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Combining participatory crop trials and experimental auctions to estimate farmer preferences for improved common bean in Rwanda

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ABSTRACT

Participatory crop improvement raises the prospects for developing seed varieties that meet the needs of subsistence farmers but may face challenges regarding preference elicitation, particularly in complicated policy environments. We integrate binding experimental auctions with participatory variety selection to elicit farmers' preferences for improved common bean varieties in Rwanda. We find that auctions reveal farmer preferences more accurately than stated nonbinding rankings in this context and that participatory on-farm crop research is essential to understanding how farmers evaluate tradeoffs between multiple crop attributes. We also find that farmers highly value intercrop yield despite government policy that encourages farmers to monocrop.

Introduction

Improved varieties of staple crops can be an important development tool simultaneously targeting malnutrition and chronic low yields (Becerril and Abdulai, 2010). However, successful introduction of improved varieties in developing countries can be hindered by the challenges associated with the heterogeneous microclimates found throughout the tropics (Morris and Bellon, 2004). Identifying varieties that farmers are likely to adopt is also complicated by the complexity of traditional cropping systems, suboptimal conditions found on farmers' fields and a lack of understanding of farmers' preferences.

Classic plant breeding typically focuses on improving the biological attributes of a crop rather than specifically trying to understand "the specialized production and consumption requirements of people who live in these environments" (Morris and Bellon, 2004, p.22). Participatory crop improvement methods emerged as a way to collaborate with farmers in order to better understand their preferences for new varieties and improve adoption. Two specific forms of participatory crop improvement research are Participatory Plant Breeding (PPB) where farmers evaluate plant characteristics during the breeding process and Participatory Variety Selection (PVS) where farmers evaluate varieties emerging from breeding programs (Witcombe et al., 1996). Both methods seek to identify plant trait preferences and generate plant varieties to better meet farmers' needs. Engaging farmers in participatory variety selection is particularly important when on-farm conditions are likely to be different from those on research stations, which is common in areas with diverse agroecological environments and low input systems (Morris and Bellon, 2004).

One potential challenge with participatory variety selection is that it may still remain difficult to obtain information from the participating farmers on which varieties they actually prefer. Improved attributes of staple crops are often accompanied by negative attributes such as poor taste or unorthodox color that hamper adoption. Understanding how farmers evaluate multiple attributes is essential for more efficient plant breeding, policymaking, and resource use. Depending on their relationship, however, farmers may be inclined to tell the researchers what they think the researchers want to hear, a form of social desirability bias (Norwood and Lusk, 2011). In such a situation, which appears to describe the case we investigate in this article, more sophisticated elicitation methods may be required. In this research we compare two elicitation methods for improved varieties: stated nonbinding rankings common in participatory methods and revealed bids from binding experimental auctions.

The research reported in this paper engages bean and maize subsistence farmers in Northern Rwanda by combining on-farm agronomic trials with experimental auctions for improved varieties of common bean. This paper addresses two main questions regarding the quality of information that researchers can obtain about

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farmer preferences among different varieties: (1) What is the effect of the method of preference elicitation? (2) Does taking part in on-farm participatory crop improvement research influence farmer preferences for the varieties?

Background

Experimental auctions for improved staple crops

In recent years, researchers have used experimental auction techniques in developing countries to estimate preferences for improved staple crops including biofortified white and yellow maize meal in Kenya (De Groote et al., 2011), biofortified orange maize meal in Mozambique (Stevens and Winter-Nelson, 2008), biofortified orange maize in Ghana (De Groote et al., 2010), and biofortified "golden" rice in the Philippines (Corrigan et al., 2009). These papers look specifically at the tradeoff consumers make between a positive attribute (fortification) and a negative attribute (unorthodox color). For example, De Groote et al. (2011) found that the premium consumers were willing to pay for fortified maize (24%) was higher than the discount they required to buy yellow maize (11%). One limitation of such applications of experimental auctions is that they tend to focus exclusively on consumer behavior even though in some of the countries where they are undertaken, up to 90% of the population is also involved in production, which is the case in Rwanda.

If subsistence farmers' consumption and production decisions are interdependent as economic theory predicts, their preferences for a new crop variety should be based on consumption and production characteristics including nutrient content, taste, color, yield, and possibly others. Studies that concentrate only on production attributes (Asrat et al., 2010) and do not provide farmers with information on the consumption attributes do not capture the interdependency of decision-making. Two papers that specifically look at both consumption and production traits find evidence that both are determinants of farmer preferences. Dalton (2003) concludes that evaluating only on production characteristics in research with rice farmers in West Africa leads to 19.1% of all varieties being miscategorized as inferior. Asfaw et al. (2012) conclude that combining drought tolerant attributes with marketability and attractive culinary traits is most important to common bean farmers in Ethiopia.

This research extends previous work in the consumer choice literature by estimating farmer preferences for common beans in Rwanda based on consumption attributes (taste and nutrient content) and production attributes (locally specific yield data) through the use of information treatments in a field experiment. We also examine the differences in revealed preferences between farmers who took part in participatory variety selection and those who only tasted the beans and received information treatments. We treat farmers as both consumers and producers and we use an incentive-compatible elicitation method to investigate the effect of participating in research and the effect of binding preference elicitation methods.

Improving common beans in Rwanda

Common bean (*Phaseolus vulgaris* L.) is a major grain legume crop in Rwanda produced mainly for subsistence agriculture but also to a limited extent for regional markets. Much of Rwanda's bean production is on small farms averaging 0.65 ha, traditionally intercropped with maize or other crops (NIS, 2010). There are estimated to be at least 550 varieties of common bean in Rwanda (CIAT, 1993) and farmers traditionally plant mixtures containing as many as 30 varieties (Voss, 1992). The Rwandan Agricultural Board (RAB) reports that bean farmers' average yield is 25% of its potential as a result of rain variability, poor soil, and inadequate soil nutrients or inputs (RAB, 2012).

