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Nigerian Farmers' Preferences on the Timing of the Purchase of Rice, Cowpea, and Maize Seeds

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THE NIGERIA STRATEGY SUPPORT PROGRAM (NSSP) WORKING PAPERS

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The Nigeria Strategy Support Program (NSSP) of the International Food Policy Research Institute (IFPRI) aims to strengthen evidence-based policymaking in Nigeria in the areas of rural and agricultural development. In collaboration with the Federal Ministry of Agriculture and Water Resources, NSSP supports the implementation of Nigeria's national development plans by strengthening agricultural-sector policies and strategies through:

- Enhanced knowledge, information, data, and tools for the analysis, design, and implementation of pro-poor, gender-sensitive, and environmentally sustainable agricultural and rural development polices and strategies in Nigeria;
- Strengthened capacity for government agencies, research institutions, and other stakeholders to carry out and use applied research that directly informs agricultural and rural polices and strategies; and
- Improved communication linkages and consultations between policymakers, policy analysts, and policy beneficiaries on agricultural and rural development policy issues.

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Executive Summary

Nigerian farmers have been slow in adopting improved seeds due to constraints in both supply and demand. Demand-side constraints pertain to farmers' characteristics, while supply-side constraints are related to capacity.

Farmers' seed demand is complex, and empirical information on Nigerian farmers' seed demand is scarce. One of the less-studied issues is farmers' preference for obtaining seeds closer to planting time. Farmers often purchase seed around planting time, when seed prices tend to be higher. On the other hand, the formal seed sector, often constrained by capacity, distributes seed before or after planting time but not at planting time. Knowing whether farmers are willing to pay higher prices for seeds at planting time may provide useful information on whether the formal seed sector can significantly raise the adoption of improved seeds by ensuring their availability around this season. This study estimates the premium that farmers are willing to pay for seeds if they can buy the seeds one month closer to planting time, and how this premium varies across farmers with different income levels and specific crops (cowpea, rice, and maize).

The literature suggests at least three potential reasons why low-income farmers may be willing to pay higher prices for seeds at planting time. First, low-income farmers may be afraid of losing seeds in storage before planting. Second, they may have less opportunity for reselling seeds at planting time. Third, they may face higher risks in obtaining goods other than seeds before planting time. Farmers may be willing to pay even higher prices for cowpea seeds at planting time partly because cowpea seeds are more susceptible to damage in storage than rice and maize seeds.

This study therefore tests the following hypotheses;

- *Hypothesis 1*: Low-income farmers are willing to pay a higher premium for obtaining seeds near planting time than ahead of planting time.
- *Hypothesis 2*: The premium is larger for cowpea seeds than for maize and rice seeds.

The study estimates farmers' willingness to pay (WTP) using revealed preference (RP) and stated preference (SP) models. The RP model relies on information of farmers' actual seed purchase behavior (when and how much they pay for certain seeds). The SP model relies on the information on farmers' imaginary behaviors in hypothetical situations. Using both models could improve the reliability of the estimated results.

The research team surveyed 420 producers growing rice, cowpea and maize in Kano, Kaduna, and Ebonyi states. While the sample is not nationally representative, important features of seed purchase behavior were observed. The dataset indicates that seeds are often purchased within two months leading up to the planting season. In particular, cowpea seeds are purchased during the month of planting, while maize and rice seeds are generally purchased 1–2 months earlier. The closer the purchase is to planting time, the higher the price paid for the seeds, particularly, cowpea and rice.

The results generally support the hypotheses. Low-income farmers are generally willing to pay higher prices for cowpea seed if they can buy it closer to planting time. The results from the RP model indicate that farmers with an annual household income of US$2000 (which is the median of the sample) may be willing to pay 5 to 10 percent higher price for cowpea seed, if the seed can be obtained one month closer to planting time. Low-income farmers earning less than the median income level may even be willing to pay 10 to 40 percent more. While less accurate, results from the SP model indicate that low-income farmers' have preference for obtaining seeds closer to planting time. On the other hand, farmers' preferences for rice and maize seeds seem consistent across different purchase times and for different income levels, which may be explained by the greater ease of storing rice and maize seeds until planting time than for cowpea seed, which is susceptible to pests and more difficult to store.

