A Mobile Market for Agricultural Trade in Uganda

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ABSTRACT

Information failures lead agricultural markets to exhibit substantial inefficiencies in developing countries such as Uganda. Trade links between buyers and sellers are created informally by word of mouth and rarely grow beyond established social circles. Various mobile systems have aimed to improve market efficiency, but have been hampered by poor availability of Internet-enabled devices, users' extreme cost sensitivity to network charges, and cultural expectations of face-to-face negotiation. Previous work in this area has thus focused on price advisory systems or classified advertisements, which we argue are not effective. We analyze past price data from the rural agricultural market in Uganda, gauging inefficiency by estimating opportunities for arbitrage by transporting commodities from one city to another and from warehousing nonperishable commodities to resell them later; in both cases, we find striking price imbalances. We describe a novel double auction mechanism that we have designed to be practical given the constraints of SMS-based communication, and argue that it provides market participants with appropriate incentives. We present the results of field trials of the system, which after six months registered more than a thousand farmers and traders across Uganda and received $1.0M USD in bids and $1.7M USD in asks.

Categories and Subject Descriptors

H.4 [**Auction Design**]: Markets, Economics, Algorithms, Information Theory; D.2.8 [**Security**]: Incentives, Reputation—*Reliability*

General Terms

Auction, Design, Markets, Mobile

Keywords

Auction, Markets, Commodities, Developing World, Mobile Devices.

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INTRODUCTION

Agricultural markets in developing countries tend to be inefficient, due largely to poor information flow between buyers and sellers [1]. There have been recent attempts to use technology to create agricultural advisory services, with a particular focus on providing price information to farmers [9]. There have also been attempts to use phones or the Internet to set up markets in the developing world, usually based on classified advertisement listings or single-sided auction markets [6]. In this paper, we consider the constraints for technology deployment in developing-world agricultural markets and conclude that neither of these approaches is sufficient. We argue instead for the introduction of a novel market mechanism better adapted to these constraints—particularly, to the need for interacting with the market via a basic (non-Internet-enabled) phone.

In developing-world agricultural markets—like the one in Uganda—there are three key obstacles to the adoption of new technology for commodity trading. First, there is limited access to Internet-enabled devices: while phone penetration is very high, the majority of handsets are "feature phones" that only offer voice, SMS and USSD functionality. Second, potential users are often extremely price sensitive: the cost of a single SMS message may be significant to many small-scale farmers. Third, many traders are accustomed to a personal or word-of-mouth culture of buying: transactions are normally conducted face to face, or traders are connected to farmers by trusted go-betweens. Despite these challenges, a great deal of trade is conducted rurally. For example, Uganda's agricultural sector, which contributes 24.4% ($12 billion) to GDP annually [3], is dominated by small-scale farmers. Within the last year, new opportunities have been presented by the widespread adoption of mobile services such as mobile money transfer and by high mobile phone penetration.

The structure of the rest of this paper is as follows. We begin by analyzing the current market environment, assessing market efficiency by looking for arbitrage opportunities in historical market data. We also present anecdotal accounts of the shortcomings of the current system of agricultural trade based on interviews with buyers and sellers. We then review existing technological attempts to support this market, and attempt to explain why the impact of these attempts has been limited. Next, we propose a double-auction based market mechanism for this setting, and show that it provides appropriate incentives to buyers and sellers, while being practical under the constraints of SMS-based communication. Finally we present both quantitative and qualitative results of field trials, showing that our system experienced rapid

	Plantain	Maize	Beans
First quartile	-16.0	2.6	2.1
Median	13.0	22.6	14.0
Third quartile	30.1	36.2	28.5
Maximum	51.0	58.0	52.0

Table 1: Percentage return on investment (ROI) figures for spatial arbitrage on three different staple crops in the period January 2008 to October 2010. Given accurate real-time knowledge of prices in different locations and the ability to transport goods between markets with high price differences, consistently high profits would be achievable.

adoption and considerable trading activity.

The web interface for the implementation described in this paper can be accessed at `http://kudu.ug`.

THE CURRENT MARKET

First, we present a quantitative analysis of market efficiency and a qualitative analysis of interviews with traders.

Analysis of arbitrage opportunities

We begin with an analysis of the efficiency of agricultural markets in Uganda. One way to quantify this is by looking at arbitrage opportunities given past data. We analyzed historical data to estimate the profit or loss that would follow from a "spatial arbitrage" strategy: buying produce at the market price in one city, transporting it to another city (and paying transportation costs), and then immediately selling it at the market price in the second city. Similarly, we estimated the profit or loss that would follow from a "temporal arbitrage" strategy: buying produce at the market price, storing it for up to 18 months (and paying warehousing costs) and then reselling it at the market price.

In an efficient market, it should be impossible to make a consistent profit by following either of these strategies. (In particular, observe that further opportunities to profit from these strategies are "arbitraged away" when the strategies are employed: e.g., employing the spatial arbitrage strategy has the effect of increasing prices in the first city and decreasing prices in the second city.) The persistence of large arbitrage opportunities is thus indicative of a market failure such as poor availability of price information.

We now describe our methodology more specifically. To evaluate market efficiency for Ugandan agricultural produce, we analyzed market data from January 2008 to October 2010, obtained from the Famine Early Warning System Network (FEWS-NET) Uganda [7]. We considered market prices for Kampala (the capital city) and the towns of Lira, Masindi, Gulu and Mbarara. All of these towns are at least 200 Km from Kampala and at least 100 Km from each other.

