Adverse Selection in Fertilizer Markets: Evidence from Tanzania

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Abstract

For decades, fertilizer use has remained substantially below recommended rates in most of Sub-Saharan Africa, a shortfall contributing to poor crop yields and low incomes. We explore the role of adverse selection in the fertilizer market in Tanzania. We tested 823 samples of fertilizer in Tanzania, and collected quantitative and qualitative data from 225 fertilizer dealers and 164 farmers. We find that (1) in terms of nitrogen content, the quality of fertilizers is often substandard, (2) sellers know more about this quality problem than buyers, (3) buyers are willing to pay considerably less for fertilizers in the market than they are for (researcher) certified fertilizers, and (4) buyers (incorrectly) base this willingness-to-pay on the observable physical condition of the product, commonly an inaccurate indicator of actual nutrient content. We also provide the first evidence that problems of adulteration in these markets are concentrated at the level of the local agro-dealer. Our results suggest that adverse selection afflicts the Tanzanian market for mineral fertilizer. While nutrient certification, if credible, could be a step towards solving this problem, decreasing physical degradation from poor storage and transportation will also be critical, given that farmers rely on visual evaluation for conclusions about nutrient quality.

JEL Codes: Q12, D82, O13
1 Introduction

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 4–4.5 metric tons per hectare, cereal yields in Sub-Saharan Africa lag far behind, averaging 1.2–1.7 metric tons per hectare (World Bank, 2014). One common explanation for this stalled productivity is widespread failure to adopt modern agricultural inputs, including hybrid seeds and mineral fertilizer (Sheahan and Barrett 2017; Sanchez 2002). For instance, Tanzanian and Kenyan farmers, on average, apply 10 kilograms of fertilizer per hectare, in contrast with Brazilian and Indian farmers, who commonly apply 175 and 165 kilograms per hectare, respectively (World Bank, 2014).

Researchers have attributed persistently low rates of mineral fertilizer use in Sub-Saharan Africa to factors primarily related to individual preferences (Duflo et al. 2011) or to conditions in input and output markets (Minten et al. 2013; Croppenstedt 2003), especially uninsured production and consumption risk (Karlan et al. 2014; Dercon and Christiaensen 2007). An underexplored possibility is proposed by Akerlof (1970): the presence of “dishonest sellers”, who “wish to pawn bad wares as good wares and thereby tend to drive the good wares out of the market” (p. 495). The agronomic quality and efficacy of mineral fertilizer is determined by its nutrient content. Urea fertilizer, for example, should contain 46% nitrogen. This nutrient content is not observable to the buyer at the time of purchase, however. Combined with a weak regulatory framework and limited enforcement of product standards common in Sub-Saharan Africa, this problem with unobservable quality provides opportunity for Akerlof’s “dishonest sellers”.

Reports from Tanzania, the site of this study, do suggest the presence of such dishonest sellers in the fertilizer market. Anecdotal evidence indicates that farmers in Tanzania believe that the mineral fertilizer available in local shops is substandard in quality, and regional newspapers report dramatic stories of criminal fertilizer adulteration, widely believed to be the root cause of the problem. Farmers report suspicions about fertilizer sold past its expiration date, along with concerns about purchasing Urea fertilizer that has been mixed with table salt or DAP diluted with powdered concrete. Such concerns are reinforced by stories in the popular press. For example, The Citizen, a major Tanzanian English Language newspaper, reported that the Tanzania Fertilizer Regulatory Authority (TFRA) had discovered “fake” fertilizer in markets across the country and that 40 percent of fertilizer for sale in the country was counterfeit.\(^1\) In 2014 the same newspaper documented the seizure and destruction of counterfeit fertilizer (Lugongo 2014).\(^2\) Even so, hard evidence to confirm these suspicions and allegations has been lacking;

\(^1\)http://www.thecitizen.co.tz/magazine/businessweek/40pc-of-fertilisers-fake–study/1843772-3120846-109ri8oz/index.html
\(^2\)http://www.thecitizen.co.tz/News/national/New-law-to-protect-public-from-fake-fertilizers/1840392-2308462-
nor has research focused on how farmers evaluate fertilizer available to them in the local market and how such assessments affect purchasing.

The anecdotal evidence from Tanzania is consistent with the few other studies in Sub Saharan Africa on the quality of fertilizers and other inputs. Bold et al. (2017), for instance, find that fertilizer in Uganda is missing, on average, 30 percent of its advertised nitrogen content. Similarly, Ashour et al. (2017) report that herbicides in Uganda also, on average, contain less than 75 percent of the labeled concentration of glyphosate, the active ingredient.

If some sellers opt to sell poor quality fertilizer, and if buyers are aware of the presence of these sellers, buyers will lower their willingness-to-pay for fertilizer in accordance with the average lower quality in the marketplace. In response, sellers of high quality fertilizer might, under certain conditions, be driven out of the market; this is Akerlof’s classic case of adverse selection. In some cases, the market may unravel and disappear altogether. Trades that could have happened between buyers who value good quality fertilizer and sellers who would provide such high quality fertilizers no longer take place, resulting in efficiency losses. In the context of fertilizer markets, such efficiency losses would have further negative consequences with longer-term implications for the economy including a loss of entrepreneurship, decreased crop productivity, and worsening soil fertility.

In this study, we use quantitative and qualitative data on fertilizer quality, pricing, and beliefs, collected from a census of fertilizer sellers within Tanzania’s Morogoro Region as well as a sample of the buyers, farmers in the same region, to determine the presence and possible scale of adverse selection in the fertilizer market and to analyze its implications.

Identifying this presence and quantifying its consequences of adverse selection is a complex process. Adverse selection lowers both the average quality on the market and the corresponding market price. However, the counterfactual is not observed; i.e. we do not know what the market price would be in the absence adverse selection. Moreover, data on quality is often lacking altogether.

Our data is well-suited to the task of assessing the presence and effects of adverse selection: we generate the counterfactual of a high quality product through a willingness-to-pay assessment with Tanzanian farmers in which farmers inspect three samples of Urea fertilizer which we procured in the local markets and which differed in terms of physical condition but which laboratory tests all found to contain 46% nitrogen (meeting industry quality standards). For each sample, we asked each farmer to state his or her willingness-to-pay, first without providing any additional information about tested fertilizer nutrient content; after, we informed the farmer that a reputable laboratory had found that the nitrogen content
of each sample was 46% or above and we asked them to provide a second willingness-to-pay for each sample.\footnote{Using a willingness-to-pay exercise to gain insight into the counterfactual scenario is not uncommon in this literature. Sanogo and Masters (2002), for instance, present mothers in Mali with a choice experiment of infant food. 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 (2016) 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.}

While this willingness-to-pay exercise allows us to study farmer beliefs, we also establish the full range of fertilizer quality in the market. We used mystery-shoppers to purchase 636 fertilizer samples from all 225 fertilizer sellers in the region. We had these samples of fertilizer tested by laboratories in Kenya and the United States, and we supplement these data with qualitative and quantitative data from farmers and dealers to provide further insights into the nature of asymmetric information in this market and its effects on the market.

This research makes four primary contributions to the literature on asymmetric information in developing country markets. First: using state-of-the-art laboratory tests and double testing across multiple labs, we show that nitrogen content is indeed low in mineral fertilizer for sale in Tanzanian shops: on average, marketed fertilizer is missing about 10% of its nitrogen. The quality of the fertilizer is variable, ranging from missing 50% of the nitrogen to missing no nitrogen: it is the fact that the quality is both unobservable and can vary that drives the adverse selection.

Second: building on qualitative interviews with fertilizer sellers and farmers as well as analysis that indicates that local agro-dealer retailers are likely the ones adulterating mineral fertilizer, we argue that that the sellers are better informed about actual nutrient content than farmers. Sellers pre-test mineral fertilizer on their own fields and test-plots; they know the supply chain and suppliers; and they accumulate feedback from farmers who praise or critique what they purchase. In addition, we find that information about which agro-dealer sold a sample of mineral fertilizer is the single most predictive factor of the fertilizer’s nitrogen content, even after controlling for other observable factors. Moreover, our analysis indicates that where an agro-dealer sourced his product is NOT informative about the quality of the mineral fertilizer that he sells.

Third: we find that farmers’ willingness-to-pay for fertilizer in the absence of information about its nutrient content is 38% lower than their willingness-to-pay with full information about nutrient content. Critically, farmers’ post-information willingness-to-pay is 50% higher than the current average market price for fertilizer in the region. This finding is consistent with Bold et al. (2017) who elicited Ugandan farmers’ yield beliefs conditional on expected nitrogen content in fertilizer and found evidence of a strong relationship between expected quality and expected yields. Moreover, we find that farmers’ willingness-to-pay...
to-pay strongly responds to credible information about the nutrient content (here, nutrient test results from a United States laboratory presented to the farmers by the research team). The fact that farmers respond to information is evidence that they value good quality fertilizer and that beliefs can be altered, i.e., that signaling could work.