In addition, the results indicate that the timing of seed purchases are relatively rigid for all three crops, and is not greatly affected by seed price or income level; indicating that farmers are relatively inflexible in their purchase timing. Such inflexibility indicates that some farmers currently buy seeds ahead of time because sellers are available, although others may prefer to wait until planting time, even if it means they have to pay a higher price. Building supply-side capacity in the formal seed sector for timely seed distribution is as important as mitigating the various constraints on the demand-side facing farmers.

The findings of the study provide several important research and policy implications. Importantly, low-income farmers may be willing to pay higher prices for seeds—particularly for cowpea seed—when they are accessible at planting time. Whether such premiums are high enough for the formal seed sector to substantially increase the adoption rates of improved seeds, however, needs to be assessed with more information about the functioning of the market, such as the price elasticity of seed supply. In addition, studies based on nationally representative surveys may be needed to obtain robust results and to identify how the differences in WTP may be attributed to different factors, such as the risks associated with seed storage between purchase and planting, absence of resale opportunities at planting time, and the risks of higher expenditures on other agricultural inputs in order to better target farmers when distributing improved seeds at planting time.

Keywords: seed, timing of purchase, revealed preference (RP), stated preference (SP), Nigeria

Introduction

Adopting improved seed varieties in Sub-Saharan Africa, including Nigeria, has been slow due to constraints in supplying improved seeds with the appropriate attributes and constraints facing farmers when demanding improved seeds. African farmers have access to the local informal seed sector where other farmers provide traditional seeds with attributes suitable for the local production environment at affordable prices and quantities. On the other hand, improved seeds from the formal sector, while having various desirable attributes such as high-yield potential and uniform quality, may not have the set of attributes farmers prefer, such as good taste or suitability to the local production environment. These improved seeds may require complementary inputs such as fertilizer, agrochemicals, or irrigation facilities that farmers do not always have easy access to.

This study focuses on the timing of seed availability. The available literature in Nigeria and the international community emphasizes the importance of the prompt availability of seeds. The prompt availability of seeds and other inputs often allows farmers to realize maximum production potential (Alene 2007). Farmers without access to improved seeds at planting time may turn to local varieties, since delaying planting times often lowers their yield (Gachimbi et al. 2003). For example, the timing of planting significantly affects the susceptibility of rice varieties to certain pests such as false smut, thus lowering productivity (Ahonsi et al. 2000).

Seed availability at planting time is particularly important for low-income farmers. While better-off farmers often have surplus grain in storage, which can be used at planting time (Almekinders and Louwaars 2002), low-income households tend to lack enough grain stock[1] and often rely on any seeds accessible at planting time (Almekinders 2001). Thus, the limited availability of seeds at planting time is often a major constraint to the adoption of improved varieties (Akulumuka, Mwakitwange, and Ngowi 2001;Okoko et al. 2008). The seed distribution programs in many African countries also often target farmers only a few weeks before they plant (White, Potts, and Hunt 1988). This includes disseminating the information on available varieties (Chirwa et al. 2007).