Common bean provides a valuable source of protein, minerals and vitamins with bean consumption in Rwanda estimated to be as high as 48 kg per capita per year (Broughton et al., 2003). Rwanda has the world's 10th highest percentage of population suffering from undernourishment at 40% in 2009 (FAO, 2012) as well as high rates of iron deficiency: 11% among women and 42% among school age children (World Bank, 2012). Common bean is conducive to biofortification of iron and zinc content because the baseline grain iron content is high and there is wide variability of mineral content, 30–110 ppm for iron and 25–60 ppm for zinc (Beebe et al., 2000). HarvestPlus estimates that an additional 40 ppm above baseline iron levels in common bean could meet a large proportion of the recommended daily intake of iron (Welch et al., 2000).

Adoption of bean varieties with improved nutrient content and yield performance has the potential to improve health outcomes and reduce poverty in rural areas of Rwanda. In the late 1980s and early 1990s, the low adoption rates of improved bean varieties in Rwanda led to extensive advancements in client-oriented plant breeding, where researchers collaborated with farmers to identify suitable varieties (Sperling et al., 1993). The success of participatory research with improved bean varieties allowed farmers to intensify bean production and gradually become part of the national agricultural research system in Rwanda. The institutionalization of methods like PVS makes it increasingly important to examine the contexts within which the participation is embedded. This is especially true in the current policy environment in Rwanda as the relationship between farmers and the Rwandan government is affected by sweeping changes in agricultural policy.

Multiplication and dissemination of improved varieties of crops is one component of phase II of the Strategic Plan for the Transformation of Agriculture in Rwanda (PSTA II), released in February 2009 (Ministry of Agriculture and Animal Resources, 2012). The plan incentivizes farmers with improved seeds and fertilizers, post harvest storage facilities, and extension services, to shift from diverse intercropping systems to monocropping. Previous research and anecdotal evidence paint a more authoritarian picture of local authorities destroying farmers' crops if they do not comply with the policy, effectively making intercropping illegal (Huggins, 2013). PTSA II is a radical departure from traditional farming in Rwanda and presents a challenging context to elicit farmers' preferences for improved crop varieties using participatory methods.

Methods

In this research, we are interested in whether the results of stated and revealed preference elicitation methods for improved common bean varieties are consistent given the policy context in Rwanda. We also want to understand the impact of taking part in the participatory research on farmers' preferences. To explore these issues we conducted experimental auctions and non-binding rankings with farmers who participated in on-farm crop trials and farmers with similar soil and climatic conditions who did not participate in the crop trials.

Data

Two types of data were used: (1) agronomic data collected through on-farm research of climbing bean varieties and (2) preference data collected through stated rankings, experimental auctions, and a brief survey with two subject pools of farmers. The agronomic data and a subset of the experimental auction data came from farmers who participated in an on-farm study of variety and cropping system interactions (Isaacs, 2013). These farmers grew each of the bean varieties on a single farm collectively, in a central location using a randomized complete block design of five bean varieties and one local mixture planted both in a monocrop and an intercrop with maize. The preference data were generated in experimental auction sessions for beans with bean and maize farmers who participated in the crop trials and farmers from neighboring communities who did not. The auction procedure is described in more detail below.

Sample

Rwanda is divided into five provinces: North, South, East, West, and Kigali. The sample consisted of farmers from five sectors (labeled A, B, C, D, and E to protect the identity of the farmers) across three districts around the central market town of Musanze, in Northern Province, Rwanda (see Fig. 1). A sector is an administrative division, which is a subdivision of a district, which is a subdivision of a province in Rwanda. The topography of Northern Province is mountainous with altitude differences between the districts and sectors within each district ranging from 1660 to 2100 m. Soils in the province are highly diverse, ranging from rich volcanic soils to nutrient-deficient clay soils.

Farmers involved with the on-farm agronomic research were members of farmer associations that were randomly selected from a list of farmer associations actively working with a local NGO. The geographical distribution of these farmer associations roughly captures the diversity of agroecological conditions found in Northern Province. An auction was conducted with a single farmer association in each sector except for sectors B and E where one combined auction was conducted and in sector A where two farmer associations were combined due to the small size of the groups (see Table 1). In total, four auctions were conducted with farmers that participated in the on-farm research ($n = 79$).

The second group of farmers ($n = 182$) belonged to farmer associations in the same five sectors as the farmers that participated in the on-farm research. Two farmer associations were randomly selected from a list of all farmer associations in each of the five sectors with the help of a local NGO extension agent. Due to the rugged terrain, long distances and poor communications between communities in this part of Rwanda it can be safely assumed that the new group of farmers did not have prior knowledge about the varieties from interaction with the original group. The NGO extension agent invited the entire farmer association, which ranged between 15 and 25 farmers (average of $n = 17$), to participate in a two-hour session in which bean varieties would be discussed. All members of the farmer association that attended the session participated in the auction. In total, three auctions were conducted in each sector, except for the two combined auctions mentioned above for a total of 14 auctions and total sample of $n = 262$ participants.

Experimental auction mechanism and procedure

The experimental auctions used a Vickrey (1961) third price mechanism, where the third highest bidder's bid was selected as the "market price" for each bean variety and the participants who offered higher bids won the auction and paid the market price. The quantity of bean seed auctioned was 500 g which is roughly equivalent in value to the daily wage for unskilled labor and enough to plant what is locally considered to be an average plot (10 m × 10 m). The Vickrey auction mechanism is designed such that it is optimal for farmers to reveal their true preferences since overbidding can result in paying too much and underbidding can result in missing out on a good deal (Lusk and Shogren, 2007). The following eight steps were used for all auction groups.

In Step 1, prior to the start of the auction, each participant completed a short survey including basic demographics. Farmers received a set of bid sheets for each round stapled together and labeled with a unique ID number. The moderator read an oral informed consent statement to each participant explaining the confidentiality agreement and their rights as participants.

