. Urea fertilizer for example is 46% nitrogen and is considered out of compliance if it is found to have less than 45%.

Second, to obtain and understand the farmers' perspective, we interviewed 165 farmers, collecting information on fertilizer use and their perceptions regarding fertilizer quality. To assess demand for fertilizers, we set up a "store" at a central village location, with three samples of urea fertilizer which we purchased in the local market (we will return to these three samples later, for now it suffices to say that they differed in terms of observable attributes) and had tested to ensure that they all met the required industry standards for nutrient content of 46% nitrogen. For each urea sample, we asked the farmer to state her willingness-to-pay, first without providing any additional information about the nutrient content, and then when informed that the fertilizer had been tested by a reputable laboratory and found to meet industry standards for nitrogen.[5] This type of hypothetical willingness-to-pay exercise is a standard method for establishing demand (for a recent overview, see Penn and Hu 2018), and is well suited to establish demand in the presence of asymmetric or incomplete information in this context.

Consistent with anecdotes regarding farmers' expectations of low quality, we find that farmers are willing to pay considerably less for untested fertilizers in the market than they are for the tested fertilizers: the willingness-to-pay for one kilogram of urea fertilizer in the absence of information about its nutrient content proved to be 48% lower than the post-information willingness-to-pay (1489 TZS versus 2201 TZS; or 0.65 USD versus 0.96 USD). The prevailing market price for one kilo of urea at the time was 1500 TZS. These pessimistic beliefs among farmers about agricultural input quality are consistent with the survey results (43% of farmers in our sample suspect adulterated fertilizer is sold in local markets) and further qualitative interviews. They are also in line with Ashour et al. (2017B) for herbicides in Uganda, Gharib et al. (2020) for seeds in Kenya and Norton et al. (2020) for fertilizer in Tanzania.

We also find that willingness-to-pay depends on physical appearance of the samples. The exercise included three samples: one sample was in pristine physical condition; the second sample contained large caked aggregates of urea; and the third included a small amount of visually obvious foreign material and impurities. This sort of physical degradation of fertilizer is common in the market (38% of the fertilizer samples our mystery shoppers purchased exhibited some degradation in physical appearance, whether it was caking, powdering, foreign material like bugs or small bits of dirt, or discoloration), although there is no (statistically significant) correlation between a fertilizer's physical appearance and its unobservable nutrient content. Degradation in fertilizer's appearance tends to result from poor storage and transport conditions, common problems in the region.

In the willingness-to-pay exercise, farmers' pre-information willingness-to-pay for the pristine sam-

[5] We discuss the willingness-to-pay exercise in detail in section 3.3 but it bears mentioning that farmers in the sample were experienced using and purchasing fertilizer and understood well the concept of nitrogen content.

ple is, on average, twice the willingness-to-pay for the samples with poor physical appearance. When presented with information on the true nutrient content, farmers revise their willingness-to-pay upwards for all samples, but significantly more for samples with poor observable attributes. This difference-in-differences is suggestive of a learning process in which farmers use the physical attributes as signals of the underlying quality. We estimate this signaling value at 20% of the market price. Qualitative interviews confirm that many farmers use the physical appearance of fertilizer as an indicator of the underlying quality.

These incorrect farmer beliefs may persist due to the difficulties farmers face in assessing quality in a stochastic production environment (Beaman et al. 2013, Bold et al. 2017, Norton et al. 2020). Smallholders grow crops under conditions of adverse and variable weather and pest pressure. In addition, farmers may under-invest in complementary inputs such as labor as they lower their estimate of the marginal productivity given beliefs that the available fertilizer is poor (Beaman et al. 2013). Farmers may also be applying fertilizers incorrectly, possibly based on inaccurate government recommendations.[6] Consequently, they may incorrectly attribute low yields to fertilizer nutrient problems, especially if the fertilizer shows compromised attributes that they can readily observe.

The third and final component of our analysis focuses on fertilizer prices. As expected, the fertilizer price does not reflect nutrient content. But surprisingly, we note no statistically significant relationship between physical appearance and prices. Overall, prices exhibit little variation within or across markets on a given day, even if the physical appearance of the fertilizer differs. While our qualitative surveys reveal that some farmers receive a discount for fertilizer with highly compromised physical condition, and some sellers admit to giving them, these discounts are not common, or substantial enough, to change the null relationship we find in our data.

We hypothesize that this lack of market response is the result of a combination of factors. First, while the average farmer might care about physical attributes, a significant subset of farmers might not – in our sample, 16% of the farmers in the willingness-to-pay assessment do not respond to fertilizer with poor observable characteristics. Second, the cost of shopping around for good-looking fertilizer is high given the prevalence of fertilizer with poor physical appearance in the supply chain (as 72% of sellers have fertilizer samples with poor physical appearance). This is likely the result of storage and transportation problems occurring upstream in - what we show to be – a very concentrated value chain. Our data confirms this interpretation. We note significant degrees of physical degradation and poor storage practices during

[6] Harou et al. (2020) find evidence of agronomically important local within-village variability in soil nutrient needs distinct from government fertilizer recommendations among a sample of 1000 farmers in 50 villages in the same region in Tanzania where our research is conducted.

our visits to importing facilities in the Dar es Salaam port. In addition, the presence of fertilizer with poor physical appearance is not correlated with sellers' investment in improved storage or transportation. Third, sellers themselves report confidence in the nutrient quality of fertilizer they sell, and report that they do not receive discounts from their suppliers based on the physical appearance of the fertilizer delivered. The combination of these factors limits the pressure on sellers to decrease prices for fertilizers with poor physical appearance.

Nonetheless, if sellers cannot easily change the perceptions of farmers, why isn't adulteration at the agro-dealer level more widespread? One key insight, well established in industry yet absent from the academic literature, is that successful, profitable adulteration of fertilizer is actually difficult (Joaquin Sanabria, personal communication, March 27, 2018, Yara International, 2012, Rutland and Polo, 2015). Substantial quantities of low-value fillers must be included for adulteration to pay-off given low margins and low sales volumes of most retailers; and only farmers with minimal knowledge of fertilizers are likely to be deceived.[7] Given that small farmers currently represent only a small share of Sub-Saharan Africa's fertilizer market in terms of purchase quantities, such deception is unlikely to pay off at the retail level. Moreover, large-scale fraud at the point at which the fertilizer is bagged (it arrives at the port in bulk) runs higher risks of detection.

In the next section, we provide additional background and context for the study. The third section provides an overview of the data collected from agro-dealers, farmers, as well as fertilizer sampling and testing. We present the empirical analysis and results in Section 4. We conclude with reflections for policy and further research, including the possibility of a certification scheme for fertilizer in Tanzania.

Before we proceed, a note on terminology. When we refer to fertilizer in this paper, we mean mineral, inorganic fertilizer; as opposed to organic fertilizer, such as mulch or compost.

2 Background

Agriculture is a critical sector for employment and food security in Tanzania but its growth has lagged the rest of the economy in recent years. Low-input and rain-fed subsistence farming dominates the sector and the use of fertilizer is extremely low. A recent report by the International Food Policy Research Institute (IFPRI) found that the most commonly used fertilizers in the country include urea, diammonium phosphate (DAP), calcium ammonium nitrate (CAN), and nitrogen-phosphorous-potassium fertilizer

[7] This contrasts with the findings of Kroll and Rustagi (2017) who tested the quality of buffalo milk in New Delhi (for the presence of water) and investigated motives for dishonesty. They find, on average, a 17% water content in the tested milk and note that dishonest milkmen consequently earn, on average, 210 USD more per year, compared to honest ones.

(NPK). In 2010, urea and DAP accounted for half of the fertilizer used in Tanzania with NPK consisting of about 20% and CAN 9% (Benson et al., 2012). While the official government recommendation for one acre of maize cultivation is 60 kg of urea and 40 kg of DAP, farmers on average apply fewer than nine kilograms of fertilizer per acre (IFDC 2012). The report also found that urea was the fertilizer most commonly stocked and sold by agro-dealers, accounting for more sales income than all other fertilizers put together.

Nearly all fertilizer in Tanzania is imported to the port in Dar es Salaam. Upon arrival at the port, the fertilizer is removed from the shipping containers (where it is transported loose and in bulk) and bagged in 25 and 50 kg manufacturer bags. Tanzania's fertilizer trade association included ten firms in 2011 but only three of these consistently imported fertilizer into the country; the remaining seven companies obtained their product from these importers (Benson et al. 2012).

From Dar es Salaam, fertilizer begins its trip inland, passing through the hands of multiple wholesalers and sellers before reaching rural farmers. The ten companies who bag imported fertilizer either sell to intermediate wholesalers or transport the fertilizer inland themselves to storage depots used to supply the large number of small retail sellers. In this context, these retail sellers are referred to as agro-dealers, as they buy and sell agricultural inputs. We will henceforward also use this terminology so as to distinguish agro-dealers from the wholesale sellers and importers. These agro-dealers operate independently of the large fertilizer companies; that is, they are not subsidiaries of specific companies though they sometimes receive stock on credit or negotiate an exclusive relationship with a brand.

Fertilizer quality is only minimally monitored in Tanzania. The Fertilizer Act of 2009 established the Tanzania Fertilizer Regulatory Authority (TRFA) to enforce policies related to fertilizer manufacturing, importation, and use but a 2017 report by the African Fertilizer and Agribusiness Partnership (AFAP 2017) noted:

> "TFRA remains under-funded with few professional staff...it depends on 100 "inspectors" (who) do not provide reliable inspection (and testing) services to TFRA as they have multiple responsibilities and lack the resources (transport, testing equipment) and technical skill (proper taking of samples) to do their job properly...What should be an important regulatory body is, therefore, quite weak due to a lack of institutional and human resource capacity." (p. 11)

We conduct this work in Tanzania's agricultural Morogoro Region. Morogoro Region's fertilizer sales market is geographically disperse, reaching far out into rural areas along major roads, with small clusters of agro-dealers located in a large number of market centers. The agro-dealer census we conducted in Morogoro Region identified 102 market centers with shops selling fertilizer. Of these, 54 had only one agro-dealer, 23 had two agro-dealers, 11 had three, and 14 had four or more. Nearly all agro-dealers are open year round rather than running seasonal operations. In urban areas, agro-dealers tend to cluster along major roads or thoroughfares. In rural areas, agro-dealers tend to locate along the road in clusters with other village shops. It is uncommon for agro-dealers to be located in isolated areas far from major roads or other shops and businesses.