Finally: we find that farmers’ willingness-to-pay depends on observable characteristics of the mineral fertilizer indicating physical quality degradation: clumps, powdering, discoloration, and the presence of foreign material. Among the three samples we presented to farmers in the willingness-to-pay exercise, only one was in pristine physical condition; the second sample contained large clumps; and the third included foreign material and impurities. Problems with the physical condition of fertilizer are common in the market, generally attributable to poor manufacturing, transport and storage conditions; among our 636 purchased fertilizer samples, almost 25% exhibited some degradation in physical quality characteristics. Using variations in the willingness-to-pay assessment, we establish that farmers hinge their beliefs and decisions on these observables, i.e., farmers use observable characteristics as “signals” of unobservable nutrient content. However, these “signals” have no correlation between how a fertilizer looks and its unobservable nutrient content in our set of 636 fertilizer samples representing the market.

The poor mapping between observed and unobserved quality characteristics in mineral fertilizer and farmer reliance on physical characteristics to infer quality presents a special policy challenge – especially in regions where supply chains lack resources for adequate storage, training, and transport essential to preserving physical quality. Our results suggest that visual quality degradation from problems in manufacturing or poor supply chain management may be at least as important as adulteration in these markets because it deters small farmers from purchasing fertilizer with good nutrient quality and that policies that work to solve nutrient quality problems without attention to observable fertilizer characteristics, especially those resulting from poor storage and supply-chain logistics, could have limited effect.

In sum, we find strong evidence of the presence of adverse selection in the fertilizer market, impacting both average quality of the available product and farmers’ willingness-to-pay. In addition, we find that farmers make incorrect inferences about the quality of the fertilizer based on observable characteristics. When presented with information about the quality, farmers frequently revise their beliefs and willingness-to-pay. Though this response suggests that labeling or other quality certification could help, it is not clear that Tanzania currently has the regulatory capacity and authority to implement and enforce quality certification; we discuss such possibilities in the paper’s conclusion. For such a strategy to succeed, it may be necessary for initiatives to come from NGOs or the private sector.

In the next section, we provide some background on the Tanzanian fertilizer market. The third section
provides an overview of the data collected. We present the empirical analysis and results in Section 4. In Section 5 we discuss mineral fertilizer prices and we conclude with some reflections for policy and further research.

2 Setting and data

2.1 Fertilizer markets in Tanzania

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 mineral fertilizer is extremely low. While the official government recommendation for one acre of maize production is 50 kg of Urea and 50 kg of Di Ammonium Phosphate (DAP), farmers on average apply fewer than nine kilograms of mineral fertilizer per acre (Tanzania Fertilizer Assessment 2012).

In 2010, Urea and Di Ammonium Phosphate (DAP) accounted for half of the fertilizer used in Tanzania in 2010 with nitrogen-Phosphorous-Potassium fertilizer (NPK) consisting of about 20 percent and calcium ammonium nitrate (CAN) nine percent (IFDC 2012). Nearly all mineral fertilizer in Tanzania is imported to the port in Dar es Salaam. Mineral fertilizer quality is only minimally monitored. The Fertilizer Act of 2009 established the Tanzania Fertilizer Regulatory Authority to enforce policies related to fertilizer manufacturing, importation, and use of mineral fertilizer but a 2017 report by the African Fertilizer and Agribusiness Partnership (AFAP 2017) noted that (p. 11):

“TRFA 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.”

Upon arrival at the port, the mineral 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. 2013). From Dar es Salaam, mineral fertilizer begins its trip inland, passing through the hands of multiple wholesalers and agro-dealers before reaching rural farmers. Large companies either sell to intermediate wholesalers or transport the fertilizer inland themselves to storage depots used to supply
the large number of retailers selling agricultural inputs (referred to henceforth as agro-dealers). These small retailers 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.

Morogoro is an agricultural region of Tanzania with a reasonably developed market system. The region’s mineral fertilizer sales market is geographically disperse, reaching far out into rural areas along major roads, but locally concentrated, 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 mineral fertilizer. Of these, 54 had only one agro-dealer selling mineral fertilizer, 23 had two agro-dealer locations, 11 had three, and 14 had four or more. The mean within-market center Herfindahl index is 0.75 (0.25 is considered a high market concentration threshold); for the subsample of market centers with more than one agro-dealer, the mean Herfindahl index is slightly lower, 0.63. 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 be located along the road in clusters with other village shops. It is uncommon for dealers to be located in isolated areas that are away from major roads or other shops and businesses.

3 Data collected

Between November 2015 and May 2016, we collected data from 225 agro-dealers in the Morogoro region of Tanzania and a sample of 164 farmers in the same region. We collected qualitative and quantitative data from these dealers and farmers using surveys, including information on prices, beliefs, and willingness-to-pay; laboratory tests of sampled fertilizer provided information on fertilizer quality. We first introduce the samples and then discuss these various data collections in turn.

3.1 Agro-dealer sample

We used a census to identify all agro-dealers with operations in the Morogoro Region and then proceeded to survey these 225 agro-dealers. Previous to our work, to our knowledge no census had been conducted of the number of fertilizer retailers operating in Morogoro or Tanzania as a whole. The 2009 Fertilizers act requires that all fertilizer dealers and sales locations must be registered with the government but few of the dealers 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 dealers operating in the region.
transport facilities, participation in government programs, wholesalers where the shop sourced mineral fertilizer, types of fertilizer stocked and in which months, and terms of shop transactions (financing, transport) when purchasing and selling mineral fertilizer. We also collected the geographic coordinates of all shops. Figure 1 presents the locations of the 225 input dealer shops located in Morogoro Region, Tanzania.

![Figure 1](image.png)

Figure 1: Circles indicate locations of all agro-dealers surveyed and sampled in Morogoro Region in the research. Circle indicates area in which sampled farmers are located.

Table 1 presents descriptive statistics for the agro-dealers (Panel A). About one quarter of agro-dealers reported sourcing their fertilizer direct from a wholesaler in Dar es Salaam. Agro-dealers operated businesses in clusters of other agro-dealers, with an average of 2.22 agro-dealers per market location in the sample. Finally, agro-dealers tend to source mineral fertilizer from between one and two suppliers.

An enumerator operating as a mystery shopper 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.

 Enumerator mystery shoppers purchased a total of 636 samples of Urea, DAP, and CAN mineral fertilizer. We present the results of the laboratory analysis of these samples in a subsequent sub-section. When purchasing the samples, we also recorded information on features of the transaction such as whether the seller was the owner of the establishment, the price, the brand, whether the fertilizer was scooped from an open bag (and if so whether it was agitated before scooped) or repackaged previously by the seller, whether the transaction (the fertilizer scooping) occurred in front of the enumerator.

### 3.2 Farmer sample

The farmer survey was conducted in Mvomero District, Morogoro Region. The red circle in on the map in Figure 1 indicates the location of the farmer sample. We worked with the International Institute of Tropical Agriculture (IITA)’s Africa RISING initiative to select the sample and conduct the survey. Farmers were purposively selected to have had prior experience purchasing and applying mineral fertilizer to their crops as we wanted farmers experienced with fertilizer and we wanted to collect a sample of fertilizer from all farmer participants in the WTP exercise. We worked with the International Institute of Tropical Agriculture (IITA)’s Africa RISING initiative to identify 12 villages where farmers were known to use mineral fertilizer. All farmers were invited to participate within these villages. In total, we surveyed 164 maize and rice farmers in 12 selected villages in Mvomero district. We collected data on farmer demographics, crops grown, previous experience purchasing and using mineral 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. In addition, we completed a WTP and quality assessment exercise. We return to the latter below.

Farmers also provided the researchers with a small (0.25 kg) sample to the research team of mineral fertilizer from their home and answered questions about the source and use of that fertilizer.\(^5\) The

\(^5\)On the day of the survey, the research team arrived earlier than the agreed-upon time. This ensured that the team
objective of collecting these samples from the farmers was to compare the quality of the fertilizer we purchased from agro-dealers with the quality of mineral fertilizer that farmers bought themselves. We discuss the lab analysis of the mineral fertilizer samples acquired from farmers and agro-dealers below.

### 3.3 Mineral Fertilizer Sample Testing

We collected a total of 636 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 mineral fertilizer samples. A randomly selected subsample of the fertilizer was sent to Thornton Labs in the United States. The correlation coefficient between the nitrogen content of the 59 samples tested at both ICRAF and Thorton is 0.97.