Fig. 1. Map of Rwanda showing the approximate location of Musanze in Northern district, around which the five research sites were located.

Table 1
Descriptive statistics of socioeconomic information gathered in a pre-auction survey by location (A–E) and auction (1–3).

	Men	Age	Edu	Class	HH num	HH farm	Other income	Land	Bean yield	Net seller	Net buyer	*N*
A1	0.00	45.35	5.18	1.59	6.00	2.59	0.12	0.52	38	11%	37%	19
A2	0.29	47.90	5.76	2.76	4.71	2.62	0.47	0.75	48	0%	33%	21
A3	0.19	41.63	5.81	2.50	5.13	2.44	0.13	0.63	58	0%	25%	16
B1	0.38	39.13	5.50	2.75	4.38	2.13	0.00	1.00	84	13%	75%	8
B2	0.47	40.06	4.76	2.88	5.53	2.18	0.18	0.90	154	44%	11%	18
B3	0.37	53.32	3.95	2.63	5.68	3.95	0.16	0.53	74	17%	61%	18
C1	0.16	52.74	3.28	2.68	5.16	2.63	0.11	0.31	129	37%	26%	19
C2	0.47	45.80	5.50	2.94	4.80	2.50	0.35	1.00	121	24%	24%	17
C3	0.00	44.39	4.33	2.61	4.72	2.33	0.00	0.30	53	6%	83%	18
D1	0.44	39.48	3.04	2.76	5.28	2.28	0.04	0.48	54	12%	60%	25
D2	0.65	36.65	4.65	2.85	4.55	3.05	0.20	0.51	58	0%	65%	20
D3	0.38	34.19	3.75	2.88	4.63	3.00	0.25	0.45	68	6%	38%	16
E1	0.25	47.43	4.71	2.88	6.38	2.88	0.13	0.83	123	25%	38%	8
E2	0.47	42.65	3.82	2.88	5.06	2.12	0.18	0.64	103	35%	18%	17
E3	0.13	54.25	2.56	2.44	4.19	2.38	0.06	0.46	30	65%	12%	17
AV	0.31	44.33	4.44	2.67	5.08	2.60	0.16	0.62	80	20%	40%	17
SD	0.18	6.07	1.02	0.33	0.61	0.47	0.13	0.23	37	0.19	0.23	4.3

Note: Auction 1 in each location only consisted of farmers who participated in the crop research, while auctions 2 and 3 consisted of farmers who were otherwise unfamiliar with the bean varieties.

In Step 2, the monitor described the practice auction procedure and third price Vickrey mechanism to the participants and then they received 200 RWF (1 USD is approximately 600RWF). Participants learned that they could bid on either or both of the items in the practice round. One item was a bag of peanuts (worth approximately 100 RWF) and the other was a package of biscuits (worth approximately 100 RWF). Participants were informed that if they won the auction(s) they would be expected to pay the third highest bidder's bid. Bid sheets were collected and ranked from highest to lowest; winners were announced and they exchanged money for the goods if they won the auction.

In Step 3, farmers visually inspected the five varieties of beans placed in bowls at the front of the room labeled in Kinyarwanda by the name the research farmers created for them (the names reflected the color of the beans). Samples of the beans weighing 500 g were lined up behind each bowl in plain brown paper bags labeled with the variety name and weight. The beans were arranged in a random order at each auction by blindly selecting the sample bags from a larger bag and placing them on the table from left to right.

In Step 4, participants received a plastic cup and were served approximately one tablespoon of each variety of bean, prepared in a traditional way (salt and oil), in the same order they were lined up on the table in the previous step.

In Step 5, farmers received a participation fee of 700 RWF bringing the total amount they received to 900 RWF (approximately $1.50). The average daily unskilled wage in Musanze at the time of the auction was between 800 and 1000 RWF and a kilogram of the traditional local mixture sold for 150 RWF. Auction participants were told they could choose to use this money in the auction and they would take home whatever money they did not spend. The purpose of giving each farmer the participation fee is that most farmers did not have cash on hand and might not be comfortable participating in the auction otherwise. Participation fees can create a ''house money effect'' (List and Rondeau, 2003), where participants make riskier decisions because they are bidding with money they do not perceive as their own. At the same time participation fees can also mitigate the effect of ''field substitutes'' or product substitutes found outside the experiment and focus the participant on the task at hand (Lusk and Shogren, 2007). We felt that the advantages of the participation fee outweighed the disadvantages.

In Step 6, participants were presented with a simple bar graph displaying the zinc and iron content in each of the five varieties. The significance of zinc and iron for human health was explained to the farmers as well as the interpretation of the simple bar graphs. Because it was essential for farmers to understand the concept of biofortification this step of the auction was explained once, clarification questions were taken and then it was explained a second time in a slightly different way. Farmers then ranked their top three preferred varieties. After the rankings were collected farmers were asked to write on a single bid sheet their maximum willingness to pay for all five varieties. The bid sheets were collected.

In Step 7, participants were presented with simple bar graphs on how the five varieties performed in on-farm trials in neighboring farmer associations' fields for both monocrop and intercrop. At each auction farmers were shown only the yield of the on-farm trial that was located closest to their farmer association. These yield graphs were explained to participants in the same way as the nutrient graphs. Following this information, farmers were asked to rank their top three preferences and after the rankings were collected farmers were asked to write their maximum willingness to pay for the five varieties on a single bid sheet. The bid sheets were collected.

In Step 8, a coin toss determined which round was binding. The bids were ranked from highest to lowest for each of the five varieties in that round. We departed from the convention of randomly selecting one product as binding in each round and made all five varieties binding in a single randomly selected round. This decision may have decreased the overall magnitude of the bids but should not have affected the relative valuation of the five varieties, which is the focus of this paper.