3 Data collected

Between November 2015 and May 2016, we collected data from 225 fertilizer agro-dealers in the Morogoro region of Tanzania and a sample of 165 farmers in the same region. We collected qualitative and quantitative data from these agro-dealers and farmers using surveys, including information on prices, beliefs, and willingness-to-pay; laboratory tests of sampled fertilizer provided information on fertilizer quality. In 2018, we collected additional qualitative data among agro-dealers and farmers in the area; and in 2016-18 we visited locations upstream in the supply chain, including warehouses and ships at the port of Dar es Salaam for further observation and laboratory testing. We first introduce the agro-dealer and farmer samples and then discuss the willingness-to-pay elicitation, the qualitative surveys, and the fertilizer testing.

3.1 Agro-dealer sample

We conducted a census to identify all agro-dealers with operations in the Morogoro Region and then proceeded to survey these 225 agro-dealers.[8] We interviewed the agro-dealers and collected information about the scale, seasonality, and history of the operation, participation in government programs, wholesalers where the shop sourced fertilizer, and types of fertilizer stocked and in which months.

Table 1 (Panel A) presents descriptive statistics for the agro-dealers. Nearly all agro-dealers report selling urea fertilizer: 98% answered affirmatively to the question "Have you ever sold urea fertilizer?" and 81% report that they stock some kind of fertilizer throughout the year.

Agro-dealers operated businesses in clusters of other agro-dealers, with an average of 2.22 agro-dealers

[8]To our knowledge no census had before been conducted of the number of fertilizer sellers operating in Morogoro or Tanzania. The 2009 Fertilizers Act requires that all fertilizer sellers and sales locations must be registered with the government but few of the sellers we found in our regional census had the required registrations. This is an important methodological point: any researcher exclusively using the government's licensing lists as a sampling frame would have missed the majority of the sellers operating in the region.

per market location. The mean within-market center Herfindahl index[9] is 0.75, indicating a lack of competition between agro-dealers; for the subsample of market centers with more than one agro-dealer, the mean Herfindahl index is slightly lower, 0.63. The upstream market is also concentrated, 65% of the agro-dealers source from just one supplier, with an average of 1.66 suppliers per agro-dealer. For all 225 agro-dealers, we only have 36 suppliers.

In addition to the survey visit, enumerators operating as mystery shoppers visited each surveyed shop twice to purchase fertilizer – once in November or December 2015 before the start of the primary growing season and once during planting and cultivation in March and April 2016. The enumerator followed a pre-defined script: he greeted the shopkeeper and asked the shopkeeper to buy 1 kg of urea, DAP, and CAN. If the shop had all three types available, the enumerator purchased all three. If the shop had only two types or one type available, the enumerator purchased the type(s) that were available. Enumerators dressed in the way that a farmer would dress if he was making a visit to town; enumerators were all male and wore collared shirts, trousers, and sandals. In the case that enumerators were asked additional questions by the agro-dealer, they were prepared to respond with locally appropriate responses. For example, on occasion, our enumerators were asked by agro-dealers on which crop they intended to apply the fertilizer(s).Enumerators were aware of the major crops grown in the location, and, as such, were able to engage the agro-dealers.

While the mystery shoppers were unknown to the agro-dealers, this situation is not uncommon given that shops selling fertilizer are located in market centers with other retail shops and receive customers from surrounding areas. 60% of the surveyed farmers reported purchasing mineral fertilizer from a shop located outside of their village area and only 16% reported that they had a relationship with an input shop that would allow them to delay payment (purchase on credit) for fertilizer if they needed to do so. Moreover, analysis of farmer level price data indicates that prices reported by farmers are not statically different from those collected by mystery shoppers (these results are available upon request from the corresponding author). Finally, physical characteristics and nitrogen content was also statistically indistinguishable across the farmer and mystery shopper samples (see Table 2).

Enumerator mystery shoppers purchased 300 urea samples, 137 DAP, and 196 CAN, a total of 633 samples of fertilizer. After purchasing the samples, the enumerator also recorded features of the transaction including the price, the brand, and whether the fertilizer was scooped from an open bag. It should

[9] A measure of market competition calculated by squaring the market share of each firm competing in a market and then summing the squares.

be noted that not all agro-dealers had all types of fertilizer in stock during these visits; hence the total number of samples is less than what one would expect.[10]

Table 1: Agro-dealer and farmer descriptive statistics.

Panel A: Fertilizer sellers (n=225)	Mean (SD)	Min	Max
Sell fertilizer all months of the year (share)	0.81		
Sell urea fertilizer (share)	0.98		
Have an exclusive relationship with a fertilizer manufacturer (share)	0.21		
Source fertilizer directly from Dar es Salaam (share)	0.28		
Licensed by the government to sell fertilizer (share)	0.41		
Report selling the largest amount of fertilizer to small farmers (share)	0.92		
Distance from Dar es Salaam (km)	273.26 (85.62)	127.49	443.24
Number of fertilizer sellers per market location	2.22 (2.52)	1	21
Number of suppliers where agro-dealer sources fertilizer	1.66 (0.93)	1	4
Years in business	4.18 (4.34)	0.1	30
Panel B: Farmers (n=165)			
Male (share)	0.62		
Ever purchased mineral fertilizer (share)	0.99		
Purchased urea fertilizer in the past 12 months (share)	0.78		
Grew maize in 2016 season (share)	0.81		
Grew rice in 2016 season (share)	0.85		
Grew vegetables in 2016 season (share)	0.44		
Purchasing high quality fertilizer among top two concerns at season start (share)	0.24		
Believe $\geq 50\%$ of the fertilizer in the market adulterated (share)	0.15		
Believe > 0 but $< 50\%$ of fertilizer in the market adulterated (share)	0.28		
Age (years)	45.93 (11.34)	22	79
Land owned (acres)	5.84 (10.50)	0	100

Source: authors' own calculations from agro-dealer and farmer surveys.
Sell urea fertilizer is the agro-dealer's response to the question - "Please tell me the types of fertilizer that you sell at this location".

3.2 Farmer sample

We worked with the International Institute of Tropical Agriculture's (IITA) Africa RISING initiative to select a sample of 12 villages in Mvomero District, Morogoro Region. We selected these 12 villages purposively as villages where at least some farmers were regularly using fertilizers given the goal of our

[10] Two factors are relevant here: first, there is considerable churning in inputs supply shops, with shops going in and out of business and closing temporarily or not being able to get stock when they need it. For instance, among the 225 agro-dealers, 45 did not have urea in stock when we visited them before planting (2015 round) and were not open on the day that the mystery shoppers returned again during the planting season (2016 round) – either because they were idiosyncratically closed or because they had closed permanently. Of the other 180 agro-dealers, 60 either had urea in stock before planting or after but not both.

project was to understand the region's entire fertilizer supply chain. As part of the project, we needed to understand farmer fertilizer use and purchasing behavior. As we were aware of the low share of farming households using fertilizers in rural Tanzania, and our budget was relatively limited to cover only 12 villages, we opted to purposefully select villages which would have a significant share of farmers with some experience with fertilizers. All farmers with prior fertilizer experience were invited to participate in our survey. In total, we surveyed 165 farmers and collected qualitative and quantitative data on farmer demographics, crops grown, previous experience purchasing and using fertilizer, and general perceptions of fertilizer quality in markets.

Table 1 (Panel B) introduces the farmers' sample. Farmers in the sample are more likely to be male, are 46 years of age on average and have mean landholdings of 5.84 acres. On average, farmers in the sample had at least completed primary school; only one percent of the farmers reported no schooling. Farmers grow a range of crops and while nearly all had purchased fertilizer previously, 78% had purchased urea in the 12 months previous to the survey. 24% of the farmers interviewed listed purchasing high quality fertilizer among their top two concerns as they prepared for the start of a typical agricultural season (other options included the start and duration of the rains, purchasing high quality seeds, and access to financing for inputs). We view 24% as a relatively high percentage of farmers reporting concerns about quality, given that farmers in this region of Tanzania face a multitude of constraints, ranging from credit and insurance limitations, to a lack of bargaining power and access to reliable output markets, and an increasingly variable climate (for some recent studies set in Sub-Saharan Africa, see, Gine and Yang 2009, Sexton 2013, Shiferaz et al. 2014, Manda et al. 2015, Baffes et al. 2019 and Janzen and Carter 2019). Moreover, 43% of the farmers reported concerns about adulterated fertilizer in markets, with 15% of farmers believing that 50% or more of the fertilizer for sale in local markets was likely adulterated and 28% believing that between zero and 50% was adulterated.[11]

Farmers also provided the research team with a small (0.25 kg) sample of fertilizer from their home and answered questions about the source and use of that fertilizer.[12] Finally, we completed a willingness-

[11]Farmers were asked were asked to assess "How big of a concern is mineral fertilizer adulteration for you" and were asked to choose among the following responses: not a problem; a very big problem affecting a majority of the fertilizer in the market; somewhat of a problem, affecting about half of the fertilizer in the market; a little bit of a problem, affecting fewer than half of the fertilizer in the market.

[12]On the day of the survey, the research team arrived earlier than the agreed-upon time. This ensured that the team would be able to observe the behavior of the extension officer, lead farmer, or other participants and to verify that none of the fertilizer samples had been divided or shared among participants. In each village, the survey was conducted at the local village government office. As participants arrived, the research field supervisor began a screening process of each of the participants and their fertilizer. The field supervisor asked each of the participants a set of questions about their fertilizer sample/s, including: (1) What type of fertilizer did you bring? (2) To which crop/s did you apply this fertilizer? (3) Did you apply this fertilizer during the planting stage or the cultivation stage? (4) Where did you buy this fertilizer? (5) What was the original amount of fertilizer purchased? (6) How much did you pay for it? Participants who were able to answer these questions easily and confidently were invited to participate in the survey. Five participants were excluded from the survey as a result of the screening process.

to-pay exercise with the farmers. We discuss the implementation of this exercise next.