To analyze the opportunities for spatial arbitrage, we estimated transportation cost per kilometer for a kilogram of produce for the years analyzed by taking into account prevailing prices for vehicle hire, fuel and other running costs. Our analysis evaluated the percentage return on investment (ROI) that could be achieved by transporting matooke (plantain), maize and beans from upcountry markets to Kampala. The results, summarized in Table 1, show that dramatic arbitrage opportunities exist; indeed, in some cases spatial arbitrage strategies offered more than 50% profit.

To analyze temporal arbitrage opportunities, we took into account the cost of renting warehouse space and conducting insect treatments. Figure 1 shows our calculation of percentage profit for buying and holding beans. In Gulu, a town far from the capital, the potential gains and losses are high, and a simple strategy such as buying in the harvest months and selling during dry months can be highly profitable. This volatility was not present in the market for beans in the capital city, Kampala, which are closer to the marginal-at-best gains we would expect in an efficient market.

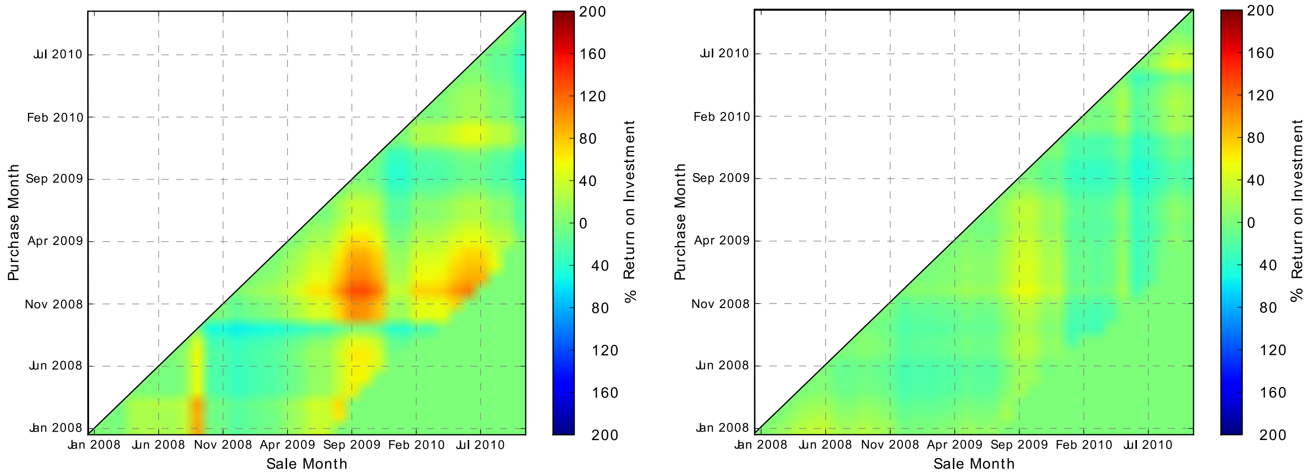
Interviews with farmers and traders

To gain further insight into the current operation of agricultural trade in Uganda, we interviewed farmers and traders in and around Kampala to learn about their subjective experience. Specifically, we met with five traders and seven farmers dealing in maize, beans, groundnuts and coffee. We were particularly interested in the trading process between wholesale dealers in Kampala and producers in the countryside. Confirming our quantitative findings, the findings from our interviews suggested that after goods arrive in urban markets, trading is more efficient and the potential gains from new market systems are smaller.

Overall, we learned that wholesale dealers commission trucks to pick up produce, and vary in the rural locations they are willing to travel to in order to find sellers. We found that communication between farmers and traders in the current trading environment has been greatly improved in recent years by the introduction of mobile phones and the wide coverage of the GSM network in the country. However, this communication has had little impact on the ways that farmers and traders actually find each other and conduct transactions. In particular, traders still rely on word of mouth for discovery of new farmers, and farmers still rely on informal links with a loosely connected network of brokers to sell their merchandise.

More specifically, we found that:

- The current trading environment has a high opportunity cost for both sellers and buyers. Farmers harvest their produce and wait by the roadside for traders to collect their merchandise, risking spoilage if there are no buyers. Similarly, traders bringing trucks from an urban market have to devote resources in traveling to areas in which they hope to buy produce without being sure of what they will find.
- Prices for farmers' produce are negotiated when traders arrive. Traders incur higher transaction costs in finding trading partners, but also tend to have a stronger bargaining position because they have a greater number of options in their trading partners and access to better price information. Farmers with fresh produce can be forced to sell at a low price when faced with potential spoilage if no agreement is reached.
- Farmers take longer to learn of changes in supply and demand than traders. The profits resulting from short term spikes in urban wholesale prices therefore tend to be taken by traders.
- Traders can face considerable uncertainty in finding the goods they are looking for. Local brokers in rural locations advise traders about farms with produce ready



(a) Gulu

(b) Kampala

Figure 1: Temporal arbitrage opportunities for beans in the town of Gulu and the capital city Kampala. The hue indicates the percentage profit from buying and selling beans at different times, taking into account the costs of storage. A simple trading strategy such as buying in months of production and selling in months of dry weather (For Gulu, buying in December-March and selling in June-September; for Kampala, buying in January-March and June, selling in August-October and May) can be highly profitable in Gulu, less so in the urban market of Kampala which operates more effectively.

to sell, but traders find this process unreliable. Traders may try to get a seller to agree to reserve their produce (though without settling on a price, as mentioned above), relying on gentleman's agreements established through mobile phone calls and broker contacts. Despite entering into such agreements, farmers may sell to the traders or brokers that show up first.