The third highest bidders' bid was selected as the ''market price'' for each variety and the participants who bid higher than this price won 500 g of the improved bean variety and paid the researcher the effective market price. Due to the frequency of tied bids we implemented a tie-breaking rule. If the third highest bidder's bid was tied with either the second or second and first highest bidders' bid a random coin flip decided who was effectively the second highest bidder. In each case the participant was still required to pay the third highest bidders' bid even though in some cases it was equivalent to what they bid. With the tie-breaking rule the price the winner paid was still independent of their bid and it is still a weakly dominant strategy to bid one's true value.

Summary statistics of farmers by auction

The sample was more heavily weighted towards women, who tend to do most of the bean production and in one site (A1) the entire farmer association was women (see Table 1). The average participant was 44 years old with 4 years of schooling, and 26% of the sample was illiterate. The average wealth class score reported was 2.67, where 1 is food-poor and 5 is food-rich (Howe and McKay, 2007). The average household consisted of 5.08 people with 2.60 working on the farm and 0.13 people earning off-farm income. The average farm size was 0.62 ha, close to the estimate from the latest National Agricultural Survey of 0.65 ha per household in Northern Province (NIS, 2010). Farmers reported an average bean harvest of only 37 kg per farm in the past season, far short of the 48 kg per capita annual bean consumption figure reported by Broughton et al. (2003). Twenty percent of the sample was net sellers of beans in the previous season, 40% were net buyers and 40% did not buy or sell any beans in the last season.

Results of an ANOVA test revealed that in an overall model using all the independent variables in Table 1, research farmers were not statistically different from non-research farmers. However, the variable *wealth class* was different between the research and non-research farmers at the 5% level indicating that the mean wealth group between the two groups was in fact different. The on-farm research group was slightly poorer which is likely attributed to the group A1, which was by far the poorest group in the sample where most farmers reported being in the poorest wealth category.

Summary of bean performance

At each location a randomized complete block variety by cropping system design was set up for the five improved varieties (B1-5) and the traditional local mixture (B6) in monocrop and intercropped with maize for a total of 12 plots (3 m $\times$ 4 m) per site. RAB and HarvestPlus estimated the iron and zinc content of the beans prior to replication and dissemination of the improved varieties. Varieties B1, B3 and B5 had similar levels of iron (65) and zinc (30). Variety B2 had slightly higher levels of iron (75) and zinc (36) than the other varieties and B4 had very high levels of iron (95) but average zinc content. Based on iron and zinc biofortification standards in common bean, varieties B2 and B4 are biofortified.

Varieties B1 and B5 were established varieties in northern Rwanda while varieties B2, B3, and B4 were newly introduced. Some farmers reportedly were familiar with B1, which was a local landrace that was cultivated by a farmer and replicated by RAB. B5 was also somewhat familiar as it was introduced in the 1980s and was released in 1991 by RAB, and a variant of B5 appeared to be found in local mixtures. At the time of the auctions in 2012, variety B2 was not released and varieties B3 and B4 were pending release. Varieties B2 and B3 were much lighter in color than the other improved varieties (white and beige respectively) although some varieties in the traditional mixture were similarly light in color. The other varieties ranged from purple (B1) to red (B4) and maroon (B5).

The on-farm trials described in this paper were part of a larger experimental design that involved on-farm trials at other locations and replications on research stations (Isaacs, 2013). The on-farm trials presented here were not designed to isolate the statistical differences in yield between the varieties since the yield data at each site were only used as information treatments for farmers at that site. Below we briefly discuss the differences in mean and standard deviation across the five sites to give the reader a general idea of how the varieties performed across locations on average (see Table 2).

In each of the locations, the on-farm trials included a local variety mixture of common beans (B6) as a control and in the following section we compare the improved varieties with this control. The mean yield of variety B1 was almost identical to the local variety mixture on average in both mono crop (0.03 kg difference) and intercrop (0.06 kg difference). The higher standard deviation of B1 was due to poor performance in monocrop and intercrop in site D where excess water damaged or washed away many of the seeds. The mean yield of the unreleased and biofortified variety B2 was the lowest of any variety in intercrop and the second lowest yield in monocrop but it exhibited the lowest yield variance of all varieties in monocrop. The newly released variety B3 yielded highest on average in monocrop (3.65 kg/plot) with relatively consistent yields but was the second lowest performing variety on average in intercrop, producing less than two kilograms/plot in two locations. The mean yield of unreleased and biofortified variety B4 (3.2) was slightly lower than the local variety mixture (3.31) in monocrop and was the highest in intercrop (1.63). B5 proved to be particularly susceptible to anthracnose and had the lowest average yield in monocrop (2.67 kg/plot) but performed well in intercrop with the second highest mean yield.

Table 2
Mean yield between the 6 varieties in monocrop and intercrop system on farmers' fields (averaged across locations A–E).

Variety	Monocrop			Intercrop		
	Mean	SD	SE	Mean	SD	SE
B1	3.28	1.82	0.36	1.55	0.93	0.19
B2	2.74	0.55	0.11	1.08	0.65	0.13
B3	3.65	0.73	0.15	1.27	0.61	0.12
B4	3.20	0.71	0.14	1.63	0.49	0.10
B5	2.67	0.98	0.20	1.59	0.64	0.13
B6	3.31	1.08	0.22	1.49	0.79	0.16

In summary, based on nutrient content alone varieties B2 and B4 are the most attractive. Based on yield performance there was wide variation between improved varieties on average and these new varieties do not seem to have a sufficient yield advantage over the traditional mixture to be competitive. From this small sample variety B3 appears to have the most advantage in monocrop and varieties B4 and to a lesser extent B1 have a chance of outcompeting the local mixture across both systems.