Samples were tested for the degree to which they deviated from what is known as their mineral fertilizer grade – the guaranteed content of nutrients. 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.

### 3.4 Mineral Fertilizer Observable Quality Characteristics

Poor manufacturing, storage, and logistics can impact a second mineral fertilizer quality dimension that has received less attention in the literature than nutrient content: the observable physical characteristics. Photographs were taken of all samples on the day of purchase and were used to visually code observable

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6ICRAF, 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 fluorescence (pXRF) spectroscopy. In general, spectroscopy measures the quantities of chemical elements (i.e., nitrogen), by analyzing how infrared radiation responds to physical matter (i.e., fertilizer). Although spectroscopy is used widely in many fields, ICRAF has been a world leader in developing and utilizing these technologies for agricultural applications.

7Thornton Labs used the traditional Kjeldahl wet chemistry method for sample analysis.

8International standards specify maximum moisture content by weight, nutrient content by weight, particle size, and packing guidelines.
quality characteristics: caking and clumping, discoloration, presence of foreign material (ex: dirt, grass, maize grains, stones), and powdered granules. Because photographs were taken the day of purchase, observable characteristics were not impacted by transport or storage. Two independent coders completed visual coding. Presence of any single or combination of these physical characteristics is evidence of problems in manufacturing, storage, transport, or handling.

- **Mineral fertilizer clumping** occurs when the fertilizer is 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).

- **Mineral fertilizer can become discolored** when the fertilizer is exposed to moisture or high humidity. In the case of DAP and CAN, this exposure discernibly darkens the color of the mineral fertilizer and can produce an oily film that can secrete through the packaging, leaving a residue on the outside of the bag.

- **Mineral fertilizer can include foreign material** such as dirt, sand, insects, or grains of maize. While deliberate adulteration can be one source of the presence of foreign material, more incidental cases result from the way that mineral fertilizer is imported and prepared for wholesalers and retailers in Tanzania.9

- **Mineral fertilizer powdering** is a result of the breaking of the small aggregate prills into smaller, powdery fragments due to poor handling and storage. Fertilizer that contains powdered or dust particles can be difficult to apply and hazardous to work with (Rutland and Polo 2015). The powder is highly hydroscopic and likely to quickly absorb water in humid conditions.

Physical quality characteristics are discussed in agro-dealer technical training manuals (Rutland and Polo 2015) and fertilizer standards and analysis manuals (Sanabria et al. 2013, Yara 2012), yet scant literature considers the relationship between physical and unobserved quality (specifically, nutrient content).11

9While at port, the fertilizer is often exposed to humidity and high temperatures, as well as sand, dust, and dirt. Mineral fertilizer sold by agrodealers 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.

10IFDC agro-dealer training manuals mention the importance of a range of physical characteristics 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)

11One explanation for the lack of literature may be the fact that that few quality problems exist now in industrial countries but it is surprising that few papers have considered these issues in developing countries.
While nutrient quality – specifically fertilizer missing nutrients – can result from either manufacturing impurities or adulteration by wholesalers or agro-dealers, degradation of observable quality generally results from poor supply chain management and logistics problems: poor handling at port, poor transport conditions, storage, exposure to high temperatures and humidity (Sanabria et al. 2013; Rutland and Polo 2015). These observable quality characteristics can affect profitability of fertilizer use on the margin. For example, a farmer must break up any clumps before applying the fertilizer lest it burn his crops and powdered fertilizer can be difficult to apply and can result in losses during handling or storage.

3.5 Eliciting Willingness-to-Pay

We assessed 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 – asking farmers how much they are willing to pay for a particular good or service is a common method to establish demand in developing country contexts (see, among others, Matuschke et al. 2007 and Vargas et al. 2013).

We showed farmers three samples of Urea fertilizer that we had previously purchased from agro-dealers in the Morogoro region and which had been lab-tested for nutrient content. All samples were of nutrient and moisture content that met international fertilizer standards and can therefore be considered good quality. However, the three samples differed strongly in terms of their physical characteristics. Figure 2 presents pictures of the three samples: Sample A was of good appearance (bright white and clean with no clumps or foreign material present); Sample B included large hard clumps and discoloration; and Sample C included the presence of foreign material; the fertilizer in Sample C appeared to have been mixed with darkly colored pebbles or prills of another kind of fertilizer).

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

1. First, farmers were provided with the samples to inspect as they wished. Farmers were asked to assess the quality and to report their willingness to pay for 1 kg of Urea of equivalent quality for each of the three samples. 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, Coursey et al. 1999).

12Farmers were permitted to respond with a WTP of zero shillings. In estimations, we drop any farmer that responded
Figure 2: Pictures of samples shown to farmers for the WTP assessment. Sample A represented. All three 1 kg samples of Urea were purchased as shown by the research team in the market. All three samples were tested by Thornton Labs in the United States and were found to contain 46% N. Sample A was clean with no clumps; Sample B included two large, hard clumps; and Sample C included the presence of foreign material mixed in the Urea.

For each sample, the enumerator asked the farmer:

Assume that you need to buy 1 kilogram of Urea, you have the funds you need to purchase it, and the quality of the Urea is the same as this sample. What is the highest price you would be willing to pay for the 1 kilogram of Urea?

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 is worth to the farmer.

2. Second, the enumerator presented farmers with test results on the nitrogen content of each of the three Urea samples. The following script was used for each sample:

Now, I would like to provide you with information on the nutrient and moisture content of these fertilizer samples. Fertilizers, including Urea, have nutrient and moisture standards that ensure that the fertilizer will improve soil fertility and help the crops to grow. For example, in Urea, the most important element is nitrogen and samples of Urea should contain 46% nitrogen. Also, Urea should not have moisture content greater than 1%.

We tested the nutrient and moisture content of these Urea samples to ensure that they meet industry and national standards. We tested the fertilizer samples at a laboratory in Florida, USA. This particular laboratory tests the nutrient and moisture content of fertilizers for farmers and agricultural companies in the United States. We have the results of those tests and would like to share them with you.
This sample has a nitrogen content of 46% and a moisture content less than 1%. According to the results from the laboratory, this sample meets industry standards and when applied correctly, will improve soil fertility and help crops grow.

3. Finally, the farmer was asked to rate the quality and report his (post-information) willingness to pay.

Enumerators reported that questions, despite being hypothetically framed, were well understood by the farmers, all of whom were literate and had experience purchasing fertilizer from the market. On average, farmers in the sample had at least completed primary school; only one percent of the farmers reported no schooling. Showing the actual samples of Urea to the farmer to inspect as he saw fit added a measure of realism to the exercise, partly compensating for the hypothetical nature of the assessment. Some farmers touched the fertilizer, others placed a small amount on their tongues. Urea is a familiar, commonly used fertilizer in the region.

Urea fertilizer is a private good available in local markets, and hence the local market price plus or minus farmer transaction costs should serve as an upward bound on the WTP. In fact we find that this is the case: less than three percent (15 out of 494 responses to the pre-information WTP) of farmers’ reported WTP exceed the highest per kg market price for mineral fertilizer we observed in markets (and this comparison is made without factoring in transactions and transport costs for farmers). 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 certified by an independent third party (here, a research team using a US lab).

All farmers were asked to report WTP for sample A, followed by the WTP of sample B and then WTP for sample C; the question order was not randomized across farmers. We recognize that order effects might be a concern, and farmers may 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 2005) and cases without any evidence of order effects (as in Alpizar et al. 2010, Harrison et al. 2005). In the analysis, we will focus on differences in WTP between farmers and samples, which avoids some of the primary concerns associated with order effects.

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 clumps and the same amount of foreign material. Hence, selling the fertilizer to one particular farmer would have prevented us from using the same product in the next village.

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 Hold and Laury 2002) while others have found no such discrepancies (Binswanger 1980). Kahneman and Tversky (1979) argued that “the subjects have no special reason to disguise their true preferences” (p. 265) in hypothetical elicitations and Beattie and Loomes (1997, pp 165) conclude “the absence or presence of financial incentives is not a crucial factor in encouraging or discouraging violations of standard axioms in pairwise risky choice problems”. Less evidence is available for the elicitation of WTP of agricultural technologies in developing country contexts. Our exercise was explicitly framed as a fertilizer-buying scenario with experienced fertilizer purchasers, and respondents expressed and displayed little trouble imagining how they would react.

4 Analysis and Results

We first present evidence from the laboratory tests. We tested all samples for nutrient content and also documented their observable characteristics. We then proceed with a review of some of the qualitative evidence documenting the beliefs of both dealers and farmers, and then analyze the farmers’ beliefs using the willingness-to-pay exercise. We conclude with an analysis of the relationship between nutrient content and physical quality characteristics.