3.3 Eliciting willingness-to-pay

We elicited farmers' willingness-to-pay (WTP) using a series of hypothetical questions based on the contingent valuation method commonly used to value environmental public goods (for an introduction see Mitchell and Carson 1989; and Bateman and Willis 2001). The method is hypothetical – i.e., the farmers did not actually purchase any fertilizer from the enumerators. It is, however, a common method to establish demand for yet unavailable goods and services in developing country contexts (see, among others, Matuschke et al. 2007, Hill et al. 2013, and Penn and Hu 2018). In our case, we use the method to create a counterfactual scenario for the fertilizer market: What would the demand be if the farmers had no concerns about fertilizer quality? Using a WTP exercise to gain insight into this counterfactual scenario is not uncommon in this literature. Sanogo and Masters (2002), for instance, present mothers in Mali with a choice experiment focused on infant food.[13]

We used an open-ended elicitation of the farmer's valuation of the fertilizer, which has been shown to better elicit values than methods based on dichotomous choice (Lybbert 2006, Balistreri, et al. 2001, List and Gallet 2001). We showed farmers three samples of urea fertilizer that we had previously purchased from agro-dealers in the Morogoro region and whose nitrogen content we had tested in a lab. We carefully explained to the farmer that each of the three samples was purchased in markets in the Morogoro region. We did this in order to emphasize to the farmers that they were not encountering an entirely new product (a new fertilizer from the United States for example).[14]

All samples met international fertilizer standards and had the same nutrient content: 46%. All three samples can therefore be considered good quality in terms of their unobservable (to the farmer) nutrient content. However, the three samples differed in terms of their physical attributes. Figure 1 presents pictures of the three samples: Sample A was of good appearance (bright white and clean with no caked aggregates or foreign material present); Sample B included large hard caked clumps; and Sample C included the presence of a small amount of dark colored foreign material, likely prills of another kind of fertilizer.

[13] Other methods are also possible. Bai (2015) uses an experimental approach, and provides quality certification labels and branding in the watermelon market in China. Anagol (2017) contrasts two markets for cows in India: an open market, which is subject to adverse selection, and within-social network market, where asymmetric information is less present.

[14] Note that is possible that farmers perceived this post-information treatment product as an altogether new product, and hence any discrepancy in pre and post information does not necessarily capture the pessimistic beliefs about quality. We however believe this not to be the case as we made explicit to the farmers that we had purchased the samples in local markets, and, as we describe in the results section, the discrepancy in pre-information WTP between the different samples is too substantial to not reflect pessimistic beliefs.

A: Good appearance
Good quality

B: Large clumps
Good quality

C: Foreign material,
Good quality

Figure 1: Pictures of samples shown to farmers for the willingness-to-pay assessment. All three 1 kg samples of urea were purchased as shown by the research team in markets in Morogoro Region and this was communicated clearly to the farmer. All three samples were tested by Thornton Labs in the United States and were found to contain 46% nitrogen. Sample A was clean with no caking; Sample B included two large, hard caked aggregates; and Sample C included the presence of a small amount of darkly colored foreign material mixed in the urea.

The assessment was conducted in a central location in each village but each farmer completed the exercise individually with an enumerator, separated from the rest of the respondents. We proceeded in three steps[15]:

1. First, farmers were provided with the samples to inspect as they wished. Farmers were asked to assess the quality and to report their WTP for 1 kg of urea of equivalent quality for each of the three samples. Enumerators were asked to explain to the farmer that he should respond with a price (in Tanzanian Shillings) reflecting not what he thought the urea would cost, but instead a price reflecting what the urea was worth to the farmer.

2. Second, the enumerator presented farmers with test results on the nitrogen content of each of the three urea samples. Farmers were informed that nutrient content tests were conducted in a lab in the United States, and that the sample met industry standards for nitrogen.

3. Finally, the farmer was asked to report his (post-information) WTP.

As urea fertilizer is available in local markets, the local market price (plus farmer transaction costs) should serve as an upper bound on the pre-information WTP (that is, before the farmers are informed about the quality of the product). We find that this is the case: less than 3% (15 out of 494 responses to the pre-information WTP) of farmers' reported WTP estimates exceed the highest per kg market price

[15]Further details about the elicitation are available in the appendix.

for fertilizer we observed in markets. However, the second half of our assessment exercise introduces a good that is not currently available in markets: there is no market currently for fertilizer with nutrient quality tested by an independent third party (here, a research team using a United States lab).

Throughout the WTP exercise, farmers demonstrated awareness and understanding of the concept of fertilizer nutrients, and nutrient content. This is consistent with the results of our focus group interviews (summarized in the next sub-section) indicating that farmers understand that urea provides nitrogen and that the fertilizer is supposed to have the content of nitrogen advertised on the bag.

All farmers were asked to report WTP for Sample A, followed by the WTP for Sample B and then WTP for Sample C. All samples were shown to each farmer simultaneously to reduce the possibility of anchoring or ordering effects. In the analysis, we will focus on differences in WTP between samples as well as pre/post information, which avoids some of the primary concerns associated with order effects, should they be present.[16] Enumerators elicited these three WTP one-after-the-other and the whole exercise took less than ten minutes.

Social desirability bias, i.e. the tendency to present oneself in the best possible light while being observed, could have affected the results (Nederhof 1985), and in particular the estimates of the information effects. Our elicitation strategy employed best practices, including a neutral phrasing of the questions, and careful training of enumerators to not prompt respondents. Moreover, no one apart from the respondent and enumerator was present to observe the bidding and survey. It should also be noted that fertilizers on their own lack any normative attributes; the presence of normative attributes may exacerbate social desirability bias (Lusk and Norwood 2006).

As mentioned above, the WTP questions were hypothetical; farmers did not actually purchase the urea fertilizer bags we presented to them. This decision to elicit hypothetical WTP was made for logistical reasons – in order to make between-farmer comparisons it was essential that the exact same products were presented to each farmer, i.e., fertilizer of the same color, with the same number of caked aggregates and the same amount of foreign material. Selling the fertilizer to one particular farmer would have prevented us from using the same product in the next village. Our exercise was explicitly framed as a fertilizer-buying scenario with experienced fertilizer purchasers, and respondents, all of whom were literate and had experience purchasing fertilizer in the market, expressed and displayed little trouble imagining how they would react. Hence, following conclusions in Kahneman and Tversky (1979 and 1997), noting that in this case, "subjects have no special reason to disguise their true preferences" (p. 265, Kahneman and

[16]We recognize that order effects might still be a concern, and farmers might benchmark their valuation of samples B and C to what they stated for sample A. We have however no prior as to the degree to which order effects would be present in this setting as the literature has reported cases with significant order effects (as in Holt and Laury 2002, and 2005) and cases without any evidence of order effects (as in Alpizar et al. 2011, Harrison et al. 2005).

Tversky, 1979) we are confident that results provide some first insights into farmer assessment of fertilizer quality and response to information about unobservable nutrient content.[17]

3.4 Qualitative surveys

In addition to the farmer surveys, we completed a series of qualitative interviews with farmers and agro-dealers in 2018. These additional interviews were motivated by the first set of research results reported in this paper, and hence had a focus on the physical attributes of the fertilizer.

The qualitative surveys included 15 in-person interviews with randomly selected agro-dealers in Morogoro town, and their 41 customers in May 2018; two focus group interviews with a total of 40 farmers in two villages near Morogoro town in November 2018, and 43 phone interviews with farmers in Morogoro town and nearby villages in September 2018.

We asked agro-dealers about the prevalence of physical degradation, the relationship between physical appearance of the fertilizer and the price, and the prevention of physical degradation. With the store customers, we also inquired about the prevalence of physical degradation, their interpretation of such degradation, and the prevalence of bargaining, discounts, and refunds when fertilizer has poor physical appearance. The later phone interviews not only expanded the sample of farmers, but asked farmers directly about their perceptions of and experiences with adulterated fertilizer. Finally, the focus group interviews at the end of 2018 focused on how farmers think about nitrogen content, beliefs formation, and the role of the media in their understanding of fertilizer quality in the region.

3.5 Testing the fertilizer samples

We collected a total of 633 fertilizer samples from agro-dealers and 187 samples from farmers. Purchased samples were stored in their original plastic bag packaging and labeled with the store and purchase information for the purposes of creating unique sample identifications. Samples were packed and sealed in doubled Ziploc bags immediately after purchase and placed in airtight plastic bins for storage until testing. The Soil-Plant Diagnostics Spectral Lab at the World Agroforestry Centre (ICRAF) in Nairobi, Kenya, conducted the nutrient content testing for all of the fertilizer samples. Details on the testing are provided in the appendix.[18] A randomly selected subsample of the fertilizer was sent to Thornton Labs

[17] The effect of using hypothetical payments as opposed to real payments has not yet been settled in the literature. The validity depends on the nature of the context and elicitation method. In the literature focused on risk-preferences, some studies have found evidence of differences between the two methods (as in Holt and Laury 2002) while others have found no such discrepancies (Binswanger 1980).

[18] ICRAF, a CGIAR center, has contributed to advancing spectroscopy techniques and methodologies for measuring soil (Terhoeven-Urselmans et al. 2010, Towett et al. 2015) and plant (Towett et al. 2015) chemical composition. ICRAF utilized two methods to determine the nitrogen content: Mid-infrared diffuse reflectance spectroscopy (MIR) and portable X-ray

in the United States.[19] The correlation coefficient between the nitrogen content of the 59 samples tested at both ICRAF and Thorton is 0.97 and all samples had a difference between the measures of less than 1%.

Samples were tested for the degree to which they deviated from what is known as their fertilizer grade – the guaranteed content of nutrients.[20] The nutrient content is expressed as a percentage of the fertilizer weight. For example, urea is 46% nitrogen and is referred to as a straight fertilizer because it only contains one nutrient, whereas DAP contains two nutrients and is 18% nitrogen and 46% phosphate.

In addition, we took photographs of all samples acquired from agro-dealers and farmers on the day of purchase, and used these to visually code physical condition: caking, discoloration, presence of foreign material (ex: dirt, grass, maize grains, stones), and powdered granules. These are readily observable, physical attributes. Because photographs were taken the day of purchase, these observable attributes were not impacted by transport or storage. Two independent coders (one in Tanzania and one in the United States) completed visual coding with a correlation across the attributes of 0.96. Details of the observable attributes are as follows:

- Fertilizer caking occurs when fertilizer granules fuse together to form larger aggregates. In the most extreme cases, the entire bag can fuse into a single, hard aggregate.

- Fertilizer discoloration, in the case of DAP and CAN, implies a discernibly darkening of the color of the fertilizer, sometimes accompanied by an oily film that can secrete through the packaging, leaving a residue on the outside of the bag. Urea can similarly become dirty and pick up a gray discoloring.

- Foreign material can be present in the fertilizer including dirt, sand, insects, or grains of maize.

- Fertilizer powdering implies the breaking of the small prills into smaller, powdery fragments.