Modeling farmers' WTP for improved varieties

Linear regression models are easy to interpret and can tell us about average effects but they do not necessarily provide accurate estimates of partial effects at censored values. Experimental auction bids can be censored at zero when participants would require payment in order to accept the good in question. It can occur for a good that the bidder perceives to have a negative attribute, for example a genetically modified crop (Rousu et al., 2007). Given the poor performance of many of the varieties compared to the local traditional mixture we can assume that some farmers' bids for the bean seeds could have been censored.

Tobit type models (Tobin, 1958) are often used with experimental auction bids because of the possibility that vales are censored. We use a generic Tobit model assuming the error term follows a normal distribution and the probability of observing a censored observation is $P(y_i = 0) = \Phi(-x_i\beta/\sigma)$ where Φ is the standard normal distribution. In this case β and σ indicate the probability of observing a non-zero value for y and also the mean of y for positive values of y. The generic Tobit model was amended to incorporate a random effects component to account for the panel nature of the data. In a random effects model the error term is split into the participant-specific part (u_{ij}), which captures the participant characteristics that influence value, and the idiosyncratic part (ε_{itjr}). The u_{ij} are allowed to be serially dependent, which is necessary in this case since the second round bids are dependent on the first round bids. The following model was estimated:

$$\mathrm{WTP}_{itjr} = \alpha + \beta x_{itjr} + \gamma z_{itjr} + \delta v_{itjr} + (u_{ij} + \varepsilon_{itjr}) \tag{1}$$

$$\mathrm{WTP}_{itjr} = \max[0,\ \mathrm{WTP}^{*}_{itjr}] \tag{2}$$

The observed bid by participant i ($i = 1, \dots n = 25$) for bean variety j ($j = 1, \dots n = 5$) in session t ($t = 1, \dots n = 14$) during auction round r is expressed WTP_{ijtr}. WTP_{ijtr} is modeled as a function of three vectors of independent variables. The first is a vector of x_{ijtr} dummy variables for each variety. A vector z_{ijtr} is composed of experimental design variables including a dummy for the auction round, a dummy for whether or not the farmers participated in on-farm research, the auction session ($i = 1, \dots n = 14$), the order of presentation of bean varieties, and the time of day. A vector of socio-demographic variables v_{ijtr} contains information gathered in a pre-auction survey including gender, age, education, literacy, income category, land holding, bean harvest last season, net selling position, and familiarity with bean varieties (reported in Table 1). The conformable vectors of coefficients to be estimated are α, β, γ, and δ.

In order to analyze the ranked data we fit a rank-ordered logistic regression model by maximum likelihood estimation (Beggs et al., 1981). Three ranked alternatives form an observation and all observations are related to the individual farmer. Given the estimates of the bean variety valuation by farmers, the rank order logistic form estimates the probability that each of the varieties is ranked first. Under the assumption that the π_i are independent and follow an extreme value type I distribution, the probability (π_i) that alternative i is valued higher than alternatives 2, $\dots$, k can be written in the multinomial logit form:

$$\pi_i = \Pr\ \{\mathrm{value}_1 > \max(\mathrm{value}_2, \dots, \mathrm{value}_m)\} = \frac{\exp(\mathrm{value}_i)}{\sum_{j=1}^{k} \exp(\mathrm{value}_i)} \tag{3}$$

Results

Demand for improved and traditional bean varieties

The estimated demand curves for bean varieties appear to follow a step function. This is attributable to the common practice of using only 50 or 100 franc coins for informal exchanges. Five, 10, and 20 franc coins exist but are not commonly exchanged (see Fig. 2).

At the current market price for traditional beans (150RWF/500 g), slightly less than half of the farmers were willing to buy any of the improved varieties after receiving information about the nutrient content and yield performance of the varieties. Only about 50% of farmers would pay at least 150 francs for varieties B1 and B4 (slightly less for B4 overall). For varieties B2 and B5 only 25% of farmers would pay 150 francs and even less than 25% for variety B3. These demand curves form an ordering of preferences for the improved varieties that does not appear to be consistent with the relative order of the nutrient values or yields of the varieties suggesting that neither of these attributes clearly explains farmer preferences. In the next section we explore the determinants of farmer WTP.

Determinants of WTP

In this section we pool the bids from both rounds and look at WTP derived from auction bids using a random effects Tobit model of all farmers with the individual farmer as the group variable to control for the separate but related bids in each round (Table 3, column 1). The implied order of preferences for the bean varieties derived from these regression coefficients is consistent with the preferences implicit from the demand curves estimated above and each is significant at the 5% level. Variety B1 was dropped due to the overidentification problem with dummy variables and the negative coefficients on the other variety dummy variables indicate that B1 has the highest implicit WTP value.

The socioeconomic variables that are significant at conventional levels include age, income class, and the quantity of beans bought in the previous season. An *F*-test was used to eliminate socioeconomic variables that do not contribute anything to the overall model. Age is positive but small in magnitude, indicating that older farmers were willing to pay slightly more across bean varieties. A negative coefficient on income class means that as farmers move up an income category, they are willing to pay on average 15 francs less per 500 g of beans. This might be because farmers in higher income groups are more food secure and able to save more seed allowing them to buy beans cheaper when prices are lower later in the year. Farmers who purchased beans last season were willing to pay 0.3 francs less on average for every 1 kg of beans bought. In other words, a farmer who bought 50 kg of beans last season would offer approximately 15 francs less for 500 g of beans than a farmer who bought no beans last season. Farmers who are persistent net buyers of beans appear to be more price-conscious or possibly underbidding because they are only interested in the beans for consumption and are thus seeking a bargain.

Next we add interactions between the variety dummies and other relevant independent variables to explore whether there is an income, gender, or net selling effect associated with any of the varieties (Table 3, column 2). The only interaction that was significant was for wealth class and variety B2. Wealth class was decreasing in WTP for variety B2 by 18 francs per wealth class. This relationship is possibly indicative of risk aversion behavior where poorer farmers are less willing to trade low yield for high nutrient content or they associate the unorthodox color (white) with market sales rather than home consumption. There is no significant relationship between net buyers of beans and individual bean varieties. The dummy variable for the biofortified variety B2 is no longer significant when we account for this interaction.