4.1 Nitrogen Content

According to results from the laboratory tests, 91.4% of the 636 agro-dealer samples have nitrogen contents less than their advertised nitrogen level and 98% of the farmer 187 samples are similarly missing nitrogen. On average, ten percent of the nitrogen is missing from Urea, eight percent from DAP, and five percent from CAN (see Table 2). Figure 3 presents a histogram of the fractional deviation in nitrogen\(^{13}\) for the 636 agro-dealer mineral fertilizer samples.

\(^{13}\)For each type of mineral fertilizer, the standardized nitrogen content was calculated as follows: the nitrogen content standard was subtracted from the measured nitrogen content. The difference was divided by the nitrogen content standard, resulting in the standardized nitrogen content. A negative figure represents a nitrogen deficiency, whereas zero represents adequate nitrogen content relative to the manufacturing standard.
Our results provide evidence that farmers are paying for mineral fertilizer that does not on average meet the national, international, and industry standard for nitrogen content. Missing nitrogen has consequences for the agronomic effects of mineral fertilizer applied, lowering yields (Cerrato and Blackmer, 1990) as well as farmer revenues and profits. Mather et al. (2016) calculate a linear maize-nitrogen response rate for Tanzania of 7.6 kilograms of maize per kilogram of nitrogen applied; a ten percent nitrogen loss from the input means a ten percent loss in production. The nitrogen response rate at the Tanzanian government’s agricultural research centers is considerably higher: nearly 20 kilograms of maize per kilogram of nitrogen applied, a rate similar to other parts of East Africa (Mather et al. 2016, Snapp et al. 2014). A higher nitrogen response rate would imply higher foregone farmer revenues and profits due to the application of compromised fertilizer, all else equal.

4.2 Observable Quality Characteristics

In addition to measured nutrient deficiencies, about one quarter of the mineral fertilizer samples had observable quality issues such as caking or clumping, discoloration, powdering, or the presence of foreign material. Table 3 presents the prevalence of poor visual characteristics across the mineral fertilizer samples collected from farmers and agro-dealers. Caking was observed in 15% of farmer samples and 28%
of samples obtained from agro-dealers; approximately 8% of all samples contained powdered granules.

Farmers are attentive to the observable characteristics of mineral fertilizer. Table 4 describes farmers’ previous experience with adulterated, expired, low nutrient content, and caked mineral fertilizer. More than half of the respondents reported having purchased caked mineral fertilizer before and 82% reported knowing someone who had purchased caked fertilizer.

Physical quality problems can have associated costs for farmers independent of inferred implications about nutrient content or agronomic efficacy. 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. Some severe physical quality problems can result in direct losses to farmers. For example, Approximately 30% of surveyed farmers reported that they will not apply large clumps of mineral fertilizer to their crops, instead disposing of the product.14

4.3 Qualitative Evidence: Agro-dealers

Evidence from agro-dealers suggests that dealers know more about the quality of the fertilizer they sell than farmers. Table 5 presents dealer responses to the question of how he or she identifies high quality fertilizer. The dealers responded with respect to the mineral fertilizer that they purchase for sale from their own suppliers and were permitted to choose multiple responses. Dealers report using physical characteristics of the bag such as the labeling and weight as well as relational factors such as their trust in their own supplier and in the brand. Dealers also responded to open-ended questions about how they assess fertilizer quality and how they ensure that the fertilizer that they purchase for their store is of good quality. Numerous dealers mentioned paying attention to the printed expiration dates, the weight of bags (bags short weight considered a sign of adulteration), condition of the bags (whether it had been double-sewn, indicating that it had been previously opened, whether the bag had a hard plastic inner liner intact with official stamps), as well as their relationship with their own supplier and observations of the storage conditions used by their suppliers.

Dealers report testing the fertilizers that they sell on their own fields and small demonstration plots and explain that they rely on aggregated feedback from their farmer customers to assess the quality of the products they sell. “I depend on farmers to provide information about the performance of the fertilizer on their fields,” one dealer noted. A second reported, “my clients have never complained about the fertilizer I

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14Nearly a third of respondents indicated that they will break the clumps with their hand, another third indicated they will use a tool, and the final third of respondents indicated that they will use some combination of the two to break the caked clumps. Fifteen percent of farmers indicated that they will break the clumps down to the size of a bottle cap, whereas 38% will break the clumps to the size of a grain of maize and then apply the mineral fertilizer.
sell to them”; and another: “if you sell a quality fertilizer you will see that customers come to congratulate you and if they don’t you will notice.” Customers provide details on specific manufacturers that dealers report attending to: “three years ago we bought fertilizer and most of the customers said that it was not clean. Then we stopped ordering from them because we don’t trust them.”

Despite dealers’ self-reported attention to the packaging and characteristics of the mineral fertilizer that they source and the dealers that they source from, they reported having purchased fertilizer with both physical and nutrient quality problems in the past: 34% report having purchased mineral fertilizer that was past its expiration date, 58% report having purchased caked fertilizer and 21% report having purchased mineral fertilizer that had been adulterated.

4.4 Are Local Level Agro-dealers Adulterating?

An additional reason that local agro-dealers may have asymmetric information: our analysis suggests that they may be the source of nutrient quality problems in the supply chain.

No analysis of mineral fertilizer quality has yet attempted to determine the source of the problem of nutrient quality in Sub-Saharan Africa’s supply chains; the focus so far has been on documenting the existence of a problem (Bold et al. 2017). Is compromised mineral fertilizer entering the country at the port and then making its way through supply chains to farmers? Is the problem one of intermediary wholesalers adulterating and selling to retailers? Or is it the last link in the chain: small shops adulterating and selling compromised fertilizer to farmers? Understanding the source of the problem is critical for policy.

Our evidence does not support the hypothesis that all mineral fertilizer imported into Tanzania is of substandard quality in terms of nitrogen content. In fact, mineral fertilizer sold in local shops sometimes does meet quality standards: fifteen percent of the samples we collected and tested in 2016 have a fractional deviation from the manufacturer standard of less than 2%.15 However, on average, quality is a problem: the mean nitrogen content of the Urea samples based on lab analysis is 35.68%, well below the manufacturer standard for Urea of 46% nitrogen; the standard deviation is 9.81.

We find that information about which agro-dealer sold a sample of mineral fertilizer is the single most predictive factor of the fertilizer’s nitrogen content, even after controlling for other observable factors. Table 7 presents an analysis of the nitrogen content of the 636 purchased samples, regressing the fractional deviation in nitrogen on the physical quality characteristics of the mineral fertilizer. Column (2) adds

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15We purchased 636 samples of mineral fertilizer from 225 agro-dealers in Tanzania’s Morogoro Region. We purchased multiple samples of fertilizer from 185 of the 225 agro-dealers.
a fixed effect for the market location (village) where the fertilizer was purchased and Column (3) adds a fixed effect for the agro-dealer. Inclusion of the agro-dealer fixed effect dramatically increases the explanatory power of the regression (based on the R-squared).

Similarly, comparison of the intraclass correlation coefficients (ICC) for nitrogen content of mineral fertilizer by agro-dealer versus by market location provides further evidence that the problem is at the level of the retailer and not at the level of the village or market cluster (market clusters include 2.2 agro-dealers on average). The ICC, which quantifies the similarity of a characteristic among observations within a group, is 0.38 for Urea at the level of agro-dealers but 0.00 at the level of the market cluster. Descriptive evidence therefore suggests that the agro-dealers are the source of the problem.

Two possible explanations could explain why some agro-dealers sell fertilizer that is on average worse than other agro-dealers:

1. an agro-dealer might purchase lower quality fertilizer from his or her supplier (which would suggest that problems emerge higher up the supply chain) or

2. an agro-dealer might purchase higher quality fertilizer but then adulterate the product in his or her own shop.\(^\text{16}\)

Our data on the linkages between agro-dealers and their suppliers indicates that agro-dealers are on average purchasing high quality fertilizer but then adulterating the product. We do not find evidence in the data that bad quality mineral fertilizer is associated with agro-dealers purchasing from a subset of suppliers.

Our data includes information about where the 225 surveyed agro-dealers purchased the fertilizer sold in their shops. We therefore link sets of mineral fertilizer samples and their nutrient content to common intermediary suppliers to assess whether particular intermediary suppliers are a source of the problem in the supply chain; whether, for example, the problem might be adulteration at one or several critical choke point suppliers where multiple retail-level agro-dealers source.