While nutrient quality – specifically fertilizer missing nutrients – can result from either manufacturing impurities or adulteration by wholesalers or agro-dealers, degradation of physical appearance generally results from poor supply chain management and logistics problems: poor handling at port, poor transport conditions, storage problems, exposure to high temperatures and humidity and product aging (Sanabria

fluorescence (pXRF) spectroscopy. In general, spectroscopy measures the quantities of chemical elements (ie., nitrogen), by analyzing how infrared radiation responds to physical matter (ie., fertilizer). Although spectroscopy is used widely in many fields, ICRAF has been a world leader in developing and utilizing these technologies for agricultural applications.

[19] Thornton Labs used the traditional Kjeldahl wet chemistry method for sample analysis.

[20] International standards specify maximum moisture content by weight, nutrient content by weight, particle size, and packing guidelines.

et al. 2013).[21]

These observable attributes are discussed in agro-dealer technical training manuals (Rutland and Polo 2015) and fertilizer standards and analysis manuals (Sanabria et al. 2013, Yara International 2012).[22] To our knowledge, there is no literature, either academic or technical, which considers the relationship between observable condition and nutrient content.

In addition, we collected data further upstream in the supply chain. In 2018, we secured permits to sample fertilizer on the ships upon arrival into Tanzania for 12 months. A relatively small number of ships arrive with mineral fertilizer each year – between 12 and 16 ships on average. We collected eight total samples of CAN, DAP, and UREA fertilizer at the point of importation. We also collected 34 samples from the warehouses run by large importers in Dar es Salaam and we visited the facilities to observe the storage conditions and bagging operations. All these additional tests where conducted in the United States using the laboratory and method described above. We also accessed data from the Tanzanian Bureau of Standards (TBS), the institution charged since 2010 with sampling and testing fertilizer at the point of importation. We secured and digitized comprehensive records for all ships arriving at port with fertilizer going back to the beginning of 2016, covering a total of 48 samples of urea, CAN and DAP. We conducted interviews with the Tanzanian Regulatory Authority charged with testing and assessing and maintaining fertilizer quality.

4 Analysis and Results

We begin by presenting evidence on the nutrient content of the sampled fertilizer from the results of the laboratory tests, their physical condition and the relationship between fertilizer nutrient content and physical condition. We then analyze the farmers' beliefs and market responses using the willingness-to-pay exercise, survey data, and qualitative data. We conclude this section with an analysis of the fertilizer market, considering price responses, investment strategies, and incentives.

[21]Caking is often a result of the fertilizer having been exposed to water or high humidity during initial packaging and handling of manufacturer bags as well as subsequent transportation and storage (Sanabria et al 2013). Caking is especially sensitive to temperature and humidity, pressure in piles and stacks, and storage time (Rutland and Polo 2015). Discoloration is also the result of moisture or high humidity. In the case of foreign materials, while deliberate adulteration can be one source of the presence of foreign material, more incidental cases result from the way that fertilizer is imported and prepared for wholesalers and sellers in Tanzania.While at port, the fertilizer is often exposed to humidity and high temperatures, as well as sand, dust, and dirt. Fertilizer sold from opened bags or sold in informally repackaged parcels is also vulnerable to the inclusion of foreign material. Foreign material decreases the per weight nitrogen content of the fertilizer; the quality dilution can be incidental (in the case of fertilizer which includes a handful of maize kernels or insects) or more harmful if the fertilizer has been deliberately and significantly adulterated. Fertilizer powdering is the result of poor handling and storage or excessive handling or product aging.

[22]IFDC agro-dealer training manuals mention the importance of a range of physical attributes and guidelines for storage and transport to preserve quality. For example, on caking: "Caking can cause many handling and application problems and is considered by most fertilizer producers to be the single biggest physical quality problem in fertilizers." (p. 7)

4.1 Fertilizer nutrient content and physical attributes

Table 2 presents the results of the laboratory tests. The top panel presents the results for the agro-dealers' samples, the bottom panel presents the farmers' samples. Column (1) presents the manufacturer standard for the nitrogen content for each fertilizer. Column (2) presents the share of the samples found to be out of compliance based on the guidelines for nutrient compliance from the Economic Community of West African States (ECOWAS), which are the standards used in Tanzania.[23] Column (3) presents the mean and the standard deviation (in parentheses) of the tested nitrogen. Column (4) presents the mean deviation from nitrogen standard. This was calculated as follows: the nitrogen content standard was subtracted from the measured nitrogen content and the difference was divided by the nitrogen content standard, resulting in deviation from the nitrogen standard expressed as a share of the standard. A negative figure represents a nitrogen deficiency, whereas zero represents adequate nitrogen content relative to the manufacturing standard.

On average, among the agro-dealers' samples, urea contained 45.9% nitrogen rather than 46%, CAN contained 24.5% nitrogen rather than the standard 26%, and DAP contained 17.5% rather than the standard 18%. We note that urea fertilizer available from agro-dealers is largely in accordance with international standards, with only 2% of samples out of compliance and 0.03% of samples exhibiting a fractional deviation exceeding 20%. More CAN and DAP are out of compliance, but the deviations from industry standards are small, in the order of 5.9% and 3.0%, respectively.[24]

Figure 2 presents a histogram of the fractional deviation in nitrogen for the agro-dealer samples: 146 (out of 633) agro-dealer samples are found to be out of compliance. A handful of samples have fractional deviations exceeding 20%: two CAN samples, five DAP samples, and one urea sample.

Our results are based on data from a handful of years, but the quality of fertilizer might vary from year to year. In section 2, we explained that nearly all fertilizer is imported via the port of Dar es Salaam by three large companies, suggesting a concentrated value chain, as often observed in Sub Saharan Africa (Theriault et al. 2018, Hernandez and Torero 2011, Jayne et al. 2003). A concentrated value chain could give rise to substantial shocks in quality should a poor batch be imported. In our case, we noted before that 65% of the agro-dealers source from just one supplier, and for all 225 agro-dealers, we only have 36 suppliers. This might imply that our results on the quality of fertilizer, based on data collection during one season, lack external validity beyond this season (see also Banerjee et al. 2017 and Rosenzweig and

[23] To decide whether or not a sample is out of compliance, we again use the guidelines for nutrient compliance from ECOWAS: single nutrient fertilizer with more than 20% nutrient content max .5 units (.5% for nitrogen in urea) and max 1.1 units for individual nutrients (that means 1.1% for DAP and CAN nitrogen).

[24] Comparing farmers' with agro-dealer samples, note that slighly more, 6%, of the farmer urea samples are out of compliance; the difference is small but significant, with a p-value of 0.042.

Table 2: Results of the laboratory tests of nitrogen content in fertilizer samples and observed attributes. Top panel is agro-dealer sample and bottom panel is farmer sample.

	(1) Nitrogen Standard (Minimum %)	(2) Samples Out of Compliance (%)	(3) Mean Nitrogen Content (%)	(4) Mean Deviation from Nitrogen Standard (share)	(5) Caking (%)	(6) Discoloration (%)	(7) Foreign Material (%)	(8) Powdered Granules (%)
Agro-dealer samples								
urea (n=300)	46	2	45.9 (1.5)	-0.003 (0.03)	41.6	2.4	8.2	6.8
DAP (n=137)	18	10	17.5 (1.1)	-0.03 (0.06)	14.6	23.1	1.5	0.8
CAN (n=196)	26	64	24.5 (1.2)	-0.06 (0.05)	15.5	13.8	1.7	14.9
All agro-dealer samples (n=633)				-0.03 (0.05)	28.0	10.3	4.8	7.9
Farmer samples								
urea (n=121)	46	6	45.4 (3.6)	-0.01 (0.08)	16.9	7.6	11.0	11.0
DAP (n=55)	18	27	16.7 (2.4)	-0.07 (0.13)	9.2	1.9	7.4	0.0
CAN (n=5)	26	40	23.7 (2.5)	-0.09 (0.96)	20.0	0.0	0.0	0.0
All farmer samples (n=181)				-0.03 (0.10)	14.7	5.6	9.6	7.3

Notes: Columns (1)-(4) present measured nitrogen content, deviation from industry standard and industry standards by fertilizer type. Columns (5)-(8) present observable attributes by fertilizer type. Laboratory tests conducted by the World Agroforestry Center (ICRAF). Out of compliance designations use ECOWAS tolerance limited for plant nutrients: maximum 0.5 units for single nutrient fertilizers with more than 20% nutrient content; complex fertilizers maximum 1.1 units for individual nutrients. Sample sizes for observables differ slightly than for measured nitrogen content because a handful of samples were not photographed: agro-dealer urea, DAP, and CAN samples for observables are 293, 130, and 181 respectively; farmer urea, DAP, and CAN samples for observables are 118, 54, and 5, respectively. Samples with measured nitrogen greater than the standard were set to the standard value for the calculation of the deviation from nitrogen standard mean in Column (4).

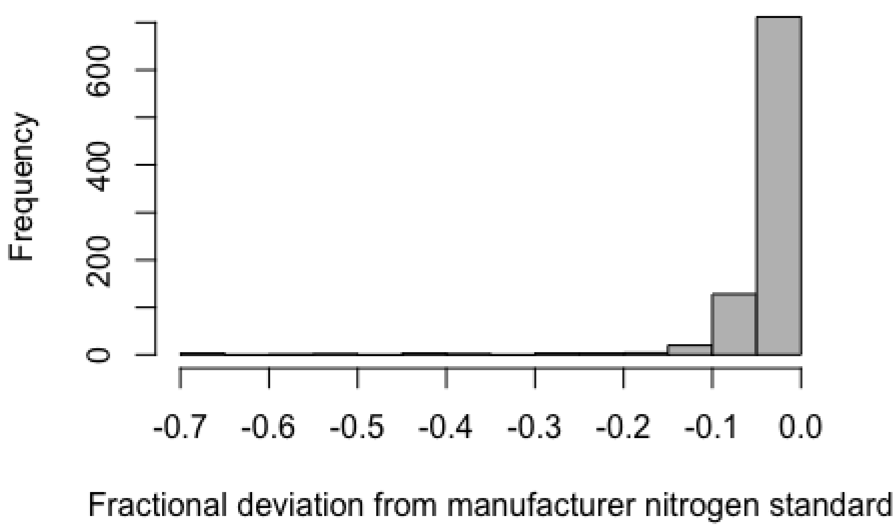

Figure 2: Fractional deviation from manufacturer Nitrogen standard in samples of mineral fertilizer purchased from agro-dealers in the Morogoro region of Tanzania. On average, mineral fertilizer is missing 3% of the advertised nitrogen (n=633).