Obstacles to mobile trade

These qualitative and quantitative findings suggest that electronic markets would have much to offer participants in Uganda's agricultural market. However, such markets face many practical obstacles. Specifically:

- The costs of SMS messages pose a barrier to participation in mobile-phone-based auctions, particularly if a large number of SMS messages needs to be exchanged to conduct a trade. To put this argument into perspective, we analyze revenues for a farmer expecting to harvest 100 kilograms of maize grain. This farmer would expect a gross revenue of 50,000 UGX ($20 USD) given a conservative price of 500 UGX per kilogram of maize grain. Getting the grain ready to sell requires field maintenance over 6 months of growing the maize and approximately a month of drying the grain. Thus, the grain yields the farmer approximately 240 UGX (or about $0.10 USD) per day over these seven months. In contrast, the average rate for a single SMS message on Ugandan networks is 100 UGX ($0.04 USD).

- Traders are accustomed to physically examining goods before purchasing, claiming "seeing is believing." They may feel skepticism about whether a farmer will provide merchandise in the quality and quantities agreed upon electronically through a mobile-phone market system.

- Traders are accustomed to finding sellers through personal recommendations, and may be reluctant to trust a seller matched to them by an automated system. For example, we heard a concern from an urban trader that thieves might pose as sellers with cheap produce on a mobile market system in order to lure them to a remote location and rob them.

- Farmers may deliberately misinform traders about the quality and quantities of their products.

- Buyers who have committed to a farmer remotely may fail to arrive at the farmers' residences or markets to pay and take collection. Farmers are accustomed to immediate physical cash payments.

- Most farmers, traders and brokers are neither good writers nor readers. A complex SMS interface for participation in the trade would limit accessibility.

EXISTING SYSTEMS

We now review existing technological systems for supporting markets in the developing world and discuss some of the reasons that their impact has been limited. Most existing work has been on price advisory systems [9]. **FarmGain Africa Ltd** (`http://farmgainafrica.org`) is a firm that specializes in market information for agro-business development. Farmgain has been providing market information to rural farmers over radio and SMS, and also offers an alternate web interface for Internet-connected users. Prices are obtained from retail and wholesale markets spanning Uganda and Kenya. **Warid Telecom** (`http://www.waridtel.co.ug`) has implemented a SIM toolkit application that distributes market information obtained from FarmGain. Since September 1999, **Foodnet** (`http://www.foodnet.cgiar.org`), with support from the International Institute of Tropical Agriculture (IITA) (`http://www.iita.org`), has collected daily data from 19 (mainly wholesale) markets across Uganda. Initially this information was disseminated through national newspapers, email, fax, radio stations, government departments and agricultural development agencies. In July of 2008, **FIT Uganda** (`http://www.fituganda.com`)—a private sector business consulting firm that provides capacity building to SMEs—launched an agricultural market information service to provide real-time market information to subscribers. **The Grameen Foundation** (`http://www.grameenfoundation.org`), with local telecom service provider MTN, launched "village phones" to extend mobile phone services to remote areas of Uganda. These village phones were also used to pioneer initiatives for providing agricultural market information to the rural poor via group-led or call-center units. A collaboration by the Grameen Foundation, Google and MTN was started to develop a suite of mobile applications to provide market linkage information between buyers and sellers. A mobile based service known as **Google Trader** (`http://www.google.co.ug/local/trader`) was launched in 2009 as a result of this collaboration. Google Trader is essentially a classified advertisement service, providing listings of general merchandise (agriculture, appliances, housing, etc) with their price information, location and contacts through web and SMS interfaces.

Shortcomings of price advisory systems

Price advisory systems are ineffective for several reasons. First, there can be problems with data accuracy and relevance. Information is gathered by asking buyers and sellers to report the current price for different products. However, both parties are biased, and reported prices may therefore fail to accurately reflect actual sales taking place. Even when price estimates do accurately reflect actual sales in one place, they often fail to reflect prices for individuals of different circumstances across a wider region. For example, a farmer selling goods who is located a long way down a bad road will be able to sell good at a lower price than a farmer conveniently located next to a highway. In addition, only mean prices are reported, giving no indication of supply and demand curves. Price information is therefore unhelpful to farmers who are very eager to sell even at a low price, or farmers who have less need to sell and are prepared to wait for a high price.

The structure of most advisory services also fails to provide detail about produce specifications. For example, we found that all price information provided by FEWSNET does not contain species information. This is important because prices can vary by 20% between different species of crops such as beans, potatoes, coffee and rice.

Shortcomings of classified listings and single-sided auctions

Classified listings, in which sellers and buyers post descriptions and offered prices, are problematic when the mode of communication is SMS on a simple phone, because the medium makes it impractical to view the details of more than one or two items. Single-sided auction markets, in which buyers view and bid on individual items, have the same problem, and indeed may require even more communication to complete a trade. Such markets are not well suited to commodity trading, as they do not take into account the fact that commodities are inherently exchangeable and thus not every potential match needs to be viewed by a buyer or seller.