Location-specific effects

The point of doing on-farm agronomic research is that wide variation in climatic and soil conditions can lead to very different performance outcomes by a single variety. In this section we explore farmer WTP by location to see if location-specific preferences are different from the average preferences calculated above. Again we use Tobit estimations with the addition of a dummy variable for each location and bean variety combination (Table 4). B1 is the dropped variety as in previous regressions and the effects are summarized in Table 5 for comparison.

The coefficients on each variety represent the amount of each farmer's WTP that we can attribute to the individual variety after controlling for the significant experimental and socioeconomic variables (auction round, wealth class, number of members in the household, and the quantity of beans sold in the last season). When we compare these coefficients with the location-specific yields (from Figs. 3 and 4) we can see that in each location the variety with the highest average WTP was the variety with the highest average intercrop yield.

In location A, variety B4 was tied with B1 for the highest intercrop yield (and was the only variety to outperform B6 in monocrop). In location B, variety B4 had the highest intercrop yield and farmers offered the highest overall WTP. In location C, B1 was the highest yielding variety in intercrop and monocrop. In location D, B4 was the best performer in both intercrop and monocrop. And in location E, variety B1 was the highest yielding of the five improved varieties in intercrop although the farmer mixture (B6) was the highest yielding variety in intercrop, which explains the overall lack of strong preferences in this location.

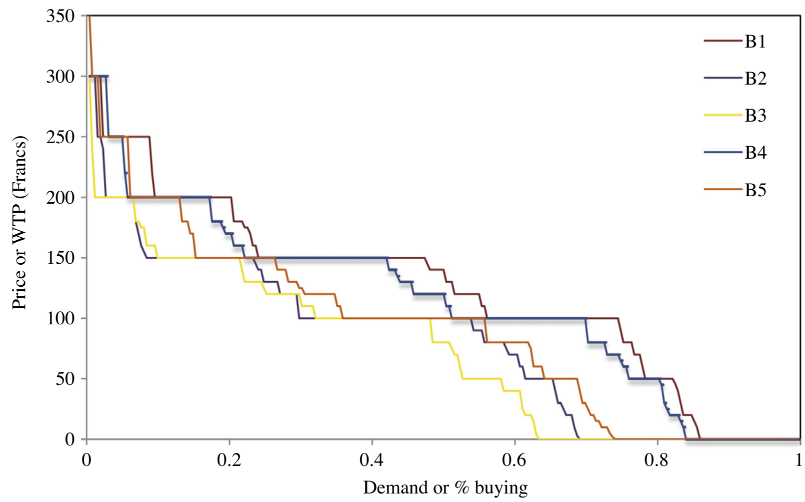


Fig. 2. Demand curves for 500 g of each bean variety (B1–B5) based on nutrient content and yield performance.

Table 3
Tobit estimations of all farmers' WTP using random effects in reduced form.

Variable	(1) All farmers, both rounds		(2) All farmers, both rounds	
	coef.	sd	coef.	sd
B2	−51.43*	5.19	−2.70	15.72
B3	−64.50*	5.22	−67.44*	5.89
B4	−13.32*	5.12	−13.32*	5.11
B5	−42.81*	5.17	−42.84*	5.17
Class	−15.29*	3.57	–	–
Household	3.17*	1.18	–	–
Beans bought	−0.35*	0.13	−0.31*	0.13
B2_class	–	–	−18.33*	5.59
Constant	149.10*	11.49	123.77*	4.44
Log likelihood	−12230	–	−12235	–
Observations	1980	–	1980	–
Censored	610	–	610	–
Sigma_u	30.27	2.39	32.03	2.43
Sigma_e	81.34	1.44	81.29	1.44
rho	0.12	0.02	0.13	0.02

Note: Both models were first estimated using all socioeconomic variables collected and then an *F*-test was performed to drop insignificant variables, which is presented here.
* Statistical significance at the 5% level.

Table 4
Reduced form location specific Tobit estimations for both rounds by location (A–E).

Location	A		B		C		D		E	
WTP_	Coef.	Std.	Coef.	Std.	Coef.	Std.	Coef.	Std.	Coef.	Std.
B2	−43.98*	10.18	−36.45*	10.77	−101.52*	13.84	−29.28*	13.28	−43.33*	9.75
B3	−62.23*	10.26	−46.02*	10.79	−151.44*	14.28	−26.97*	13.19	−51.74*	9.80
B4	33.75*	10.01	9.89	10.60	−109.21*	13.95	30.52*	12.91	−26.92*	9.72
B5	−42.11*	10.16	−63.73*	10.91	−50.19*	13.55	11.03	13.03	−74.52*	9.89
Class	−12.50*	5.29	−14.27	9.19	−14.47	9.21	−17.70	10.34	2.97	7.52
HH members	6.45	4.69	8.03*	3.54	6.75	5.16	1.39	3.94	5.79	4.14
Beans bought	−0.12	0.41	0.10	0.26	−1.06*	0.30	−0.07	0.24	0.21	0.26
Constant	139.66*	18.26	135.87*	27.81	198.11*	31.65	112.96*	30.47	109.27*	24.82
Log likelihood	−2578	–	−2147	–	−2419	–	−1987	–	−1960	–
Uncensored	427	–	358	–	377	–	316	–	336	–
Censored	113	–	92	–	163	–	134	–	74	–
Sigma u	25.48	4.70	28.91	5.04	31.10	6.57	28.39	5.91	20.01	4.54
Sigma e	73.17	2.77	70.89	2.93	98.36	4.02	84.30	3.81	61.89	2.65
Rho	0.11	0.04	0.14	0.04	0.09	0.04	0.10	0.04	0.09	0.04

* Statistical significance at the 5% level.