The timely distribution of seeds depends on the capacity of institutions involved. In Nigeria, breeder seeds are produced by the National Agricultural Research Institutes (NARIs), foundation seeds are produced mostly by private companies and public institutions like the Agricultural Development Projects (ADPs), and certified seeds (so-called improved seeds) are produced mostly by private companies (Adejobi, Omolayo, and Williams 2005). The private seed companies obtain seed stocks from the NARIs and the National Agricultural Seeds Council (NASC) to complement the seed stocks obtained from their outgrowers. Certified seeds are then distributed to farmers by the public sector (state government and public institutions like ADPs) and the private sector (private companies and agrodealers). Improved rice seeds are often distributed by the NASC to farmer service centers of the Federal Ministry of Agriculture and Rural Development (FMARD), ADPs, and farmers' cooperative societies (Adejobi, Omolayo, and Williams 2005). While private seed companies are relatively more active in Nigeria than in other African countries, these companies rarely operate in rural areas generally due to low profitability. The majority of rural farmers in Nigeria are therefore served by the aforementioned public institutions. Due mainly to insufficient financial capacity, the institutions responsible for timely delivery of inputs are ineffective (Manyong et al. 2003), and the lack of timely inputs including seeds is often the norm (Longtau 2003;Odoemenem and Obinne 2010;Omonona 2006;Saka et al. 2005). Further information on how much prompt seed availability matters to farmers is needed to determine the level of appropriate public support for prompt seed distribution by these institutions.

[1] Some farmers also reportedly prefer to buy seed just before planting to avoid the temptation of eating it (David and Kasozi 1999).

While the issues surrounding the timely availability of seeds are well understood, the magnitude of the problem is less known and there is limited empirical evidence to assess the impact of untimely seed availability on farmers' seed adoption behavior and agricultural productivity. For example, little is known about the amount that farmers would be willing to pay to obtain seeds at the optimal time, which is often during planting season.

One way to examine the effect of timely seed availability on farmers' demand is to analyze their willingness to pay (WTP) for particular seeds. This could vary depending on the timing (number of days/months before the planting date) at which they buy seed. In addition, the estimated WTPs for various delivery times can provide information on potential business opportunities for private seed suppliers who can meet the farmers' specific demands (Horna, Smale, and von Oppen 2007). As is indicated in the findings presented in the later section, the current timing for seed purchases by farmers may be rigid and may depend on the availability of sellers. Such rigidity indicates that it is important to assess how WTP varies at different times and to utilize such information in expanding the capacity of formal seed sector in Nigeria to distribute improved seeds. Though challenging, this information can best be elicited by two distinct methods. The first is to use revealed preferences (RP), i.e., to derive an approximation of demand based on farmers' actual purchasing behavior. The second method is to use farmers' stated preferences (SP) for how they would make purchasing decisions if improved seeds were to become available at various times.

This study applies the RP and SP models initially proposed by Rosen (1974) and McFadden (1974), respectively, to answer how Nigerian farmers' WTP for seeds are affected by the timing of seed availability prior to planting. This study focuses on the seeds for rice, cowpea, and maize because of their importance as primary sources of nutrition and income for the rural poor in Nigeria, as well as for key differences in characteristics relevant for farmers' seed demand. Rice is self pollinating and relatively resilient to damage while in storage. Cowpea is self pollinating, tends to be more susceptible to pests and diseases, and tends to get damaged more easily during storage than maize and rice (de Boef and Bishaw 2008). Maize is open pollinating and tends to be less appropriate for recycling.

This study contributes to the literature in the following ways: First, it provides a conceptual framework that describes the effect of farmers' decisionmaking on prices paid for seeds at different times. Second, the study provides an empirical framework for testing the specific timing of farmers' purchase behaviors of seeds. Third, this study, by using the examples of Nigerian farmers' seed-demand behaviors, also contributes to the literature by comparing the SP and RP models in assessing agents' willingness to pay for certain attributes of the commodities. This paper first presents the conceptual framework describing the causes of a higher WTP near planting time. This is followed by an exposition of the estimation methodology and descriptive statistics as well as presentation of results and interpretation of findings. The last section concludes with a discussion of the key implications of the results for future research.

Conceptual Framework

Seed prices in African countries often rise considerably around planting time (Tripp and Rohrbach 2001), although there is large variation across crops and locations. Farmers, however, often make decisions regarding the actual purchase of seeds (Griffiths 1994) and selection of seed from their own stock (Lewis and Mulvany 1997;Rice, Smale, and Blanco 1998;Wright et al. 1994), which affects seed purchasing decisions near planting time. Many African farmers purchase seeds at planting time, when prices are high, potentially indicating that farmers may be willing to pay higher prices at planting time than before planting time. Three potential reasons for this behavior include: 1) the risk of storing seed, 2) the lack of resale opportunities at planting time, and 3) liquidity constraints.