An auction market system known as "Robit" was proposed by Reda et al. [14] for use in settings where communication channels are narrow and possibly expensive, through the use of SMS and telephony voice kiosks. Robit makes use of a second price auction design mechanism for commodity trading. The implementation also makes use of a communication platform called Sulula [15] which provides a reliable connectivity with caching for individuals in constrained environments. While this work is interesting and useful to the research community, we have three main concerns about its practicality. First, the proposed scheme is silent about what happens when a buyer or seller has more than one match for their bid or ask; we assume that the user will be presented with possible matches one at a time following a right-of-first-refusal protocol. This means that users need to look through a list of matches for bids or asks. This is likely to be problematic for users with 'feature-phones' that have limited space for display. Second, another problem is SMS costs. Market participants would bear higher costs with the greater amount of traffic required by this system; furthermore, it would also be unsustainable for the system operator, which would be required to send a large amount of acknowledgment and notification messages. Third, Robit addresses the information asymmetry problem by providing voice product descriptions. While these descriptions may be more engaging for participants, we worry that they would do little to discourage dishonest product descriptions.

DOUBLE AUCTION DESIGN

We now describe our design of an auction mechanism to support SMS-based trading of agricultural commodities in developing countries. We propose a double auction market (see, e.g., [8]) in which buyers and sellers submit binding bids asynchronously, and the system periodically clears the market, matching compatible buyers and sellers and setting prices that are agreeable to both.

We assume a set of buyers B, a set of sellers S, and a set of mutually exclusive locations L. We represent the distance between any two locations using a function $d : L^2 \to \mathbb{R}$. C is a set of commodity types to be traded. An **ask** is a tuple $\theta_i = (l_i, c_i, q_i, a_i)$, specifying that seller located at $l_i \in L$ has $q_i \in \mathbb{N}$ units of commodity $c_i \in C$ that they are willing to sell at $a_i \in \mathbb{R}_+$ per unit. A **bid** is a tuple $\lambda_j = (l_j, c_j, q_j, b_j, L_j)$, specifying that a buyer located at l_j is willing to pay up to b_j per unit for q_j units of commodity c_j in any location within $L_j \subset L$. A bid θ_i and an ask λ_j are **feasible** iff $c_i = c_j$, $l_i \in L_j$ and $a_i \leq b_j$.

The goal of the market mechanism is to find a matching from amongst the feasible pairs. Whenever a bid and ask are matched, we set the price to be the same as the ask price. We consider the fact that buyers prefer geographically closer asks, although we do not know exactly how much each buyer values a given reduction in distance. We propose a greedy algorithm to perform matches, which cycles through the bids, offering time-limited matches to buyers that are Pareto optimal with respect to distance and price. Specifically, we consider bids in the order received, and iterate through the following steps (explained more formally as Algorithm 1):

1. For the next unmatched bid λ_j, calculate the set of feasible asks A_j.

2. Discard all asks from A_j that have been offered to another buyer.

3. Further discard all asks from A_j that are not on the Pareto frontier trading off between distance and price.

Algorithm 1: Assignment of asks and bids

Input: A set of Asks ($\mathcal{A} = \{\theta_1, \ldots, \theta_n\}$) and a set of Bids ($\mathcal{B} = \{\lambda_1, \ldots, \lambda_n\}$)

Output: A set $\mathcal{M}$ containing tuples (λ_j, θ_i) for matches between various bids and asks

$\mathcal{M} \leftarrow \emptyset$;
for $\lambda_j \in \mathcal{B}$ **do**
  $\mathcal{A}_j \leftarrow \emptyset$;
  `/* Find all feasible asks */`
  for $\theta_i \in \mathcal{A}$ *in decreasing order of* q_i **do**
    if $(c_j = c_i) \wedge (l_i \in L_j)$ *&* $(a_i \leq b_j)$ **then**
      $\mathcal{A}_j \leftarrow \{\mathcal{A}_j \cup \theta_i\}$
  `/* Keep only Pareto-optimal asks */`
  for $\theta_i \in \mathcal{A}_j$ **do**
    for $\theta_k \in \mathcal{A}_j$ **do**
      if $a_k \geq a_i \wedge d(l_j, l_k) \geq d(l_j, l_i) \wedge (a_k > a_i \vee d(l_j, l_k) > d(l_j, l_i))$ **then**
        $\mathcal{A}_j \leftarrow \mathcal{A}_j \setminus \theta_k$
  `/* Select ask with largest quantity */`
  find θ_l s.t $q_l \geq q_i \; \forall \; \theta_i \in \mathcal{A}_j \setminus \theta_l$;
  $\mathcal{M} \leftarrow \mathcal{M} \cup (\lambda_j, \theta_l)$;
  $\mathcal{A} \leftarrow \mathcal{A} \setminus \theta_l$

(That is, we discard each $\theta_i \in A_j$ for which there exists another $\theta_k \in A_j$ such that $a_k \leq a_i$, $d(l_j, l_k) \leq d(l_j, l_i)$, and either $a_k < a_i$ or $d(l_j, l_k) < d(l_j, l_i)$.)

4. If A_j is nonempty, choose the $a_j \in A_j$ for which q_j is greatest and make a time-limited offer to the buyer who submitted the bid λ_j. Mark that ask as being under offer.

5. If any offers have been accepted by buyers, match the corresponding bid and ask. If any offers have expired or are rejected by buyers, mark them as not under offer and delete the corresponding bids and asks as feasible pairs.

6. If any feasible pairs remain, return to step 1.

We note that this greedy clearing algorithm could be replaced with one that optimizes the quality of the matching using (e.g.) a mixed-integer programming formulation. However, observe that we face an online optimization problem: the rejection of a match by either party requires us to rematch the corresponding ask and bid. Because we do not know which matches will be rejected, it is therefore impossible for us to clear the whole market in a single, offline step. In ongoing work we are investigating whether we can improve market outcomes by leveraging more powerful clearing algorithms, and if so, whether these improved outcomes justify the increased computational cost of clearing.