This relationship between intercrop yield and WTP suggests that farmers still appear to conceptualize the success of a bean variety in terms of its intercrop performance in spite of the pressure farmers feel from the government to pursue monocropping. This result is also interesting since crop trials typically take place on-station in a monocrop system even though monocrop is not necessarily the system farmers use to evaluate the success of a new variety.

Table 5
Summary of location specific estimations from location specific Tobit estimates (Table 4).

WTP	A	B	C	D	E
B1	140	136	198	113	109
B2	96	99	97	84	66
B3	77	90	47	86	58
B4	173	146	89	143	82
B5	98	72	148	124	35

Note: These values are the sum of the constant (or the value of the dropped variety B1) and the individual variety coefficient.

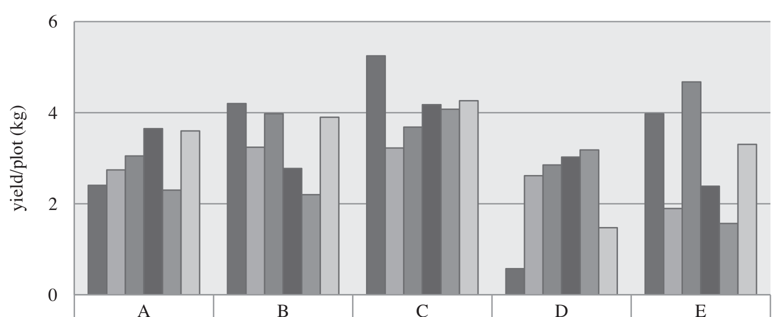
Comparing experimental auction outcomes with rankings

In this section we compare the order of preference reported in nonbinding rankings as opposed to binding auctions that are designed to be truth-revealing. A rank order logistic regression was estimated as described in the methods section, with the rank of each variety as the dependent variable. Logistic regression coefficients represent the change in the log odds of the outcome for a one-unit increase in the predictor variable and can be roughly interpreted as the odds that each of the varieties is ranked first. B1 is the dropped dummy variety again.

The likelihood ratio chi-square for the rank-ordered logistic model is 32.97 with a *p*-value of 0 which signifies that our model as a whole fits significantly better than an empty model. The coefficients in the consumption round are significant at the 1% level with the exception of B2, which is not significant and B5 which is significant at about the 10% level (see Table 6). For the production round, all coefficients on the varieties are positive and significant at the 1% level.

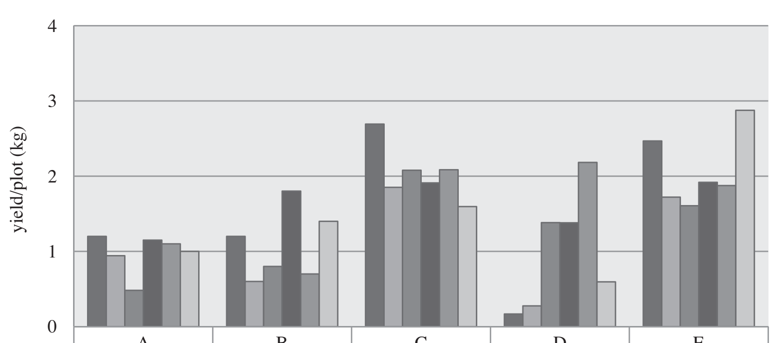
Table 6 summarizes the implied rank order of the five varieties based on the coefficients from rank ordered logistic regressions in each round. In the round following the nutrient information treatment (labeled consumption) the coefficient on B4 is negative, which implies that B4 has greater odds of being ranked first than B1, the dropped variety.

When there is no financial incentive to articulate preferences there appears to be evidence of a tendency for farmers to tell the researcher what they perceive the correct answer is supposed to be, possibly a sort of 'reciprocity effect' for allowing them to participate in the research (Corrigan and Rousu, 2006). Another interpretation is that farmers are concerned with reporting what they think



	A	B	C	D	E
B1	2.4	4.2	5.2	0.6	4.0
B2	2.7	3.2	3.2	2.6	1.9
B3	3.1	4.0	3.7	2.9	4.7
B4	3.7	2.8	4.2	3.0	2.4
B5	2.3	2.2	4.1	3.2	1.6
B6	3.6	3.9	4.3	1.5	3.3

Fig. 3. Monocrop yield across bean varieties (B1–B6) and locations (A–E).



	A	B	C	D	E
B1	1.2	1.2	2.7	0.2	2.5
B2	0.9	0.6	1.9	0.3	1.7
B3	0.5	0.8	2.1	1.4	1.6
B4	1.2	1.8	1.9	1.4	1.9
B5	1.1	0.7	2.1	2.2	1.9
B6	1.0	1.4	1.6	0.6	2.9

Fig. 4. Intercrop yields across bean varieties (B1–B6) and locations (A–E).

Table 6
Coefficients from a logistic rank regression of bean varieties.

Variety	Consumption		Consumption and production	
	Coef.	Std. Err	Coef.	Std.
B2	0.13	0.15	1.46*	0.20
B3	0.42*	0.19	0.93*	0.17
B4	−0.45*	0.14	0.83*	0.15
B5	0.25	0.16	1.14*	0.17

Note: The coefficient represents the odds that variety was ranked first in the consumption round (when farmers tasted the bean varieties and received nutrient content information) and after both consumption information and production information (yield performance in monocrop and intercrop) was received.
* Statistical significance at the 5% level.

the authorities want to hear, in this case they may fear repercussions since they know government is promoting improved beans and monoculture cultivation.

In the round where farmers received the nutrient content information treatment we are interested in whether there is evidence that farmers overstate their preferences for biofortified varieties if they know their preferences are not binding. Indeed, the two varieties that changed order in the consumption round between the two methods are the biofortified varieties B4 and B2, which were both ordered higher using the ranking method (see Table 7).