Information about the identity of the supplier where the agro-dealer sourced his or her fertilizer does not explain the variation in nitrogen content of the mineral fertilizer samples; the ICC for nitrogen content by sourcing supplier is statistically indistinguishable from zero. If a few bad-acting suppliers are consistently to blame for the presence of low quality fertilizer in the supply chain, then we should see similarity in the nitrogen content of mineral fertilizer across agro-dealers who sourced from that supplier

\(^\text{16}\)Conversations with extension agents and fertilizer industry representatives suggest that while fertilizer’s physical condition can degrade while in the possession of an agro-dealer – poor storage and handling can lead to clumping and powdering for example – the nitrogen content will NOT be affected by this sort of negligence.
(assuming all dealers receive the same quality fertilizer from a common supplier; it could be that suppliers
selectively sell poor quality to particular agro-dealers).\textsuperscript{17} The top panel of Figure 4 presents the mean
and range of the fractional deviation in nitrogen by agro-dealer. The bottom panel depicts the same
information for the intermediary suppliers of those agro-dealers in the top panel. If the hypothesis that
a few suppliers are to blame is true, we should see a different pattern in the lower panel than in the top
panel, with suppliers in the lower panel separating into regimes of significantly different mean nitrogen
content and tighter variance. Instead, we see ranges and variability in means that approximates the top
panel.

4.5 Willingness-to-Pay Assessment

To gain a better understanding of what drives farmer WTP, we regress WTP on physical attributes (clean
sample, sample with impurities and clumped sample), whether or not the farmer received information
about the nutrient quantity (the variable takes the value 0 if the WTP was provided pre or 1 if the WTP
is post information) and farmer characteristics (such as education, wealth etc.)

The intuition behind this empirical strategy is the following: If the farmer is a risk-averse, expected
utility maximizer, and if crop performance (positively) depends on the ‘perceived’ quality of fertilizer
(both a function of the physical attributes and the unobserved nutrient quantity), then both decreasing
the uncertainty regarding nutrient quantity (which is what the provision information does) and increasing
its expected value will increase WTP (which is also what the information does). Inversely, increasing
uncertainty regarding nutrient quality (which is what non-clean sample physical attributes might do) and
decreasing its expected value (again, what the observable attributes of the non-clean sample might do)
will decrease WTP.

Expressed mathematically, define $x_i$ as the yield outcome, $\theta^i$ the true nutrient quantity of sample $i$
and $P^i$ as the physical attributes of sample $i$ - we assume that a larger value of $P^i$ corresponds to a better
looking sample. Then:

$$x_i = x(\theta^i, P^i) + \mu$$ (1)

Where $\mu$ is a random variable with mean 0 and standard deviation $\sigma_\mu$. Assuming a linear and
independent relationship between the two types of qualities, we write:

$$x_i = \alpha \theta^i + \beta P^i + \mu$$ (2)

\textsuperscript{17}All fertilizer was bought over two sampling periods of one-month duration apiece and we bought a range of manufacturer
brands (brand is not predictive of nitrogen content though it is predictive of price).
Figure 4: Bottom panel presents the mean and range of the fractional deviation in nitrogen by agro-dealer (retail-level). The top panel depicts the same information for the intermediary suppliers of those agro-dealers in the top panel.
With both $\alpha > 0$ and $\beta > 0$. In writing expression (2), we allow for $P^i$ to impact the yield, independently of the nutrient quantity (while the impact is likely limited). We assume that the parameters of the model above, $\alpha$ and $\beta$ are known to the farmer. Now, while $P^i$ can directly be observed in our assessment exercise, $\theta^i$ is unknown as it is not directly observable and will be the object of learning. We turn to this learning process next.

Assume that the farmer has a prior belief about $\theta^i$, and that this prior belief is normally distributed with mean $\theta$ and variance $\sigma^2_\theta$. The prior belief is plausibly based on the actual distribution of nutrient quantity in the population: We assume that the prior belief is in fact identical to the actual quality distribution, i.e., the average quality of $\theta^i$ in the population is $\theta$ and the standard deviation of the population distribution is $\sigma_\theta$ (This assumption while it cannot be tested using our data is likely correct: Ashour et al. (2017) show that Ugandan farmers’ beliefs regarding the extent of counterfeiting of herbicide are strongly predictive of measures of the actual prevalence of counterfeiting in local markets).

Note that assuming that the beliefs are identical across our sample implies that any between-farmer divergence in WTP will be due to differences in signals and in personal characteristics (outside options and risk preferences)

In our assessment exercise, the farmer can receive two ‘signals’ of the nutrient quantity $\theta^i$. The first signal, which is the one provided by the research team, is an unbiased signal, $s^i$, of nutrient quantity. This signal is drawn from a normal distribution with mean $\theta^i$ (i.e. hence the signal is unbiased) and variance $\sigma^2_\varepsilon$:

$$s^i = \theta^i + \epsilon^i, \quad \epsilon^i \sim N(0, \sigma^2_\epsilon) \tag{3}$$

The signal errors $\epsilon^i$ are assumed uncorrelated across farmers. Note that $\sigma^2_\epsilon$ in a way measures the credibility of the information, and in the extreme, this variance can be zero, that is, if the information from the research team is taken at face value. So far, the setup above corresponds to a standard Bayesian learning model with normal priors and signals. It can be shown in such a model that the variance of the farmers’ belief distribution decreases, in effect can collapse into $\theta^i$ as $\sigma^2_\epsilon$ decreases (see, for instance, Chamley (2003)). Formally, the distribution is updated from $N(\theta, \sigma_\theta)$ to $N(\theta_{post}, \sigma_{post})$ with:

$$\sigma_{post} = \frac{\sigma_\theta \sigma^2_\varepsilon}{\sigma_\theta + \sigma^2_\varepsilon} \tag{4}$$

$$\theta_{post} = \frac{\sigma_{post}}{\sigma_\varepsilon} s^i + [1 - \frac{\sigma_{post}}{\sigma_\varepsilon}] \theta \tag{5}$$
The second ‘signal’ is the observation of the physical attributes \( P^i \) We add parenthesis, as this ‘signal’ as we will demonstrate later in the next subsection is not an unbiased signal, in effect, in the population, this signal is uninformative, as it has no relationship with the underlying nutrient quantity. However, from the farmer’s point of view, \( P^i \) might be correlated with \( x_i \) for two reasons: (i) farmers might increase labor investment on plots which received fertilizers with strong physical attributes, thereby creating an, on average, positive relationship between yield outcomes and physical attributes, which the farmer incorrectly attributes to nutrient quantity, and (ii) as noted earlier, to a certain degree, the physical attributes themselves can also marginally affect yield (they matter less though than the nutrient quantity), and the farmer might incorrectly attribute these correlations again to the nutrient quantity.

To summarize, the expected yield outcome \( E[x_i] \) is:

\[
E[x_i] = \alpha E[\theta^i|s^i, P^i] + \beta P^i
\]

And the variance of the yield outcome \( Var[x_i] \) is:

\[
Var[x_i] = \alpha^2 Var[\theta^i|s^i, P^i] + \sigma_\mu
\]

The farmer states his or her WTP on the basis of these beliefs. Assuming a risk-averse, expected utility maximizing farmer, we can define WTP as \(^{18}\):

\[
u(w + \text{outside}) = \int u(w - \text{WTP} + x_i) dF(x_i)
\]

where \( w = \) initial wealth and \( \text{outside} = \) outside option (i.e. not using fertilizer). We further assume that the utility function is increasing in wealth, and concave, reflecting risk aversion, i.e., \( u'(\cdot) > 0, u''(\cdot) < 0 \).

To ensure tractability, let us assume now that instead of an Expected Utility maximizer, the farmer maximizes the following linear mean-variance utility function:\(^{19}\)

\[
u(w + \text{outside}) = E[w - \text{WTP} + x_i] - \phi Var[w - \text{WTP} + x_i]
\]

Writing out the expectation/variance operators yields:

\[
u(w + \text{outside}) = w - \text{WTP} + E[x_i] - \phi Var[x_i]
\]

\(^{18}\)Note that we normalise the output price to one and ignore other farming costs.