Incentives for truthful bidding

Our auction mechanism offers buyers the dominant strategy of bidding truthfully. Thus, they do not need to reason about each other's bids in order to maximize their utility.

To back up this claim, we introduce notion for bidder utilities. Let v_j be the price at which the buyer expects to resell the produce in the market, and v_i be the cost incurred by the farmer to grow and harvest the produce. A buyer j's utility for trading at clearing price p is then $u_j = v_j - p$; a seller i's utility is $u_i = p - v_i$. Our mechanism always sets the clearing price to the seller's ask price a_i, and matches a buyer with a seller whenever the buyer's bid weakly exceeds the ask price ($b_j \geq a_i$). A bid is truthful if $b_j = v_j$.

PROPOSITION 1. *Buyers who want to trade only with a single seller have the dominant strategy of bidding truthfully under our double-auction protocol.*

PROOF. The result follows directly from the fact that truthful bidding is a dominant strategy in second-price auctions; nevertheless, because the proof is simple, we reproduce it here. If a buyer bids some amount $b_j > v_j$, he would either fail to get matched (obtaining utility 0) or get matched to items whose ask price $a_i \leq b_j$, being required to pay the ask price a_i. If $a_i \leq v_j$, the outcome is the same as under truthful bidding, and so the buyer might as well have bid truthfully. If $a_i > v_j$, the buyer pays more than he thinks the goods are worth, implying that he would have preferred not to trade. Similarly, if a buyer bids $b_j < v_j$, he would either receive the same match as before—meaning that he might as well have bid truthfully—or he would fail to be matched at a price $a_j < v_j$ at which he would have profited. □

Observe that this result does not hold if buyers want to trade with many sellers and have complex preferences that cannot be expressed in our bidding language; e.g., nonlinear preferences over bundles of goods, such as a desire to buy enough produce to completely fill a truck, but no desire for produce beyond this amount. Even in this case, second-price bidding simplifies the strategic problem for buyers, albeit leaving sellers to their own devices.

We designed our market to favor buyers because our interviews made it clear that sellers (farmers) are much more desperate to trade, meaning that they are most interested in seeing more trades occur. Buyers also tend to be much more sophisticated traders, making them more likely to manipulate the system with untruthful bids if not offered dominant strategies. One might hope that dominant strategies could be offered to traders on both sides of the market; unfortunately, this is impossible in any efficient market that does not operate at an (unbounded) loss [11, 10].

Price discovery

One substantial benefit of an electronic market is that it produces up-to-date price information that can be shared with market participants. In our design, such information is particularly valuable to sellers, since they can benefit by reasoning about likely market prices when deciding how to bid. (In contrast, because our market design offers dominant strategies to many buyers, they have much less need to pay attention to historical price information.) To meet this need, our implemented auction system provides an interface through which buyers and sellers can learn the previous day's prices for given commodities.

Robustness to shill bidding

A shill bidder is an insincere bidder (or, in some cases, a sincere bidder bidding under a second identity) who bids in order to extract more surplus from a sincere bidder. Our market design is robust against shill bidders, as follows. Because both sides of the market make sealed-bid offers that are revealed only when the market clears, neither side has the opportunity to place shill bids in response to information learned about a counterparty's bid. Placing extra bids under a false identity cannot benefit a buyer, because he already obtains all of the surplus in any trade, with the seller taking the amount of his own bid. Thus, shill bidding will only drive up the price a buyer pays. A shill bid can indeed yield a higher price for a seller; however, the effect is identical to placing a higher bid, making shill bidding useless.

Practical advantages of the auction design

We now discuss why this auction design is well suited to the constraints of developing-world agricultural commodity trading identified earlier. First, the sealed-bid, double auction mechanism requires very little communication between traders and the market. Each user has only to submit their bid or ask, and (in the case of buyers) to respond to individual offers. SMS costs are therefore kept low.

The process for dealing with location is necessary because it would be quite complicated for a buyer to specify the price they would be happy with at several distances from their home market, which might involve factors such as vehicles available to the buyer, road condition, and so on. A simpler alternative is to offer buyers a small number of Pareto optimal matches, and let them choose their preferred tradeoff themselves. The ability to specify simple bids covering large areas is necessary in order to make offers to buyers outside their accustomed trading areas, thus avoiding a fragmented market.

We note that once a price is proposed to both buyer and seller, it can be advantageous to allow them to negotiate further at the point of collection. It is important for the proposed system to provide room for negotiation in order to achieve wide acceptance by users, particularly as a mobile market system has the problem of not being able to specify in detail the quality of a product as accurately as a buyer would be accustomed to in face-to-face dealing. Indeed, this explains why our system does not allow for the specification of produce quality. (We note that produce of different qualities could in principle be represented as different commodities, in which case we could extend our definition of feasibility, since bids should be matchable to asks where the produce is either of the quality specified or higher.) Instead, we quote all prices for a baseline quality level, and allow traders to negotiate after a match has been made in the event that quality falls above or below this baseline.

Robustness and user reputation

Trust can be difficult to achieve in electronic markets: when market participants are relatively anonymous, bad behavior (failure to honor an agreement; attempting to trade in produce which is adulterated or otherwise below a reasonable standard) can go unpunished, and traders therefore become cautious. To mitigate this problem, it is necessary to institute some kind of reputation system in the market, to give traders information about the reliability of the buyers or sellers with whom they are matched [2, 5, 4, 16, 12].