Farmers may not prefer to purchase seeds until planting time due to the risk of losing their seeds in storage. Farmers' lack of resources for storing seeds, both recycled and purchased, has been one of the major constraints for seed security in many African countries (Rohrbach and Kiala 2007;Scott et al. 2003;Wambugu et al. 2009). Some farmers also prefer to acquire seeds at planting time due to the risk of theft or civil conflict, although the evidence for this is relatively scarce (Longley et al. 2001). The constraint in seed storage is generally more common for rice, and partly for maize, as rice seed tends to get recycled over several years, while maize may be less susceptible to pests. In Nigeria, the use of fumigation is common in the Savannah region (Adejumo and Raji 2007), which significantly lowers the amount of seeds lost in storage (Olakojo and Akinlosotu 2004). On the other hand, cowpea is often subject to much higher risks of loss during storage, particularly in the low-humid tropics in Nigeria (Taiwo 1998). The appropriate storage of cowpea seeds often requires sophisticated materials, including airtight containers and agrochemicals (Dugje et al. 2009), which are often inaccessible to farmers.

Second, wealthier farmers may be able to exploit the rise in prices at planting time by purchasing seeds in advance at lower prices, and then reselling some of these at planting time for a higher price. Low-income farmers, however, may not find such opportunities practical, either because it is too difficult for them to acquire any surplus seed stocks, or because they may face higher transaction costs due to their weak access to market information. Third, liquidity constraints may be common for low-income farmers and can affect their WTP depending on their need to purchase other goods besides seeds (for example, fertilizer and labor) and uncertainties associated with such needs.

The premium in WTP for having access to seeds closer to planting time is defined in this study as ε. More specifically, ε is defined as the percentage change in WTP between two periods leading up to planting time and is empirically estimated in this research. The study captures the magnitude of ε as well as its variation across crops (maize, cowpea, and rice) and farm households' income levels. Solving the utility maximization problem of an agricultural household, ε may be explained as how 1) seed loss during storage is mitigated, 2) how high-profit farmers earn from reselling at planting time, and 3) the perception of risk of not having seeds relative to the risk of not having other goods such as fertilizer at planting time (see Appendix A for details). These three factors are expected to be closely associated with farmers' income levels and type of crops. Low-income farmers often face greater losses in seed stock due to their lack of capacity to mitigate such losses, particularly in the case of cowpea. The potential net profit from the resale of seeds for low-income farmers, with little surplus at their disposal, may be small because the chances of realizing profits through resale is minimal. Lastly, farmers often regard the risk of not obtaining seed as relatively low, compared to the risk of not obtaining other goods before planting time, as they tend to have easy access to traditional seeds as a backup (either their own stock or traditional seeds obtained from neighboring farmers), whereas obtaining agricultural inputs like fertilizer or incurring other incidental expenses between time periods is more difficult. This is expected to increase relative risk, σ, and decrease WTP for seed significantly before planting time. For low-income farmers, the effect of such uncertainty may be even greater because they are more likely to face higher liquidity constraints significantly before planting time.

Consistent with the utility maximization behavior of the farming households and their seed purchase preferences, the following propositions will be tested empirically.

Proposition 1: Low-income farmers exhibit greater ε either because of liquidity constraints at $t = 0$, or , relative to their high-income counterparts, they are subject to a greater risk of seed damage during storage and a lower prospect for reselling seeds at higher prices.

Proposition 2: ε is generally larger for cowpea than for maize and rice, because cowpea is more susceptible to damage during storage than maize and rice.