\(^{19}\)Again, we normalize the output price to one and ignore other farming costs.
Now, plug in equations (6) and (7) yields:

\[ u(w + \text{outside}) = w - WTP + \alpha E[\theta^i|s^i, P^i] + \beta P^i - \phi[\alpha^2 Var[\theta^i|s^i, P^i] + \sigma_\mu] \]  \tag{11}

And rewrite as:

\[ WTP_u = \text{outside} + \alpha E[\theta^i|s^i, P^i] + \beta P^i - \phi[\alpha^2 Var[\theta^i|s^i, P^i] + \sigma_\mu] \]  \tag{12}

We take the partial derivatives with respect to \( s^i \) and \( P^i \) to obtain:

\[ \frac{\partial WTP}{\partial s^i} = \alpha \frac{\partial E[\theta^i|s^i, P^i]}{\partial s^i} - \phi\alpha^2 \frac{\partial Var[\theta^i|s^i, P^i]}{\partial s^i} \]  \tag{13}

\[ \frac{\partial WTP}{\partial P^i} = \alpha \frac{\partial E[\theta^i|s^i, P^i]}{\partial P^i} + \beta - \phi\alpha^2 \frac{\partial Var[\theta^i|s^i, P^i]}{\partial P^i} \]  \tag{14}

Note that the partial derivative with respect to \( s^i \) consists of two terms. Recall that we had assumed that \( \alpha > 0 \). The first term (\( \alpha \frac{\partial E[\theta^i|s^i, P^i]}{\partial s^i} \)) is therefore positive, as is the second term, i.e., \( \frac{\partial Var[\theta^i|s^i, P^i]}{\partial s^i} \) is negative - in effect, Bayesian learning implies that any signal would decrease the variance of one’s posterior beliefs. The second partial derivative, with respect to \( P^i \) consists of three terms. Recall that we had assumed that \( \beta > 0 \). The other two terms can be both negative as well as positive, depending on how the farmer constructs a link between physical condition and quality. For most farmers, we would expect the first term to be positive, so unless the third term outweighs the first two terms, the overall sign of this derivative would be positive.

In Table 6, we approximate the WTP function using a linear model.\(^{20}\) We present the results of the willingness-to-pay, henceforward WTP, assessment. Column (1) regresses the WTP on the sample dummies and a post-information indicator; Column (2) adds a farmer fixed effect (each farmer completed six assessments, three before and three after the information was provided). Sample A is the pristine, white Urea; Sample B included several large, hard clumps; Sample C included the presence of dark-colored foreign material, perhaps small stones or another fertilizer like DAP. 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 Tanzanian Shillings (TS).

Analysis of the willingness-to-pay assessment yields three important insights. First, farmer willingness-to-pay...
to-pay for perfect quality fertilizer (both nitrogen content and characteristics of the physical condition, such as clumping) exceeds the market price. Farmers’ mean pre-information WTP for Sample A, the sample in good physical condition, is 1,502 shillings, approximating the prevailing market price in the region at the time. After receiving information about the lab-tested nutrient quality of the Urea, farmers’ mean price for the good condition Urea increases 47% to 2,215 shillings, well exceeding the market price of 1,500 shillings. The post-information WTP on Sample A provides a counterfactual – what farmers in our sample would pay for mineral fertilizer without uncertainty about nitrogen content.

Second, the WTP for all three samples responds to information on (unobservable) nitrogen content. Credible information works. Farmers’ WTP increases significantly for all three samples after farmers are provided the lab results showing that each has a nutrient content meeting the commercial standard for Urea: 46% nitrogen. Post-information WTP increases for Sample B (clumps) and Sample C (presence of foreign material) are approximately 1000 shillings; post-information WTP for these samples with physical quality problems are more than double the pre-information values and, post-information, exceed the prevailing market price for Urea.

Finally, the assessment establishes that farmers’ willingness-to-pay for mineral fertilizer responds to the physical condition of the fertilizer. Farmers seem to use physical characteristics as a signal of what they cannot observe. Prior to the provision of the lab tests on nitrogen content, farmers discounted Sample B (caking) and Sample C (foreign material) relative to Sample A (good appearance) by 763 and 806 shillings, respectively. These discounts represent approximately half of the average market price for one kilo of Urea in the region at the time. Even post-information, however, farmers continue to report a lower willingness-to-pay for the samples with bad observable characteristics relative to pristine Sample A. Farmers may care about the physical condition both as a signal of unobservable nutrient (nitrogen) quality and as a separate quality dimension related to ease of application and storage; hence, resolving uncertainty around unobserved quality obviously does not fully resolve the physical condition quality problems and post-information WTP is still below that of Sample A. One reason: mineral fertilizer with poor physical characteristics can imply additional costs for application. Pre-information willingness-to-pay 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; for example, farmers having to break up the clumps or sift through the adulterated mineral fertilizer to eliminate unwanted foreign material. Our post-information WTP estimates help decompose these costs; what remains after the uncertainty is resolved can be interpreted in lost time and resources from physical quality problems – including the costs of lost fertilizer if the clumps are discarded. Nearly
a third of the respondents reported that they would not apply caked or clumped fertilizer to their crops at all.

Analysis of the willingness to pay assessments provides evidence that farmers make inferences about nitrogen content from the physical condition, attributes which are often observable at the time of purchase. This makes good intuitive sense, but are farmers correct to infer unobservable quality from observable characteristics? In the next sub-section, we further investigate whether these physical observable quality characteristics are informative to farmers.

4.6 Relationship between nitrogen content and physical condition

To assess the relationship between mineral fertilizer physical condition, characteristics that are often observable at the time of transaction, and nitrogen content, we regress the fractional deviation in nitrogen on the four physical attributes for all mineral fertilizer samples purchased from agro-dealers. Table 7 presents the results. In short, the observed properties of the mineral fertilizer exhibit no relationship with the nitrogen quantity.\(^{21}\) That is, physical quality can exhibit degradation without underlying degradation in the nutrient content (and vice versa). Column (2) adds market location fixed effects (multiple agro-dealers per market location) and Column (3) adds an agro-dealer fixed effect.\(^{22}\)

We find evidence of nutrient problems in mineral fertilizer as well as problems with observable quality characteristics, but we find that observable characteristics do not help farmers identify the nutrient-deficient fertilizers, despite the fact that they use these observables as a signal of quality.

Are farmers incorrect to use physical condition as a sign of nutrient content? While the physical condition signal for unobserved nitrogen appears incorrect, it may be correct from the farmer’s point of view for at least two reasons. First, farmers may respond to poor looking fertilizer and reduce complementary inputs such as labor in the presence of, for example, clumpy or discolored fertilizer, resulting in lower yields. Second, some observables can affect yield – large clumps can burn crops if they are not broken up for example – and farmers may attribute these yield effects of these two channels to the nitrogen rather than to the physical properties of the fertilizer.

\(^{21}\) An IFDC study of fertilizer quality in West Africa found caking to be correlated with low nutrient content in a particular blend of NPK (Sanabria et al. 2013).

\(^{22}\) As a check, we also analyze the relationship between the measured moisture content of the samples and observed quality characteristics; moisture content is directly related to caking and clumping 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 clumping 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.
5 Discussion: mineral fertilizer prices

We have found that that farmer WTP responds to physical characteristics of the fertilizer, even though these characteristics appear uncorrelated with the nitrogen content. Given that farmers appear to respond strongly to the physical condition of fertilizer, we hypothesize that the fertilizer market price should relate to this physical condition. Table 8 presents the results of a regression of the per kilogram price of mineral fertilizer on the fractional nitrogen deviation as well as the coded physical properties of each fertilizer sample (clumping, discoloration, powdering, presence of foreign material. The sample is all fertilizer purchased from agro-dealers. As expected, we find no statistically significant relationship between the price and the nitrogen content. Somewhat more surprising, neither can we discover any significant relationship between physical condition and price. The high R squared reflects the high degree of price variation explained by the market location fixed effect. Column (2) of Table 8 adds features of the transaction, seller, and location that might be observable to the farmer at the time of the transaction. Fertilizer purchased from open bags in one or two-kilogram quantities are significantly more expensive than fertilizer purchased in 50 or 25 kg bags, evidence of quantity discounting. Few other characteristics of the business associated with formality seem associated with lower prices across markets with one exception: shops that have been in operation longer have lower per kg prices for mineral fertilizer, on average.

In fact, overall we observe little variation in market prices for mineral fertilizer, both within and across market centers. For example, in 58% of the market centers where we purchased Urea from multiple dealers on the same day, we find no price variation across dealers – all prices are the same (40/68 market centers).

Our results on price, in particular the lack of a relationship between either nutrient content and price or physical quality characteristics and price, suggest that the market provides agro-dealers with (1) an incentive to adulterate and (2) little incentive to invest in supply chain logistics such as improved storage or handling that could improve the physical characteristics of the fertilizer that they sell.

A back-of-the-envelope calculation suggests the incentives for adulteration. The median number of 50kg bags annually sold by agro-dealers in our sample is 46.5. The prevailing per kilo price of Urea in the region during the time of the assessment was 1500 Tanzanian Shillings (TS); generating median annual revenues for mineral fertilizer of (at September 2017 USD to shilling conversion rate) of approximately USD$1586.25. Margins for mineral fertilizer are on the order of 5-10% (Agricultural Council of Tanzania 2007). This suggests that profits for mineral fertilizer are (generously) $159 at a median sales level. How much might the median seller be gaining in profits by adulterating? Assume that the agro-dealer is
6 Conclusion

Our research in Tanzania provides evidence of a problem with implications for policy and the private sector. We find important percentages of missing nutrients—about 10% on average—from samples of Urea, CAN, and DAP acquired from agricultural input shops and directly from farmers.