Udry 2020). This would have implications for the interpretations of the WTP results as well, as beliefs would no longer be inaccurate. However, we do not believe this to be case. First, our data are consistent with Norton et al. (2020) who, in 2019, tested 45 urea samples among agro-dealers in the same region and all met the industry standards. Second, such a time-specific shock would have to originate high up in the supply chain. We tested fertilizer from ships and warehouses in Dar es Salaam in 2018. All fertilizer tested met international standards for nitrogen content.[25]

In addition, our results are consistent with recent studies in Sub-Saharan Africa and the East African region in particular. The International Fertilizer Development Center (IFDC) - a public international organization focused on international fertilizer quality - releases regular reports. A 2013 IFDC report presents and discusses the results of tests of 2,037 fertilizer samples collected from 827 wholesalers, government depots, and retailers in five West African countries (Sanabria et al. 2013). This study finds that nitrogen problems in urea are highly infrequent,[26] with only 4% of more than 500 tested urea samples out of compliance with standards.[27] IFDC reports from Uganda and Kenya in 2018 similarly find no nutrient issues in urea; all urea sampled and tested by IFDC in these studies is in compliance (Sanabria 2018A/B). Our results are also consistent with the results presented in a 2015 policy brief funded by the Alliance for a Green Revolution for Africa and undertaken by the Ugandan Ministry of Agriculture which similarly found that urea was largely in compliance in Uganda, with an average deviation of 5% across 44 samples (Mbowa et al. 2015). Ashour et al. (2017a) also found that urea and NPK fertilizers met standards for nutrient content in Uganda with only one out-of-compliance sample out of 220 tested.

Results of these studies and ours differ from Bold et al. (2017), who find highly variable nutrient content and high average nitrogen deviations of 30% in urea in Uganda. It is not entirely clear why the Bold et al. (2017) study finds significant problems in urea where other studies do not. Differences with Sanabria et al. (2013) and Ashour et al. (2017A) could be attributed to sampling strategy and testing method, while the differences with our study might also be due to features of Ugandan fertilizer supply chains, and perhaps the testing method.[28]

[25]Similarly, we noted that all samples of the TBS passed international standards for nitrogen content. In addition, the interviews with the Tanzanian Regulatory Authority revealed that they could not describe incidents in which they have discovered fake fertilizer in the market. They reported that nearly all reports they hear and investigate from farmers prove false.

[26]Quality problems are more significant for some of the fertilizer blends and the report discusses that such problems could be due to a number of factors including settling particles, blending problems, or manufacturing issues. Overall, they characterize evidence of adulteration in mineral fertilizer in the region as "weak".

[27]The nitrogen shortage tolerance limit in urea is just 0.5% due to the low variability expected for nitrogen content in urea.

[28]Bold et. al (2017) used a lab in Uganda relying on the Kjeldahl method and took the average of three test results for each sample. Ashour et. al (2017A) use two labs in Uganda using two methods - Kjeldahl and a method based on combustion - to double test 187 fertilizer samples and find the Kjeldahl method results unreliable, with a low correlation between test-retest results for the same samples. We rely both on Kjeldahl (conducted in Florida, USA) and pXRF methods (in Nairobi) but find a high correlation across the methods for our tests.

Table 2 also presents the results of the visual coding of the fertilizer's physical condition for the farmer samples and the agro-dealer samples. We observed caking in 15% of farmer samples and 28% of samples obtained from agro-dealers. Approximately 6% of farmer samples were discolored, compared to 10% of agro-dealers' samples. 9% of farmer samples had foreign material present, as opposed to 5% of agro-dealer samples. 8% of both the farmer and agro-dealer samples contained powdered granules. Overall, one quarter of the fertilizer samples had issues with their physical appearance such as caking, discoloration, powdering, or the presence of foreign material. These rates again are consistent with a 2013 IFDC report documenting comparable incidence rates of physical quality issues in West Africa (Sanabria et al. 2013). We present the observed rates of these observable quality attributes disaggregated by fertilizer type in the appendix (Tables A1-A3). Urea has the highest incidence of caking, with 42% of the agro-dealer samples exhibiting the presence of hard clumps and 17% of farmer samples. CAN and DAP are more likely to be discolored and CAN samples are the most likely to contain powdered particles.

To assess the relationship between fertilizer's physical appearance and nitrogen content, which is never observable to the farmer, we present the results of analyses in which we regress the fractional nitrogen deviation on the four observable quality attributes for all fertilizer samples purchased from agro-dealers: caking, powdering, foreign material, and discoloration. Table 3 Column (1) presents the results using standard OLS with robust standard errors. Column (2) an agro-dealer fixed effect and Column (3) adds a market location fixed effect. The standardized nitrogen share has been multiplied by 100 in analyses presented in Table 3 so that it is expressed as in change in percentage points to ease interpretation of the coefficients.

We note that the observed properties of the fertilizer exhibit no relationship with the nitrogen quantity. That is, physical quality can exhibit degradation without underlying degradation in the nutrient content.[29] This is expected, given the low magnitudes and frequencies of missing nitrogen that we found based on the lab tests and the high rates of attributes related to poor physical appearance. This lack of variation in the dependent variable, nutrient content, contributes to large confidence intervals in Table 3, limiting

[29] As a check, we also analyze the relationship between the measured moisture content of the samples and observed quality attributes; moisture content is directly related to caking and powdering of granules (powdering makes the fertilizer likely to more readily and quickly absorb moisture). As expected, evidence of powdering is positively associated with moisture content and caking is similarly associated with higher moisture content. Discoloration and the presence of foreign material have no relationship with the measured moisture content. Details available on request.

our ability to exclude any economically-meaningful correlations.[30]

Table 3: Regression of the fractional deviation of nitrogen from the manufacturer standard on observable mineral fertilizer quality attributes (agro-dealer samples).

VARIABLES	(1) Standardized N deviation (percentage points)	(2) Standardized N deviation (percentage points)	(3) Standardized N deviation (percentage points)
Clumping	-0.0142	-0.103	0.127
	(0.430)	(0.466)	(0.335)
Powdering	-0.556	-0.431	0.180
	(0.692)	(0.928)	(0.844)
Discoloration	-0.469	-0.384	-0.215
	(0.626)	(1.115)	(1.080)
Debris/foreign material	-0.0820	0.731	0.0250
	(0.852)	(0.892)	(0.233)
DAP	2.808***	2.925***	2.862***
	(0.522)	(0.736)	(0.721)
urea	5.475***	5.765***	5.637***
	(0.449)	(0.401)	(0.454)
Constant	-5.704***	-5.902***	-5.923***
	(0.354)	(0.280)	(0.275)
Observations	604	604	604
Agro-dealer FE		Y	
Market location FE			Y

Notes: Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1.

Agro-dealers appear aware of these high levels of degradation in fertilizer's observable characteristics. When we spoke with the owners of 15 agricultural shops randomly selected from the available shops in Morogoro town, nearly all reported regularly receiving fertilizer from their own suppliers with caked aggregates, powders, discoloration, and foreign material. They argued that thes presence of these characteristics is related to transportation and storage issues. However, the agro-dealers, unlike the farmers, do not, in general, view bad appearance as a signal of low nutrient content. While agro-dealers are attentive to the physical appearance of their fertilizer, they are confident in the underlying nutrient quality. In Appendix Table A4 we present agro-dealer responses to the question "How do you identify high quality fertilizer?". The agro-dealers responded with reference to the fertilizer that they purchase from their own suppliers to sell and were permitted to choose multiple responses. Agro-dealers mentioned paying atten-

[30] Fertilizer with sufficient presence of foreign material mixed would mechanically lower nutrient content. None of the samples that we purchased in the market or that we received from farmers had sufficient quantity of non-fertilizer material to do so, as many with foreign material present simply included few small sticks or maize kernels. When we tested the fertilizer, the analyst removed these items first before crushing the entire sample, and taking a random sample for nutrient testing.

tion to the printed expiration dates, the weight, and condition of bags. They also mentioned trusting in their relationship with their own suppliers. Agro-dealers also reported testing the fertilizers that they sell on their own fields and small demonstration plots and explained that they rely on aggregated feedback from their farmer customers to assess the quality of the products they sell.

4.2 Willingness-to-pay for fertilizer

To gain a better understanding of what drives farmer willingness-to-pay (henceforward WTP) for fertilizer we regress WTP on the physical appearance (clean sample, caked sample, and sample with foreign material present) and whether the WTP was stated before or after the farmer had received information about the nutrient quantity (this variable takes the value 0 prior to the information and 1 after the information was provided).

The intuition behind this empirical strategy is the following: if the farmer is risk-averse, and if crop performance (positively) depends on the quality of fertilizer, then both decreasing the uncertainty regarding nutrient quality through information about the test results and increasing its expected value will increase WTP. In contrast, the physical attributes of the non-clean samples might decrease the expected quality, and hence decrease WTP.

In Table 4 - Column (1), we approximate the WTP using a linear model. We estimate:

$$WTP_{it} = \alpha + \beta_1 \mathbf{P}_i + \beta_2 I_t + \beta_3 \mathbf{P}_i * I_t + \varepsilon_{it} \tag{1}$$

Where WTP_{it} is the WTP for fertilizer sample i at time t. This subscript t indicates whether the WTP was elicited pre-information or post-information. The physical attributes of fertilizer sample $\mathbf{P}$ correspond to a series of dummy variables referring to fertilizer sample A, B and C. Recall that Sample A is the pristine, white urea; Sample B included several large, hard caked aggregates; and Sample C included the presence of a small amount of dark-colored foreign material. The variable I for information is a dummy variable indicating whether the WTP was stated pre or post information ($I = 0$ for pre-information and $I = 1$ for post-information). Column (2) adds a farmer fixed effect (each farmer completed six assessments, three before and three after the information was provided). In the discussion of the results, we will reference the specification with the farmer fixed effect, presented in Column (2).

As a benchmark for the reported WTP, the average per kilo price of urea in the region during the time of the assessment was 1500 TZS. Analysis of the WTP assessment yields two important insights.