The most common form of reputation system asks traders to rate their counterparty after a trade has occurred. (For example, such a system is prominently used by eBay.) However, we did not consider such a system to be appropriate in our setting. For example, we were concerned that a buyer could extort a positive rating from a seller at the moment of sale. We thus sought an alternate reputation system. Our goal was to construct a system that would be resistant to the following forms of attack:

(self-promotion) users can dishonestly increase their own ratings;

(slander) users can insincerely decrease the ratings of others;

(whitewashing) users can discard an account with a bad rating and obtain better reputation by starting anew;

(sybil) users can create false profiles and use them to give themselves a positive rating.

We elected to use a reputation system with two components. First, we track positive ratings implicitly, via trades that are accepted by both parties. Second, we track negative ratings explicitly, by giving participants the opportunity to blacklist the mobile numbers of counterparties with whom they have previously been matched, and with whom they want to be guaranteed never again to be matched.

This system resists the four forms of attack previously discussed as follows.

(self-promotion) Positive ratings in the market are captured from successful completed transactions as opposed to user-submitted ratings. In our scheme self-promotion is not possible since all participants are considered to have behaved positively towards each other unless they are blacklisted.

(slander) Slander is costly, as false blacklisting denies a trader future access to a counterparty. This strongly reduces the possibility of participants threatening each other with low rating scores. Furthermore, since blacklisting is only allowed between parties that transacted, bulk slander is impossible.

(whitewashing) The attachment of mobile numbers to the registration process imposes a cost to whitewashing: the registered mobile numbers are the ones that the market system uses for communication purposes.

(sybil) The success of sybil attacks depends on the cost required for creating a new profile [4, 13]. In our system, the centralized user registration process increases the cost of sybil attacks: each sybil profile needs a distinct, active phone number to participate in the market.

PRACTICAL IMPLEMENTATION

We implemented an auction system based on the above mechanism, offering users both SMS and web interfaces. The SMS interface is accessed using a 4 digit short-code that is easy for users to remember, and is available in three languages: English, Luganda and Luo. Since most users in Uganda and other developing countries use low-end mobile devices, SMS is the main form of interaction with the system.

We also implemented a web interface, with the aim of facilitating more complex transactions for bulk buyers and sellers. Unlike the SMS interface where buyers and sellers are presented with a single dominant match on the Pareto frontier to accept or reject, the web interface presents a list of candidate matches.

Finally, we provide a helpline number with all SMS communications, which helps users who are unable to manage either of the above to verbally communicate their bids and asks. In practice we have also found it necessary to call back users who send unintelligible SMS messages.

The matching process occurs once per day. The matched asks to a bid are reserved for a specific period and during this time, those asks are not available for matching with any other bid. When the waiting period expires without the buyer accepting or rejecting, the asks are put back to a pool of available asks. While traders are asked to acknowledge acceptance or rejection of matches, we found that not all did so; knowing which matches have been accepted by both parties has therefore posed something of a challenge. We addressed this issue by matching a particular ask only a certain number of times, and assume thereafter that it has either been accepted or should be expired.

In addition to pages for buying and selling, our web interface offers a price discovery page for users to obtain price information based on locations in the country for a specified past number of days. Locations in the Ugandan setting have been defined to the level of parishes (the smallest administrative region in Uganda, with 6254 parishes in the country). This gives a high precision for location based price discovery services. More specifically, we defined each location as the centroid of a parish, and calculate $d(l_i, l_j)$ as Euclidean distance from this point.

When a new user sends any message to the system, they are first asked to provide their home parish. Following this registration step, the SMS interaction between farmers, traders and the market is keyword based and is structured as described in the following sections.

Farmer Asks

Farmers submit their asks to the market using a SELL keyword in their SMS message sent to 8228. An example SMS to sell 4500 kilograms of beans at UGX 900 would be defined in an ask SMS as follows; "SELL BEANS 4500 900". The farmer would receive an acknowledgement with an Ask ID that can be used for follow-up inquiries. Note that farmers are not required to include their location information since this information is already part of their profile.

During buying and selling there is no attempt to differentiate the quality of produce on offer; we ask farmers and traders to assume 'fair-average-quality' (normally produce that is not cleanly sorted or graded). This allowed us to keep the format of the SMS message simple. Buyers are able to inspect produce and renegotiate if necessary before making final payments.

Trader Bids

The trader bid submission follows an SMS syntax similar to that of farmers, except that the keyword changes to BUY. A trader who wishes to purchase 5000 kilograms of beans at UGX 800 would send the message "BUY BEANS 5000 800". Such a bid will attract a possibility of matches for beans across all locations in the country. Traders can optionally include location filters so that their bid matches with asks are restricted to a particular location. Such a message will be constructed as follows; "BUY [PRODUCE] [QUANTITY] [UNIT PRICE] [LOCATION]". Bids can be made on regions (5 across the country), districts (112) or parishes (6254).

Month	Total Asks	Total Bids
Jan	56	23
Feb	130	61
Mar	210	173
Apr	378	268
May	469	284
Jun	500	285

Table 2: Cumulative numbers of asks and bids received in the period January–June 2013.

Market Matches

Market matches are made using the double auction mechanism described above. Matches are not permitted if either trader blacklisted the other. Buyers are given a set of candidate offers along the Pareto frontier trading off price and distance. The accept or reject request contains the clearing price and location of the seller. Buyers are expected to respond in an SMS quoting the ID of the match. The syntax for an ACCEPT or REJECT SMS is "ACCEPT | REJECT [MATCH ID]". The match ID is typically a system-generated integer. The implementation ensures that buyers can only reject matches that belong to them; other REJECT or ACCEPT requests are ignored. The request to accept or reject is time limited; if the buyer does not respond after the specified period, then the match is removed and placed back to the pool of available asks. The same happens when a buyer rejects the offer. As noted above, however, this functionality was rarely used in practice, and so we set a limit on the number of times a particular ask can be matched.