Assuming a linear crop response to nitrogen application, the application of mineral fertilizer that is missing nitrogen (that is, containing less nitrogen than the standard crop-nutrient rating) has a direct, negative effect on farmer yields. The average cereal yield per acre for Tanzanian farmers is 697 kilograms (World Bank 2014). Assume a linear nitrogen-yield response rate of 7.5 kilos of maize per kilo of nitrogen (Mather et al. 2016). Missing nitrogen effectively lowers the nitrogen yield response; a farmer will get 6.75 kilos of maize per unit of mineral fertilizer applied when he or she should get 7.5 kilograms. In 2017, maize prices in Tanzania hovered around 60,000 Tanzanian Shillings per 100 kilograms sold (FEWS Net 2017) and the difference in the per kilo net benefit of fertilizer application given a mean per kilogram fertilizer price of 1605 TSh (assuming linear pricing) was approximately 207 TSh. This means, that, on average, farmers net profit for application of a kilo of fertilizer is about 44

Our research makes a distinction with respect to fertilizer quality for the first time: we find widespread evidence of degradation in physical quality characteristics and we find that these physical quality characteristics do not provide information about which mineral fertilizer samples are missing nitrogen. Moreover, we find evidence that farmers are attentive to the physical quality of mineral fertilizer, that they are using physical characteristics to infer unobservable nutrient quality, and that this inference directly impacts their willingness to pay for mineral fertilizer in a way that suggests broader market implications. For example, farmers’ average reported willingness-to-pay for clumpy Urea was well below the market price. We find that farmers’ quality ratings and WTP respond to information about the tested nutrient quality of the fertilizer but assessments of bad-looking samples continue to trail assessments of the good-looking sample.

We find that the nitrogen content is not reflected in price, providing an incentive to adulterate.
Surprisingly, we also find that fertilizer market price does not respond to physical quality characteristics. Though these characteristics are a result of mineral fertilizer storage conditions and handling, agro-dealers currently have little incentive to invest in improvements to their supply chains likely to improve physical quality.

Adverse selection seems to affect this market, reducing the demand of farmers and the quality of fertilizers on the market. We provide evidence that agro-dealers know more than farmers about the nutrient quality of fertilizer being sold in the market and demonstrate that the sale of mineral fertilizer that is missing nitrogen seems to be concentrated at the level of the local agro-dealer, the retailers selling directly to the farmers.

Given evidence of adverse selection and our finding that farmer WTP responds to credible information about unobservable nitrogen content, is nutrient content certification or labeling a viable solution for information problems in this market? Product labeling is common in developed countries, and increasingly used in the developing world as a strategy to bridge the information gap between consumers and producers regarding product contents, product safety and quality, and the production process (child-labor free, organic, GMO free etc.).

Numerous studies have analyzed the effects of labeling on consumers. Results suggest that labeling can effectively inform consumers about product attributes (for an overview see Messer et al. 2017, Spencer and Caswell 1999, Verbeke 2005, Klaus 2005, Costa-Fond et al. 2008). Less attention has been given to the question in developing countries, where regulatory enforcement is weaker. Hoffman et al. (2017) use an RCT in Kenyan markets to study labeling for aflotoxin and find that labeling affects consumer demand in the short term but not in the long term. Similarly, Garrido et al (2017), study the effects of labeling groundnut aflotoxin-free and find little impact on farmers’ behavior, even when the label was associated with a price premium.

Few studies have focused on the effects of labeling agricultural inputs in developing countries, though there is a small literature on labeling information on farm input choice by farmers in the United States (Hasing et al. 2012). Auriol and Schilizzi (2015) propose conditions for the design and funding of certification schemes in developing countries and consider how various options might impact market structure. Ashour et al (2017) present some initial evidence on an e-verification scheme for seeds implemented by USAID in Uganda through a Feed the Future (FTF) initiative.

In general, whether or not certification is useful 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). In the case of Tanzania, our results suggest that farmers are willing to pay a significant amount for quality fertilizer, and that they are willing and able to update their beliefs quickly.

The prospects for mineral fertilizer labeling and credible nutrient content certification in Tanzania are limited at this stage for at least two reasons, however. First, 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 mineral fertilizer are extremely thin and any undertaking that increases the fixed costs of mineral 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.

Labeling could resolve the uncertainty around unobservable nutrient content, improving the quality of fertilizer for sale in the marketplace, and helping farmers to learn not to infer unobservable quality from the physical condition. However, in the absence of credible labeling, we expect that farmers will continue to use observables as a signal of nutrient content. In such a case, solving the missing nitrogen problem is only part of the solution. 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 physical quality characteristics in mineral fertilizer in the market. Our results therefore suggest that capital constraints for small agro-dealers can have direct consequences for agricultural input adoption, agricultural productivity, and farmer investment, all of which of course impact market investment and development: (1) farmers with experience purchasing and applying mineral fertilizer may purchase less fertilizer than they otherwise would and (2) farmers with no previous experience purchasing and applying mineral fertilizer may remain unlikely to adopt the input as part of their soil and farm management practices.

Overall, variable input quality may partially explain the slow uptake of the use of mineral fertilizer in Tanzania. In the long-term, uncertainty regarding fertilizer quality could have widespread consequences for the functioning and growth of mineral fertilizer demand. Such problems could hamper efforts to increase adoption of fertilizer as a means of raising regional agricultural productivity and improving household and national food security. As a result, it is critical for policy to understand not merely the

\[25\text{For example, YARA introduced small one and two kilogram packs of fertilizer to the Tanzanian market for a few years leading up to this research but quickly discontinued them citing the additional cost that maintaining two bagging and supply lines added to their operations.}\]
determinants of quality and quality degradation but also how farmers are assessing mineral fertilizer quality, what attributes they care about, and how they decide whether a purchase has those attributes. Increasing small farmer use of mineral 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 variable quality – both physical characteristics and unobservable – is an important missing piece of the puzzle.
References


### Panel A: Agro-dealers (n=225)

<table>
<thead>
<tr>
<th>Metric</th>
<th>Mean (SD)</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source fertilizer directly from Dar es Salaam (share)</td>
<td>0.27</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance from Dar es Salaam (km)</td>
<td>269.93 (86.84)</td>
<td>127.49</td>
<td>441.24</td>
</tr>
<tr>
<td>Number of agro-dealers per market location</td>
<td>2.22 (2.52)</td>
<td>1</td>
<td>21</td>
</tr>
<tr>
<td>Number of suppliers where agro-dealer sources fertilizer</td>
<td>1.66 (0.93)</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Years in business</td>
<td>4.18 (4.34)</td>
<td>0.1</td>
<td>30</td>
</tr>
</tbody>
</table>

### Panel B: Farmers (n=164)

<table>
<thead>
<tr>
<th>Metric</th>
<th>Mean (SD)</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>45.93 (11.34)</td>
<td>22</td>
<td>79</td>
</tr>
<tr>
<td>Male (share)</td>
<td>0.61</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Land owned (acres)</td>
<td>5.84 (10.50)</td>
<td>0</td>
<td>100</td>
</tr>
</tbody>
</table>

**Table 1: Descriptive Statistics for agro-dealer and farmer samples**
<table>
<thead>
<tr>
<th>Fertilizer Type</th>
<th>Nitrogen Content (Minimum %)</th>
<th>Mean Measured Nitrogen Content (%)</th>
<th>Mean Deviation from Nitrogen Standard (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urea (n=465)</td>
<td>46</td>
<td>34.66 (10.52)</td>
<td>-8.29 (5.47)</td>
</tr>
<tr>
<td>DAP (n=70)</td>
<td>18</td>
<td>16.63 (0.86)</td>
<td>-7.60 (4.77)</td>
</tr>
<tr>
<td>CAN (n=102)</td>
<td>26</td>
<td>24.96 (1.33)</td>
<td>-4.01 (5.13)</td>
</tr>
</tbody>
</table>

**Farmer samples**

<table>
<thead>
<tr>
<th>Fertilizer Type</th>
<th>Nitrogen Content (Minimum %)</th>
<th>Mean Measured Nitrogen Content (%)</th>
<th>Mean Deviation from Nitrogen Standard (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urea (n=126)</td>
<td>46</td>
<td>39.51 (5.26)</td>
<td>-14.22 (11.26)</td>
</tr>
<tr>
<td>DAP (n=33)</td>
<td>18</td>
<td>17.10 (1.82)</td>
<td>-6.92 (3.94)</td>
</tr>
<tr>
<td>CAN (n=4)</td>
<td>26</td>
<td>21.48 (2.77)</td>
<td>-17.37 (10.66)</td>
</tr>
</tbody>
</table>