First, farmer WTP for perfect quality fertilizer (both in terms of nitrogen content and physical condition) exceeds the market price. Farmers' mean pre-information WTP for Sample A, the sample in good physical condition, is 1489 TZS, approximating the prevailing market price in the region at the time. However, after receiving information about the lab-tested nutrient quality of the urea, farmers' mean WTP increases by 48% to 2,201 TZS, well exceeding the market price. The post-information WTP on Sample A provides a counterfactual – what farmers in our sample would pay for fertilizer without uncertainty about nitrogen content. This increase indicates that credible information works, a point to which we return below.

Second, the assessment establishes that farmers' WTP for fertilizer responds to the physical condition of the fertilizer. The WTP for the three samples, pre and post information, are presented in Figure 3. Recall again that Sample A is the pristine, white urea; Sample B included several large, hard caked aggregates; and Sample C included the presence of a small amount of dark-colored foreign material.

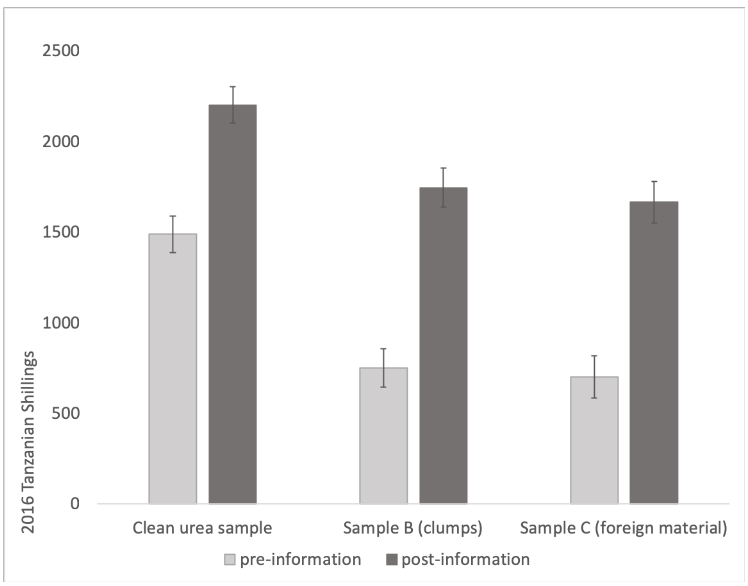

Figure 3: Results of the willingness-to-pay assessment, pre and post information; specification presented in Table 4, Column (2).

Prior to the provision of the lab tests on nitrogen content, farmers discounted Sample B and Sample C relative to Sample A by 738 and 788 TZS, respectively (Column (2)). This value includes both the signaling value of the poor physical characteristics as well as costs associated with handling fertilizer with poor physical qualities. Farmers' WTP increases significantly for all three samples after enumerators provide farmers with the test results demonstrating good quality. Post-information WTP increases for Sample B and Sample C are approximately 1000 TZS; resulting in a post-information WTP for these samples which, again, exceeds the prevailing market price. The difference in these differences gives us the

Table 4: Willingness-to-pay assessment; effect of information about unobservable nitrogen content on WTP.

	(1) WTP TZS	(2) WTP TZS	(3) WTP TZS	(4) WTP TZS
Sample B (clumps)	-748.2***	-737.7***		
	(96.8)	(75.6)		
Sample C (foreign material)	-795.5***	-787.5***		
	(100.8)	(79.4)		
Samples with poor physical attributes			-602.6***	-565.7***
			(94.65)	(73.09)
Post-information	712.2***	712.2***	741.6***	741.6***
	(71.5)	(71.4)	(105.5)	(79.63)
Sample B * post information	282.5***	282.5***		
	(105.2)	(105.0)		
Sample C * post information	252.9**	251.0**		
	(109.4)	(109.2)		
Poor phys attributes * post information			153.2	152.0
			(133.8)	(101.0)
Poor phys attributes * quality sensitive farmers			-791.8***	-876.8***
			(196.9)	(154.1)
Quality sensitive farmers * post-information			-123.7	-123.7
			(216.3)	(163.7)
Quality sensitive farmers * Poor phys attributes * post-info			513.3*	514.5**
			(278.5)	(210.2)
Quality sensitive farmers			326.5**	
			(153.0)	
Constant	1,503.5***	1,489.2**	1,425***	1,460***
	(61.27)	(454.4)	(74.60)	(62.75)
Hypothesis tests				
post-info + Sample B + SampleB*post-info =0		-455.17 (75.58)		
(P-value)		0.000		
post-info + Sample C + SampleC*post-info =0		-536.57 (79.21)		
(P-value)		0.000		
Farmer FE		Y		Y
Observations	855	855	855	855

Notes: Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. Columns (3) and (4) present the willingness-to-pay assessment, sub-group analysis; effect of information about unobservable nitrogen content on WTP with interactions for quality sensitive farmers. We omit from these estimations the responses in which farmers reported zero WTP for both pre and post information; these 150 responses comprise 13% of the sample and were nearly all for the sample that appeared to have the presence of foreign material (Sample C). Results hold with the inclusion of these zero WTP estimates and are included in the appendix (Table A6).

signaling value of poor attributes, equal to 283 TZS and 251 TZS, respectively, for Sample B and C. This signalizing value represents 16 to 19% of the market price, or the pre-information WTP for Sample A, the pristine sample. This figure is notable. Recall that in Table 3 we found no evidence of a relationship between physical attributes of the fertilizer and the nitrogen content.

Pre-information WTP therefore captures not only the farmer uncertainty about nutrient quality and inference about that nutrient content based on physical condition, but also an expected cost of dealing with poor physical attributes. The post-information WTP estimates help to decompose these costs; what remains after the uncertainty is resolved can be interpreted in lost time and resources from addressing physical quality problems. For example, caked fertilizer must be broken up by the farmer before application; powdered fertilizer is difficult to apply and can result in losses during handling or storage; unwanted foreign material may need to be sorted out. Consistent with this, post-information, farmers continue to report a lower WTP for the samples with poor physical attributes relative to pristine Sample A. The post-information difference between the WTP for Sample A, and Samples B and C provides an estimate of the usage costs; this value is estimated at 455 TZS for Sample B and 537 TZS for Sample C (see the hypothesis test in Table 4).[31]

Note that these results depend on our choice to use urea in the elicitation as well as our choice to sample farmers experienced with using mineral fertilizer. We are using a selected sample of farmers who are likely more knowledgeable and more optimistic about fertilizer quality (given that they purchase and use it). In particular, we suspect that the WTP for Samples B and C (those with poor appearance) in our sample of farmers is likely to be higher than the WTP among farmers without experience using fertilizer. This in its turn would result in an under-estimate of the signaling value, and possibly also information effects for these fertilizer samples. As such, our estimate of signaling value in particular should be treated as a lower bound. We are unsure about the direction of the bias for fertilizer Sample A, as both information constraints and credit constraints might play a significant role. Norton et al. (2020) conducted a similar WTP exercise, but sampled farmers randomly from 18 villages in the same region using an incentive-compatible Becker-DeGroot-Marschak auction. Of 348 farmers in the Norton et al. study, only 34% reported ever having used fertilizer. These farmers were willing to pay 46% more for a clean, tested sample of urea (comparable to our Sample A) than for a clean sample of urea that

[31] These computations rely on the assumption that that the information provided by the researchers fully resolves farmer uncertainty regarding the nutrient content. Given the context and the design, we expect this to be the case. The WTP exercise was executed by a team from the University of Illinois at Urbana-Champaign, and Sokoine Agricultural University. Sokoine University is Tanzania's leading agricultural university and located in Morogoro. Sokoine is well known and well respected in Tanzania, and enjoys an excellent reputation in the area among farmers due to its many outreach activities. During the WTP exercise, we noted that the fertilizer samples were tested in a United States laboratory. United States firms and standards are well-respected in the region.

lacked proof of its nutrient content. Recall, our comparative number is 48%. The fact that these results are comparable is re-assuring. Our elicitation method was hypothetical; using actual stakes might reduce any social desirability bias present (as suggested also by Olesen et al. 2010). The fact that our results are very similar to Norton et al. (2020) suggests that this bias is likely limited.[32]

Our WTP results are consistent with further survey results. Recall that (from Table 1), 15% of farmers reported that they believed that at least 50% of the fertilizer in the market was adulterated; another 28% reported believing that more than zero but less than 50% of fertilizer was adulterated. Appendix Table A5 further details the nature of these concerns. Farmers report suspicions that fertilizer in the marketplace is adulterated: 14% reported that they suspected that they had purchased fertilizer with this problem in the past and 21% reported knowing someone who had similar suspicions.[33] Farmers are attentive to the physical attributes of fertilizer; more than 50% reported having purchased caked or clumped fertilizer in a previous season and 82% reported knowing someone who had purchased caked or clumped fertilizer. When we inquired as to what one does when one receives fertilizer with clumps specifically, 29% indicated they would not even apply it to their crops (while the remainder reported they would break up the clumps before application).

Further qualitative interviews confirm that many farmers perceive a link between nutrient content and physical attributes. In phone interviews among 43 village farmers, the majority noted that they had purchased and applied poor quality fertilizer in the past (36/42). Among these, 25% deduced quality from poor crop performance, while 75% noted poor physical appearance.[34] The results of our qualitative research suggest that our estimated signaling value in the WTP exercise of 16 to 19% of the market price is within a reasonable range.

The qualitative results suggest that different kinds of customer-farmers exist, and likely only a subset of all farmers is driving the signaling effect we observe in the data. For instance, pre-information, 16% of farmers report the same (non-zero) WTP bid for all three fertilizer samples shown, suggesting that they are not prone to these incorrect assumptions related to physical appearance and nutrient quality. Given evidence that farmers might differ in their attentiveness to the physical appearance of fertilizer, we conclude this section with a heterogeneity analysis. We divide the farmers in two samples, a group that is highly sensitive to fertilizer quality and a group that did not report this sensitivity. We define the quality

[32] It is also notable that there is no a-priori reason why a social desirability bias alone could result in the differential information response across Samples A, B and C.