In the round where farmers received additional production information, we expect farmers might exaggerate their preference for varieties with high monocrop yield and hide some other preferences they believed the researcher was not interested in. In this case the only variety that changed positions was variety B3, which was ranked lower than the implied rankings from the auction coefficients. Interestingly in the auction, variety B3 was revealed as the least preferred overall despite being the highest yielding variety in monocrop on average.

The change in the relative ordering of preferences between the nonbinding ranking and the binding auction bids from varieties with high monocrop yield to those with high intercrop yield supports the hypothesis that farmers were telling researchers what they thought they wanted to hear.

The effect of participating in on-farm research

Participants in the on-farm research clearly had more information than other auction participants about the various bean varieties. To examine the effect of participating in on-farm research we look at the mean value of WTP between the research farmers and non-research group. Table 8 summarizes estimates of research and non-research farmers' WTP across both auction rounds. These summary estimates are based on calculating the effect that is attributable to each individual variety ($\alpha + \beta x_{itjr}$) using the coefficients from the models for the groups.

Variety B1 is strongly preferred by research farmers followed by roughly a tie between varieties B4 and B5, with B3 and B2 far behind. The non-research farmers strongly preferred B1 and B4 to the other varieties with variety B3 clearly the least preferred.

Table 7
Implied ranking of bean varieties based on coefficients from rank ordered logistic regressions and Tobit estimations of WTP.

	Consumption		Consumption and production	
	Rank	WTP	Rank	WTP
1st	B4	B1	B1	B1
2nd	B1	B4	B4	B4
3rd	B2	B5	B3	B5
4th	B5	B2	B5	B2
5th	B3	B3	B2	B3

Table 8
Summary table of WTP for each variety from a random effects Tobit model.

	Non-research	Research	Difference
B1	147.14	164.18	−17.04
B2	107.23	80.95	+26.28
B3	93.56	69.83	+23.73
B4	143.98	122.13	+21.85
B5	102.35	126.77	−24.42

Note: These values were calculated by summing the constant and the individual variety coefficient where the constant is the value of the dropped variety dummy variable (B1).

We might expect farmers who participated in the crop trials to offer higher bids in order to show appreciation to the researchers as a sort of 'reciprocal obligation.' On the contrary, these farmers offered slightly lower bids on average than the non-research farmers who only received information on the nutrient content and yield during the auction. After participating in the on-farm crop research, farmers offered WTP values approximately 20 RWF higher for the two established varieties B1 and B5. In contrast, the non-research farmers displayed greater openness to new varieties, submitting bids approximately 20 francs higher for the three newly introduced varieties (B2, B3, B4).

These results suggest that something in the research experience influenced the values research farmers were willing to pay for beans beyond the information that the non-research group received. Possible differences in information include production attributes such as the number of days to maturity, the plant leaf biomass relative to grain yield, or some other attribute of importance to them that was not known to the other farmers. The explanation for the slightly higher preference for variety B2 among the non-research group may be that a positive effect of biofortification came through despite the low yields presented to them in the production round. Variety B3 was strongly disliked by the research farmers despite being the highest yielding variety in monocrop, which according to some farmers was because the vigorous plant growth led to competition with maize for light and requires stronger stakes. Qualitative findings also revealed that variety B4 was valued less by some research farmers because it was slower to reach maturation and required a longer time in the field making crop loss more likely (Isaacs, 2013). In any case, it appears that the research farmers' experience led them to the conclusion that the new varieties were inferior to the established varieties.

Conclusions

Farmer participatory crop improvement research offers the prospect of greater success in developing improved varieties in areas characterized by highly variable agroecological conditions and complex livelihood systems. A sometimes hidden concern remains that in some circumstances researchers will have difficulty in drawing the correct conclusions from such research due to difficulties in communicating with farmers. In this research we aimed to overcome this challenge by combining participatory on-farm agronomic trials and binding experimental auctions, which generated several results.

The main results are as follows: (1) incentive-compatible preference elicitation methods generate different outcomes than nonbinding methods in this setting; (2) intercrop performance of new varieties is more important to farmers than monocrop performance; and (3) farmer experimentation with new varieties is essential to accurately predicting farmer preferences and adoption behavior. Each of these conclusions is elaborated in more detail below.

Estimating demand for new crop varieties among subsistence farmers may benefit from the use of non-hypothetical designs such as experimental auctions. Binding preference elicitation methods appear to produce a more accurate measure of farmer valuation for new crops when a tradeoff between multiple attributes is involved. Under nonbinding preference elicitation farmers appear to overstate their preference for both newly introduced biofortified and high yielding varieties in monocrop. In our research, changes in the order of preference expressed between nonbinding ranking and binding auctions are perfectly consistent with the hypothesis that nonbinding rankings yield stated preference for the attributes of interest to researchers. The possible tendency of farmers to exaggerate these preferences to researchers has implications for how crop breeders, policy makers, and agricultural economists approach subsistence farmers about their preferences for new varieties.

There is evidence that farmers are more concerned with the performance of a new variety in intercrop than monocrop. Replication and dissemination of varieties with high on-station yield may not address farmers' needs as much as on-farm crop research using traditional intercropping systems. Policy that treats subsistence farmers like profit-maximizing producers does not acknowledge the suboptimal growing conditions and the desire for farmers to minimize exposure to specific agro-climatic and price risk through intercropping.

Subsistence farmers might be curious to try the new varieties presented in this research but the results from comparison of research and non-research farmers suggest that they probably will be disappointed. Participatory on-farm research is necessary to accurately identify varieties that perform well in specific agroecological niches and help identify attractive varieties to farmers prior to replication and dissemination, thus saving both farmer and development resources. While farmers may be eager to try new varieties they will quickly revert if they do not find success.

The broader conclusion from this research is that there is no shortcut to determining which varieties of new crops farmers are likely to adopt. Further use of participatory methods and on-farm research with traditional cropping systems using binding elicitation methods appears to be the best way to predict adoption of new crop varieties.

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