Table 2. Measured Nitrogen and Moisture Content and Industry Standards by Fertilizer Type. Agro-dealer samples are presented in the top panel and farmer provided samples are presented in the bottom panel.
### Table 3. Prevalence of Poor Visual Characteristics in Fertilizer Samples

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Presence of clumps/caking</td>
<td>27.84</td>
</tr>
<tr>
<td>Discolored</td>
<td>10.38</td>
</tr>
<tr>
<td>Presence of foreign material</td>
<td>4.78</td>
</tr>
<tr>
<td>Presence of powdered granules</td>
<td>7.91</td>
</tr>
</tbody>
</table>

n = 636
<table>
<thead>
<tr>
<th>Issue</th>
<th>Ever had mineral fertilizer with this problem (%)</th>
<th>Ever known someone who has had mineral fertilizer with this problem (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mineral fertilizer can be adulterated</td>
<td>13.94</td>
<td>21.21</td>
</tr>
<tr>
<td>Mineral fertilizer can be expired</td>
<td>29.70</td>
<td>56.97</td>
</tr>
<tr>
<td>Mineral fertilizer can have a nutrient content that is different from what is advertised</td>
<td>20.00</td>
<td>37.58</td>
</tr>
<tr>
<td>Mineral fertilizer can be caked and clumpy from moisture</td>
<td>55.15</td>
<td>82.42</td>
</tr>
<tr>
<td>n</td>
<td>164</td>
<td>164</td>
</tr>
</tbody>
</table>

Table 4. Farmer Experience with Fertilizer Quality and Fertilizer Quality Concerns
<table>
<thead>
<tr>
<th>Share of dealers who report using as a sign of good quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bag weight</td>
</tr>
<tr>
<td>Condition of package</td>
</tr>
<tr>
<td>Labeling on package (expiration date)</td>
</tr>
<tr>
<td>Trust in supplier</td>
</tr>
<tr>
<td>Trust in manufacturer</td>
</tr>
<tr>
<td>n</td>
</tr>
</tbody>
</table>

Table 5. Dealer responses to questions about signs of good quality fertilizer
<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>(1)</th>
<th>(2)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>WTP</td>
<td>WTP</td>
</tr>
<tr>
<td></td>
<td>TZSh</td>
<td>TZSh</td>
</tr>
<tr>
<td>Sample B (clumps)</td>
<td>-763.1***</td>
<td>-737.7***</td>
</tr>
<tr>
<td></td>
<td>(96.80)</td>
<td>(75.58)</td>
</tr>
<tr>
<td>Sample C (foreign material)</td>
<td>-805.7***</td>
<td>-787.5***</td>
</tr>
<tr>
<td></td>
<td>(100.8)</td>
<td>(79.43)</td>
</tr>
<tr>
<td>post information</td>
<td>712.2***</td>
<td>712.2***</td>
</tr>
<tr>
<td></td>
<td>(93.08)</td>
<td>(71.38)</td>
</tr>
<tr>
<td>Sample B * post information</td>
<td>282.5**</td>
<td>282.5***</td>
</tr>
<tr>
<td></td>
<td>(136.9)</td>
<td>(105.0)</td>
</tr>
<tr>
<td>Sample C * post information</td>
<td>252.9*</td>
<td>251.0**</td>
</tr>
<tr>
<td></td>
<td>(142.4)</td>
<td>(109.2)</td>
</tr>
<tr>
<td>Constant</td>
<td>1,502***</td>
<td>1,044**</td>
</tr>
<tr>
<td></td>
<td>(65.82)</td>
<td>(458.4)</td>
</tr>
<tr>
<td>Farmer FE</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>Observations</td>
<td>855</td>
<td>855</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.296</td>
<td>0.666</td>
</tr>
</tbody>
</table>

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 6: Willingness-to-pay assessment; effect of information about unobservable nitrogen content on WTP
<table>
<thead>
<tr>
<th></th>
<th>N fractional dev</th>
<th>N fractional dev</th>
<th>N fractional dev</th>
<th>N fractional dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clumping</td>
<td>-0.000451</td>
<td>7.00e-05</td>
<td>-0.000753</td>
<td>0.000435</td>
</tr>
<tr>
<td></td>
<td>(0.00121)</td>
<td>(0.00135)</td>
<td>(0.00155)</td>
<td>(0.00126)</td>
</tr>
<tr>
<td>Powdering</td>
<td>-0.00173</td>
<td>0.00524</td>
<td>0.00133</td>
<td>0.00362</td>
</tr>
<tr>
<td></td>
<td>(0.00774)</td>
<td>(0.00962)</td>
<td>(0.0106)</td>
<td>(0.00880)</td>
</tr>
<tr>
<td>Discoloration</td>
<td>0.00855</td>
<td>0.00967</td>
<td>0.00646</td>
<td>0.0113</td>
</tr>
<tr>
<td></td>
<td>(0.00839)</td>
<td>(0.0101)</td>
<td>(0.00825)</td>
<td>(0.00739)</td>
</tr>
<tr>
<td>Debris/foreign material</td>
<td>-0.0136</td>
<td>-0.0158</td>
<td>-0.0113</td>
<td>-0.0160</td>
</tr>
<tr>
<td></td>
<td>(0.00989)</td>
<td>(0.0102)</td>
<td>(0.0131)</td>
<td>(0.0119)</td>
</tr>
<tr>
<td>Market location FE</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agrodealer FE</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transaction specific controls</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>-0.0747***</td>
<td>-0.0860***</td>
<td>-0.0898</td>
<td>-0.0397</td>
</tr>
<tr>
<td></td>
<td>(0.00268)</td>
<td>(0.00963)</td>
<td></td>
<td>(0.0300)</td>
</tr>
<tr>
<td>Observations</td>
<td>607</td>
<td>607</td>
<td>607</td>
<td>542</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.0050</td>
<td>0.1330</td>
<td>0.4500</td>
<td>0.059</td>
</tr>
</tbody>
</table>

Robust standard errors in parentheses. Transaction-specific controls include price, month purchase was made, whether the business had an official license, whether the agro-dealer has only seasonal operations, whether the location has a tin roof, the fertilizer brand, and whether the bag was agitated by the seller before it was scooped or sold to the farmer.

*** p<0.01, ** p<0.05, * p<0.1

Table 7: Regression of the fractional deviation of nitrogen from the manufacturer standard on observable mineral fertilizer quality characteristics (agro-dealer samples)
<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>(1) price per kg (TZ Sh)</th>
<th>(2) price per kg (TZ Sh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen (standardized)</td>
<td>-7.007</td>
<td>54.40</td>
</tr>
<tr>
<td>Clumps</td>
<td>8.769</td>
<td>9.693*</td>
</tr>
<tr>
<td>Powdering</td>
<td>-3.713</td>
<td>3.181</td>
</tr>
<tr>
<td>Discoloration</td>
<td>-26.00</td>
<td>-36.48</td>
</tr>
<tr>
<td>Foreign material</td>
<td>34.21</td>
<td>40.80</td>
</tr>
<tr>
<td>Purchase made from open bag</td>
<td>213.8***</td>
<td></td>
</tr>
<tr>
<td>Tagmark certification</td>
<td></td>
<td>40.54</td>
</tr>
<tr>
<td>Visible sign</td>
<td></td>
<td>4.688</td>
</tr>
<tr>
<td>Number of customers present during transaction</td>
<td></td>
<td>0.892</td>
</tr>
<tr>
<td>Seller gender</td>
<td></td>
<td>4.219</td>
</tr>
<tr>
<td>Seller age</td>
<td></td>
<td>2.382</td>
</tr>
<tr>
<td>Seller education (secondary)</td>
<td></td>
<td>31.05</td>
</tr>
<tr>
<td>Seller education (trade school or above)</td>
<td></td>
<td>-3.414</td>
</tr>
<tr>
<td>Years location in operation</td>
<td></td>
<td>-7.380**</td>
</tr>
<tr>
<td>Business sells fertilizer all months of year</td>
<td></td>
<td>78.01</td>
</tr>
<tr>
<td>Market location FE</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Fertilizer type</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Manufacturer controls</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Enumerator FE</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Constant</td>
<td>1,620***</td>
<td>1,229***</td>
</tr>
<tr>
<td>Observations</td>
<td>603</td>
<td>542</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.715</td>
<td>0.754</td>
</tr>
</tbody>
</table>

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 8: Regression of mineral fertilizer price on observable and unobserved quality characteristics and transaction