[33] It is notable that the 2013 IFDC report we referred to in the previous section (Sanabria et al. 2013) mentions: "With a probability of out of compliance of 0.04, the total N content compliance of urea was good. Yet, there is a perception that urea is being mixed with non-fertilizer materials in the region, which the study results did not confirm. A specific assessment is required to further verify this claim." (p. 39)

[34] Among the 41 Morogoro town customers, only 25% noted that clumping of fertilizer this indicates quality issues, while 25% just noted that it is harder to apply (with 50% noting clumps are not an issue).

sensitive group as the group that listed "purchasing high quality fertilizer" among their top two concerns at the start of a typical agricultural season during the survey (24% of farmers). We run an extension of Equation (1), interacting an indicator for these quality-concerned farmers with the pre-post-information signal indicator, the physical attributes indicator (we pool samples B and C to increase power), and the interaction between the physical attributes and information indicators:

$$WTP_{ijt} = \alpha + \beta_1 \mathbf{P}_i + \beta_2 I_t + \beta_3 \mathbf{P}_i I_t + \beta_4 Q_j \mathbf{P}_i + \beta_5 Q_j I_t + \beta_6 Q_j \mathbf{P}_i I_t + \beta_7 Q_j + \varepsilon_{it} \tag{2}$$

Where subscript j indicates farmer j. In specification (2), Q_j indicates whether the farmer self-identified as concerned about purchasing high quality fertilizer.

Table 4, Columns (3) and (4) present the results of this sub-group analysis. Column (3) presents specification (2); Column (4) drops the quality-sensitivity indicator and includes farmer fixed effects. We find that, as hypothesized, the quality-sensitive farmers are more attentive to the physical attributes of the samples; the estimate of β_4 is large, negative, and significant. Their WTP for these samples is significantly lower than the WTP of farmers who do not self-identify as quality-concerned. We find no evidence of belief stickiness however: the quality-concerned farmers have a stronger response to the quality information provided in the WTP exercise for the poor looking fertilizer samples (the estimate on β_6 is positive, and significant).

In future research, we aim to further explore what explains the origins of these incorrect beliefs. For now we speculate that incorrect beliefs, once established, may persist due to the difficulty of learning about the quality of any input into the agricultural production due to the stochasticity of production. In addition, qualitative evidence suggests that farmers might also underinvestment complementary inputs, such as in labor, if one believes the fertilizer is poor. Finally, farmers may not be purchasing and applying the right quantities or types of fertilizer, given their plot-specific nutrient limitations.

4.3 Market responses

Finally, we consider the market response. First, given evidence that farmers take observable physical attributes as a signal of nutrient content, do we see prices respond to these attributes? Second, do agro-dealers invest in improving the observable physical attributes? Third, as farmers already have established beliefs about the low nutrient content and given that nutrient content is unobservable, why *don't* agro-dealers adulterate fertilizers?

4.3.1 Relationship between prices, nutrient content and physical attributes

Table 5, Columns (1), (4) and (7), present the results of regressions of the per-kilogram price of fertilizer on the physical condition of each fertilizer sample (caking, discoloration, powdering, presence of foreign material) as well as the unobservable fractional nitrogen deviation for urea, CAN, and DAP samples (samples from fertilizer agro-dealers), respectively.

As expected, we find no statistically significant relationship between the price and the nitrogen content, with the exception of DAP, where higher-price DAP is associated with higher nitrogen. More surprisingly, we find no relationship between physical appearance and price: there is no evidence that the physical appearance affects the price. Foreign material present is actually correlated with a higher price in urea fertilizer, though the number of urea samples with foreign material is small at 20, less than 10% of the total samples. [35] This disconnect suggests that while farmers place a lower value on fertilizers with compromised physical attributes, we do not find evidence of any downward pressure on the market prices of fertilizer with these attributes.

Columns (2), (5), and (8) add features of the transaction, agro-dealer, and location that might be observable at the time of purchase. Fertilizer purchased from open bags in one or two-kilogram quantities are significantly more expensive than fertilizer purchased in 50 or 25 kg bags, possible evidence of quantity discounting. Columns (3), (6) and (9) run the model for only samples of one or two kilograms that were repacked for sale by the agro-dealer or purchased from open bags at the time of the transaction. The large standard errors on the nutrient content and the observable characteristics measure in Table 5 are related to the lack of meaningful variation in the prices.

It is plausible that downward pressure on prices would be evident only with increased market competition, especially given our limited sample. In our sample, 47% of the markets have more than one agro-dealer. In Appendix Table A6 we present the results of a regression investigating the correlation between the market price and the physical attributes of the fertilizer sample under conditions of competition. We focus on clumps and the presence of foreign materials because there is minimal powdering and discoloration in the samples in the low-competition markets (10 samples). We again note the lack of a statistically-significant relationship between physical appearance and price, even under competitive conditions (with more than two agro-dealers in the market).

In fact, overall we observe little variation in market prices for fertilizer, both within and across market centers. In 58% of the market centers where we purchased urea from multiple agro-dealers on the same

[35] While we find a small and statistically significant negative correlation between the presence of foreign materials and the fertilizer price using the famers' price data, we note that the sample of fertilizer from farmers with foreign material present is small - about 8% of the total farmer samples.

Table 5: Regression of the per kilo price on observable mineral fertilizer quality attributes, samples from agro-dealers.

	urea fertilizer			**DAP fertilizer**			**CAN fertilizer**		
	(1) TZS per kg	(2) TZS per kg	(3) TZS per kg	(4) TZS per kg	(5) TZS per kg	(6) TZS per kg	(7) TZS per kg	(8) TZS per kg	(9) TZS per kg
Nitrogen fractional deviation (%)	-9.055	-10.32	-1.649	10.25***	10.04**	11.12***	-3.477	-5.717	-7.208
	(10.11)	(7.670)	(6.562)	(3.015)	(3.931)	(3.920)	(2.974)	(4.516)	(5.127)
Number of clumps	3.570	2.870	2.833	18.27	37.92	32.05	2.052	5.380	4.835
	(9.595)	(6.528)	(7.015)	(33.12)	(33.04)	(37.46)	(5.779)	(6.505)	(6.327)
Presence of powdering (Y=1)	-0.435	-7.400	7.302				57.97***	66.93***	74.93**
	(19.11)	(23.87)	(27.29)				(14.48)	(21.91)	(37.50)
Fertilizer discolored (Y=1)	-25.27	-13.61	-35.81	13.38	-60.51	-22.42	-27.59	-33.47	-4.453
	(64.53)	(54.90)	(55.42)	(46.19)	(50.97)	(62.78)	(28.83)	(42.09)	(39.99)
Foreign material present in sample (Y=1)	76.88*	91.57**	90.16**	10.48	-15.07	-8.813	12.47	33.55	87.27
	(40.28)	(40.28)	(40.97)	(18.84)	(33.35)	(36.00)	(14.98)	(52.21)	(63.56)
Purchase made from open bag (Y=1)	151.2***	133.5**		276.4***	289.8***		300.6***	291.3***	
	(56.62)	(57.84)		(63.16)	(62.69)		(61.25)	(57.41)	
Constant	1,072***	1,304***	1,434***	1,755***	1,830***	2,123***	1,151***	929.5***	1,117***
	(57.52)	(70.04)	(66.36)	(79.14)	(88.18)	(97.39)	(77.45)	(200.7)	(206.0)
Observations	293	276	258	126	115	107	179	166	159
Enumerator FE	Y	Y	Y	Y	Y	Y	Y	Y	Y
Market location FE	Y	Y	Y	Y	Y	Y	Y	Y	Y
Agro-dealer controls		Y	Y		Y	Y		Y	Y

Notes: Robust standard errors in parentheses; Columns (1)-(3) present the results for urea fertilizer, Columns (4)-(6) present the results for DAP fertilizer, and Columns (7)-(9) present the results for CAN fertilizer. Columns (3), (6), and (9) run the model on only samples purchased from open bags. Agro-dealer controls include if the store had a visible sign, whether the store is certified/licensed by the government to sell fertilizer, the number of other customers present during the transaction, gender of respondent, age of respondent, years business has been in operation, and whether fertilizer is sold every month of the year. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

day, we find no price variation across agro-dealers – all prices are the same (40/68 market centers). In addition, we find no within-agro-dealer variation in prices for two fertilizer samples with different physical appearance (with the presence of clumping and without) purchased on the same day. We have 40 samples of urea from 20 agro-dealers (two from each dealer) that were purchased on the same day for which one sample has clumps and the other does not. In each case, the price charged by the agro-dealer was the same.

This lack of correlation between the fertilizer's physical appearance and the price is confirmed in the series of qualitative interviews we conducted with farmers. Farmers noted that prices do not tend to vary within a market center across agro-dealers. They also mentioned that while sometimes price discounts are given in the case of severely degraded fertilizer, these discounts are not expected, nor common or substantial. When we inquired about the use of discounts with the owners of 15 agricultural shops randomly selected from the available shops in Morogoro town, less than a third noted that they discount fertilizer, the main reason being that they do not get discounts from their suppliers, and they want to avoid making losses.

Why do farmers not receive a systematic discount for these fertilizers with degraded appearance, in accordance with their reduced WTP for these samples? Part of the explanation might be that there are likely still a substantial number of farmers who do not care about the physical attributes, or do not take these attributes as indicators of low nutrient content. Results from our WTP exercise indicate that 16% of farmers do not respond to physical attributes – that is they report the same (non-zero) WTP bid for all fertilizer samples shown (prior to the enumerator providing information on the tested nutrient content).

In addition, fertilizer with poor physical appearance is common. This implies that conditional on an agro-dealer presenting the mystery-shopper with a poor-looking fertilizer sample, the probability of another agro-dealer within the same market having fertilizer in pristine condition is small, 34%. Hence, any farmer looking to switch agro-dealers might have to consider traveling to another market. The nearest market is, on average, 8 km away (the range is 2 to 40 km). Public transport between markets is limited, and walking 8 km takes 1.5 to 2 hours.

The implication is that those farmers who care about fertilizer's physical appearance might decide not to purchase fertilizer at all, instead of shopping around for a better deal. But this behavior does not create a price gap based on physical attributes as there are sufficient customers in the market who do not care about these attributes.

4.3.2 Investment in storage and physical attributes

In Section 3.1 we noted that Tanzania's fertilizer market is highly concentrated. Further analysis of the data suggests that problems with fertilizer's observable quality attributes begin upstream in the supply chain. This implies that nearly all agro-dealers have some chance in any given shipment of having such issues. In our sample, 72% of agro-dealers were affected by these issues.

Table 6 presents the results of a regression analysis mapping the physical appearance onto agro-dealer investments in improved storage. We find that the physical condition is not explained by the agro-dealer's own shop infrastructure such as the use of pallets for storage.

Table 6: Relationship between shop infrastructure and physical attributes of fertilizer (agro-dealer samples).