Price Discovery

Since this is an auction system where users do not know ahead of time what typical buying and selling prices will be, the system provides an SMS interface for users to learn produce price information. The price discovery specification is similar to that of the web interface. The SMS interface uses the PRICE keyword and the syntax is as follows; "PRICE [PRODUCE] [LOCATION] [NUMBER of DAY]". In this syntax, location and number of days are optional. The user can simply send "PRICE [PRODUCE]" and they will receive price information for a given produce for the past 7 days in Uganda. If location and time parameters are specified, then price discovery will only provide price information for a particular location for the requested number of days.

Blacklisting

If buyers or sellers have a negative experience of dealing with somebody they have been matched with, they are encouraged to blacklist that user by sending a message of the form "BLOCK [PHONE NUMBER]". This results in that buyer and seller never being matched again, and provides important information about the reliability of users.

RESULTS AND EVALUATION

In order to evaluate our market design approach and environmental assumptions, we conducted field trials in separate phases, the first during September 2012 aimed at testing basic usability assumptions, and the main phase beginning in January 2013 and still active at the time of writing.

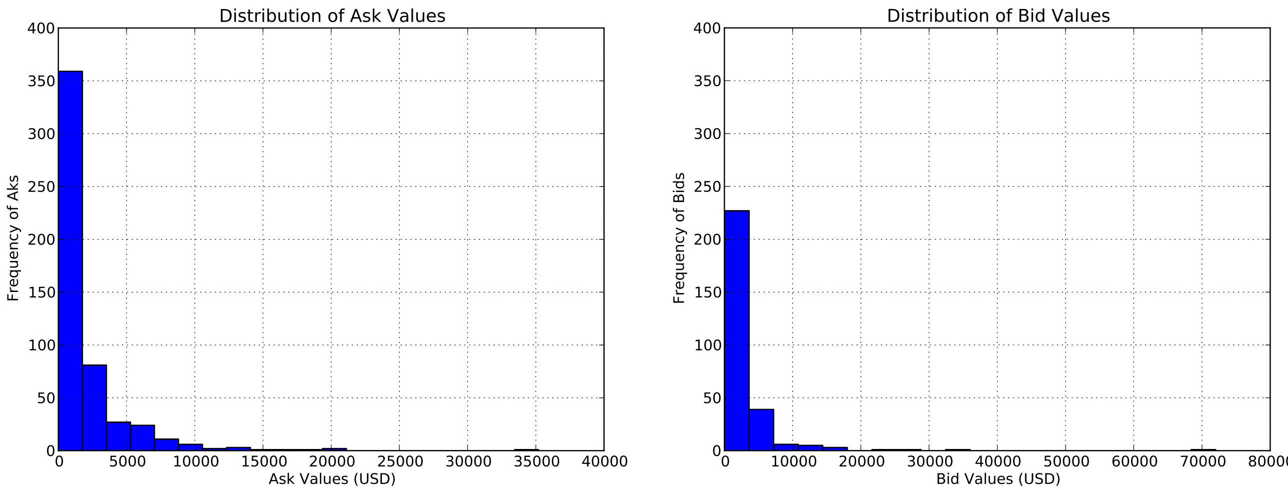


Figure 2: Distribution of bids and asks for all products in the market.

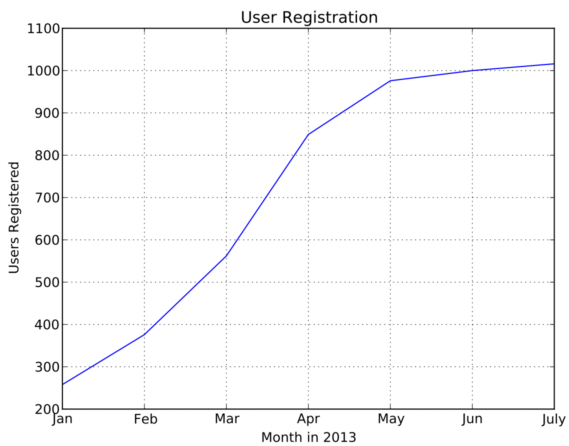


Figure 3: User registration in the market.

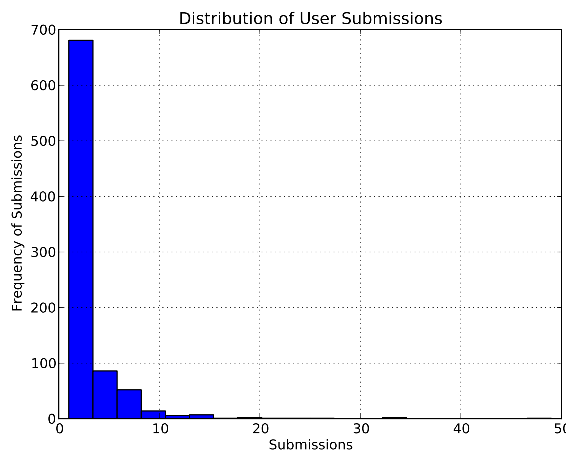


Figure 4: Distribution of user submissions to the market.