	(1) caking present	(2) powders present	(3) foreign material	(4) discolored
Concrete floor	0.00489	-0.00594	0.0122	0.00615
	(0.0445)	(0.0264)	(0.0215)	(0.0304)
Shelving	0.0865	0.0714*	0.0163	-0.0382
	(0.0711)	(0.0422)	(0.0344)	(0.0485)
Pallets	-0.0662	0.0355	-0.0318	-0.0579*
	(0.0505)	(0.0300)	(0.0245)	(0.0345)
DAP	0.00729	-0.120***	0.00645	0.103***
	(0.0515)	(0.0306)	(0.0249)	(0.0351)
urea	0.285***	-0.0577**	0.0690***	-0.103***
	(0.0428)	(0.0254)	(0.0207)	(0.0292)
Sample collected in 2016	0.00561	0.0383*	0.00439	0.0874***
(0=2015 collection)	(0.0369)	(0.0219)	(0.0179)	(0.0252)
Constant	0.185***	0.0760**	0.0281	0.131***
	(0.0633)	(0.0375)	(0.0307)	(0.0432)
Observations	542	542	542	542

Notes: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Sample is smaller than full set of samples collected because some shop infrastructure was unobservable to the enumerator at the time of the purchase.

In short, problems with fertilizers' physical appearance seem to present as shocks to agro-dealers (though these could be based on unobserved variables at the agro-dealer level). Actions in terms of improved storage and handling taken by agro-dealers may prevent further degradation but they all accept some chance of receiving product from their suppliers of compromised physical condition.

To add further support to this proposition, we visited a bagging facility in Dar es Salaam run by one of the major fertilizer importing companies. The fertilizer comes to the bagging facility from the port and is stored there until it is packaged into 50 and 25 kilogram bags. The fertilizer was kept on a bare dirt floor that was wet at the time of the visit. Vehicles bagging and scooping the fertilizer drove over it as they worked, individuals frequently walked over it before it was bagged, and the piled fertilizer included large visible clumps.

When we spoke with the owners of 15 agricultural shops randomly selected from the available shops in Morogoro town, almost all reported regularly receiving fertilizer from their own suppliers with some clumps. When asked for the reason, they agreed that the problem is related to prevailing modes of transportation and storage. Accordingly, when we inquired about what could be done to prevent physical degradation, all agro-dealers referred to improved storage practices, such as using pallets to store the bags (rather than placing the bags directly on a concrete floor), and the use of ventilation in the storage space, but all recognized that even when this is done, one cannot restore a bag of clumpy, powdered fertilizer to its original pristine condition.

4.3.3 The scope for adulteration

Profitable adulteration of fertilizer is difficult. Substantial quantities of low-value fillers must be included for a palpable effect on profits and urea presents particular problems: the small prills are relatively uniform in size and color and very few plausible fillers are available at a cost lower than urea itself. For example, kaolin clay will coat the prills and change their opacity but costs significantly more than urea by weight and sodium hydroxicide (lye) micro beads, while visually plausible before combining - is both reactive with urea and also more expensive than urea. Salt is both inexpensive and non-reactive with urea but has granuales that are considerably smaller than urea prills and that are easily visually detectably to all but the extremely inexperienced buyer. Adulteration of fertilizer blends such as NPK and CAN may be easier because particle sizes differ in the blends but still the required fillers must be used in large enough quantities that their presence is likely to be detected visually.

Researchers at the IFDC argue that the presence of such extraneous material is so evident that only smallholder farmers with virtually no knowledge of fertilizers will be fooled (Joaquin Sanabria, personal communication, March 27, 2018). Smallholder farmers represent only a small share of the market (in terms of purchase quantity) in many regions and the deception is unlikely to pay off at the agro-dealer level. Though adulterating fertilizers in large volumes is most profitable, fraud at this scale is also most likely to be caught by authorities and clients.[36]

[36]The 2013 IFDC report finds evidence of only ten cases out of 2,037 collected samples in which strange substances or excessive fillers were identified. All of these cases were a special Single Superphosphate fertilizer collected in Nigeria; seven of these were found based on chemical analysis to contain no phosphate. Ashour et al. (2017) identify one urea sample out

5 Conclusion

Crop yields have remained largely stagnant over the past 50 years in most of Sub-Saharan Africa. While cereal yields in South America and Asia have at least doubled since the 1960s and now average 4 to 4.5 metric tons per hectare, cereal yields in Sub-Saharan Africa lag far behind, averaging 1.2 to 1.7 metric tons per hectare (World Bank 2020, Ray et al. 2012). In the long-term, uncertainty regarding fertilizer quality could have major consequences for the persistence and growth of mineral fertilizer demand, hampering efforts to increase adoption of fertilizer as a means of raising regional agricultural productivity and improving household and national food security (McArthur and McCord 2017).

In this paper, we use quantitative and qualitative data on a sample of farmers and a census of fertilizer agro-dealers to ascertain facts regarding fertilizer quality and to measure the responses of small-scale farmers and agro-dealers.

We make a distinction between two types of fertilizer quality: unobservable nutrient content, which determines the effectiveness of fertilizer and observable physical appearance, which apart from some additional processing costs does not impact agronomic effectiveness. We find that the quality of fertilizers for sale in retail shops largely meets national manufacturing standards for nutrient content but find widespread evidence of degradation in physical appearance. We find no statistically significant correlation between the two dimensions of quality, i.e., the physical appearance does not provide information about unobservable nutrient content.

In contrast, we find evidence of belief of rampant product adulteration among farmers in these markets. Such concerns are reinforced by stories in the popular press. For example, The Citizen, a major Tanzanian English Language newspaper, reported in 2016 that the Tanzania Fertilizer Regulatory Authority (TFRA) had discovered "fake" fertilizer in markets across the country and that 40% of fertilizer for sale in the country was counterfeit (Kasumuni 2016)[37]. In 2014 the same newspaper reported a seizure and destruction of counterfeit fertilizer (Lugongo 2014).

In addition, farmers are attentive to the physical attributes of fertilizer, in the sense that they are using them as signals to infer unobservable nutrient quality. This directly impacts their willingness-to-pay for fertilizer. Using market price data, we find, as expected, that the nutrient content is not reflected in market price. Surprisingly, we also note that market price does not respond to physical attributes.

Farmers are widely suspicious of the agronomic quality of fertilizer for sale in their markets and yet

of compliance for nitrogen in their Uganda study and write, "this sample is easily discernible, as it does not even look like fertilizer" (p. 11).

[37] Follow-up research into this story in 2019 by members of our research team, including interviews with the journalist who wrote it, established that the 40% figure itself came from farmer speculation and was not based on testing or assessment

our research: nearly 950 fertilizer tests over four years at multiple levels in the supply chain including shops, wholesalers, farmers, and importing ships, establishes that fertilizer is good – that it has the required nutrients. Our finding that fertilizer in the region is of good agronomic quality is consistent with the majority of recent studies on the topic (Sanabria 2013, 2018A/B, Mbowa et al. 2015, Ashour et al. 2017A). Why farmer beliefs diverge from the truth in this market is an important and interesting area of future research.

Given farmer suspicions and our finding that farmer willingness-to-pay responds to credible information about unobservable nitrogen content, is nutrient content certification or labeling a viable solution for information problems in this market?[38] In general, whether or not certification increases welfare depends on the willingness-to-pay for higher quality, the costs of implementing, monitoring, and enforcing the certification, and how fast farmers update their beliefs, as well as their initial beliefs (as this will determine how quickly reputation can be established; see also Marinovic et al. 2018 and Auriol and Schilizzi 2015). Bai (2015) provides quality certification labels in the watermelon market in China but finds that profit increases may not justify certification investments for individual sellers. Oya et al. (2018) provide a systematic review of certification schemes in the agricultural sector and find mixed success.[39]

The prospects for fertilizer labeling and credible nutrient content certification in Tanzania are limited at this stage. Current government bodies charged with the task of regulating fertilizer sales and importation such as the Tanzanian Fertilizer Regulatory Authority (TFRA) and Tanzanian Bureau of Standards (TBS) lack the financial support and manpower to enforce their existing mandates. A labeling initiative could come from the private sector but margins in fertilizer are extremely thin and any undertaking that increases the fixed costs of fertilizer sales seems unlikely to succeed. A third-party certification by an independent group may have more promise but it is unclear who might assume such a task.

In the absence of credible labeling, we expect that farmers will continue to use observables as a signal of nutrient content. Our ongoing work suggests that supply chains in the region moving fertilizer from port to rural input shops are capital constrained and limited in their logistics and storage capabilities (Fairbairn et al., 2016) and our findings suggest that poor supply chain management may be leading to degradation of fertilizers' physical appearance. Our results therefore suggest that observable fertilizer degradation in a context of asymmetric information could depress demand for fertilizer and complementary agricultural investments.

[38]See Leyland (1979) for an introduction on certification, Henson and Caswell (1999), Verbeke (2005), Grunert (2005), Costa-Font et al. (2008), Messer et al. (2017) for examples.

[39]Other programs also show mixed results. Hoffman et al. (2017) finds that labeling maize for afflatoxin, a toxic fungus, in Kenya affects consumer demand in the short term but not in the long term (but Garrido et al. (2017) find overall limited impacts in a similar context). See also Ashour et al. (2017) and Sanogo and Masters (2002).

Overall, farmer suspicions about quality may partially explain the slow uptake of the use of fertilizer in Tanzania. Concerns regarding quality could affect adoption at both the intensive and extensive margin. Indeed, if concerns about quality push down farmers' expected marginal productivity for fertilizer (as suggested by the expectations elicited by Bold et al. 2017), farmers will apply less fertilizer at a given price, and at some stage, apply none on a particular crop or field. While many studies have considered the marginal yield effects of fertilizers (Kaliba et al. 2000, Duflo et al. 2008, Marenya and Barrett 2009, Sileshi 2010, Chivenge et al. 2011, Suri, 2011, Beaman et al. 2013, Liverpool-Tassie 2017), we see the need for more studies which further investigates the different margins at which farmers operate, and the role of their subjective beliefs on fertilizer quality and effectiveness.

In the long-term, uncertainty regarding fertilizer quality could have widespread consequences for the functioning and growth of fertilizer demand in low income countries. It is critical to understand not merely the determinants of quality and quality degradation but also how farmers are assessing fertilizer quality, what attributes they care about, and how they decide whether a purchase has those attributes. Increasing small farmer use of fertilizer and hybrid seeds is key to improving regional agricultural productivity and raising incomes and food security but use of these inputs remains relatively low. Our results suggest farmer concerns about quality are an important piece of the puzzle.

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