From the initial phase, the system was made accessible to users throughout Uganda via a toll-free SMS short code. We communicated information about using the system to sellers with a series of meetings in districts in farming-intensive regions of Uganda's central region, as well as via radio broadcasts. Buyers were also targeted using radio broadcasts in Kampala, and with visits to wholesale markets to hand out flyers and explain the system to potential users. We began with four commonly traded staple crops (coffee, maize, beans and peanuts) and added new produce categories to the system on demand. Currently there are 70 produce categories.

Quantitative results

The auction market has been active since January 2013 and has been available mostly in the central and south-western areas of Uganda. A total of 1024 traders and farmers were registered between January and July, 2013. The total count of bids and asks was 285 and 520 respectively. Not all registered users submitted bids and asks: 219 users only used the system to ask for commodity prices. The total value of asks from sellers was USD $1,700,000, and the total value of bids from buyers was USD $960,000. Table 2 shows the cumulative numbers of bids and asks each month. Bids and asks tended to be large quantities from wholesale traders; for instance the largest bid received was for 120,000 Kg of maize (we verified the details with the buyer and found the bid to be genuine). We received 53 bids and 94 asks for quantities exceeding 10,000 Kg. Figure 2 shows the distribution of bids and ask values for all products in the market.

Table 4 shows the total quantities of bids on the five produce categories with the highest total bid values, and Table 3 shows the total quantities of asks on the five produce categories with the highest total ask values.

We observed that market activity was highly dependent on the frequency of radio adverts. The increase in the number of bids and asks was significantly higher in months that had a higher frequency of adverts than those months with fewer adverts. We attribute the low growth in May and June to this factor.

We sampled 30 unique mobile numbers from a list of 1,748 matches that occurred in the market between the first of January and the first of July, 2013. We identified 4 users that registered successful transactions that led to exchange of money, representing a 13.3% success rate, albeit in a small

Produce type	Total ask quantity
Peanuts	512,375 Kg
Maize	1,711,935 Kg
Beans mixed	114,900 Kg
Coffee (Robusta)	36,800 Kg
Sweet Potatoes	2,221 Sacks

Table 3: Quantities of the five categories of produce with the highest aggregate ask value.

Produce type	Total bid quantity
Maize	917,300 Kg
Sesame	110,000 Kg
Beans mixed	179,050 Kg
Soya	40,000 Kg
Peanuts	35,050 Kg

Table 4: Quantities of the five categories of produce with the highest aggregate bid value.

sample. We also received calls from 28 buyers and sellers who offered (unsolicited) feedback by calling the helpline number, which helped us to confirm that real trade was occurring as a result of the matches proposed by the system.

Evaluation of user perceptions and experiences

The market system registered its first 500 users in February 2013, a month and half after starting the pilot (see Figure 3). We were encouraged by such rapid adoption, considering that users had no previous experience with a similar system.

Notwithstanding the encouraging adoption numbers, users have raised several issues regarding the usability of an SMS-based interface. While we attempted training sessions and radio announcements explaining message formats such as 'BUY [PRODUCE] [QUANTITY] [UNIT PRICE]', almost all the messages we received did not follow this format well enough that they could be parsed automatically. The most common issues were variations in spelling, ambiguous figures, or messages written in free text. In practice, whenever a malformed message is submitted to the market, we decipher meaning from the message if possible and then resubmit it on the users' behalf. In circumstances where we cannot derive the meaning from the message, we typically call back the sender to confirm their intentions. We note that this would present difficulties if we faced very large volumes of senders, though note also that labor costs are low enough in Uganda that considerable manual intervention remains feasible. We plan to mitigate this problem with a USSD interface or an interactive voice response system. Concerning the SMS interface, we also found user feedback to be more positive in the second phase of trials when the SMS system was translated into local languages, even for those who had no problem communicating in English.

The mobile auction system was more quickly adopted by sellers than by buyers. This seems to represent the fact that buyers have a stronger position in the current market, and therefore less to gain by adopting a new system. However, we observed particular interest from large-scale buyers, who face challenges in sourcing bulk quantities of produce for export or factory processing.

The addition of new product categories on the market was demand driven. Most of the species added were not anticipated by us at the outset of the field trials. Some new products were added to the market on request and we saw immediate popularity among both buyers and sellers. For example, we did not expect to sell animal hides; a hides-and-skins buyer contacted us with a desire to find sellers. Once the item was listed on the market and an announcement made on radio, 10 sellers were enrolled and 10 matches happened as a result. Other unexpected produce categories in which we saw market activity were eucalyptus poles, pineapple suckers, ginger, and soya, the latter becoming a significant commodity as shown in Table 4.

We have seen several farmers act as aggregators for produce in their areas in order to complete a large volume sale. We also find that brokers are able to become users in our system, performing an important role of produce aggregation. The majority of the farmers do not grow produce in the large quantities that are sought after by traders, making such aggregation a powerful approach to produce marketing.

In general the speed at which users grasped the double auction concept has impressed us; we find this to be compelling evidence that our proposed system is more effective than traditional methods of agricultural trade. The market system had several repeat users as shown in the distribution of user submissions in Figure 4.

CONCLUSIONS

Motivated by evidence that previous approaches to mobile markets in developing countries are ineffective, and that serious inefficiencies exist in traditional trading methods in countries such as Uganda, we have designed and implemented a sealed-bid, double-auction-based mechanism that is more compatible with the needs of buyers and sellers. In particular, it is parsimonious in terms of communication and offers a dominant strategy of truthful bidding to buyers. Field trials with a web- and SMS-based implementation have shown enthusiastic adoption and significant trading activity, providing strong evidence that our market platform meets local needs. Future work includes assessing the usability of other interface methods such as USSD or interactive voice response.

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