Estimation Methodology

Borrowing consumer theory by Lancaster (1966), the price is the sum of economic values for all attributes of seeds, including the value of its timely availability. Measuring WTP for timely availability in such a framework includes the application of revealed preference (RP) and stated preference (SP) models. Although the two models are substantially different in their approaches, they both lead to an estimate of the relationship between farmers' WTP for certain seeds and the timing of their availability. In this paper, a RP hedonic price model is estimated using least square (LS) specification, while the SP choice experiment model is estimated using conditional logit specification. Using the two models can add robustness to the estimated results and their implications. While the RP hedonic price model uses the actual price observed in the market and the attributes of goods, the SP choice experiment model asks people in the context of a hypothetical market how much they are both willing and able to pay for commodity characteristics that are not valued in the market. Both the RP hedonic price model and SP choice experiment model have their advantages and disadvantages. Unlike the SP choice experiment model, the RP hedonic price model can assess farmers' WTP, taking into account various market constraints, such as the lack of time and budget for farmers. Market constraints are not necessarily captured by the SP choice experiment model and respondents tend to overstate their preference (Ara 2003). The SP choice experiment model, on the other hand, is appropriate for assessing farmers' WTP for hypothetical market conditions that are not yet observed, and offers various statistical advantages such as less correlation between attributes, while in reality several attributes of seeds tend to be correlated. For example, high-yield varieties tend to lack palatability; and therefore, assessing the value for both yield and palatability becomes more difficult; the SP choice experiment model is free from such problems. This study thus employs both the RP and SP models to obtain a robust estimate of farmers' WTP for seed.

RP Hedonic Price Model

In deriving the RP hedonic price model, we assume that the price paid by a farmer *i* for variety ℓ ($w_{i\ell}$) is the sum of the values the farmer places on each attribute of ℓ. By dropping the notation *i* for simplicity, we get

$$\ln(w_\ell) = \alpha_\ell + \alpha_t \cdot t_\ell + \alpha_{t,income} \cdot [t_\ell \cdot \ln(\text{income})] + \alpha_{t,income,crop} \cdot [t_\ell \cdot \ln(\text{income}) \cdot \text{crop}_\ell] + \alpha_\mu \cdot \mu_\ell + \alpha_z \cdot z_u \quad (1)$$

in which $t_{i\ell}$ is how many months before planting the farmer *i* bought seeds for ℓ (months to planting date, or MPD hereafter), μ are the variables of attributes for variety ℓ perceived by farmer *i*, and α's are estimated coefficients. With respect to the attributes, yield, maturity length, palatability, and size of grain are included based on findings from previous studies (Horna, Smale, and von Oppen 2007;Mishili et al. 2009). Equation (1) is estimated using the least square (LS) method[2]. The premium ε for farmer *i* for each crop ($\varepsilon_{i,crop}$) in WTP for buying seeds one month closer to planting date is calculated as

[2] In theory, the hedonic price model consists of two steps (Rosen 1974). The first step requires estimating the economic values of attributes, which are called implicit prices of such attributes. Without further restricting assumptions, the second stage of the analysis requires information about implicit prices and the data pertaining to those attributes, and are combined with the results of the first step to identify the inverse demand function (Tyrväinen 1997). In practice, however, the strict requirements of the data and the econometric problems connected to the second step, most of the empirical studies have used only the first-step hedonic regression model, and despite the loss in accuracy these estimates are presumed adequate (Tyrväinen 1997). In addition, while various specifications have been suggested for the first-step hedonic regression model (Dalton 2004;Halvorsen and Pollakowski 1981), many studies continue to use simpler estimation techniques such as ordinary least squares (OLS) or two-stage least square (2SLS). With the assumption that the market is in a short-run competitive equilibrium and the hedonic price function is the locus of the points connecting buyers' bids' and

$$\varepsilon_{i,crop} = \alpha_t + \alpha_{t,income} \cdot \ln(\text{income}_j) + \alpha_{t,income,crop}(\ln(\text{income}_j) \cdot \text{crop}_{ij}) \quad (2)$$

By applying LS methods (1), farmers are assumed to pay the price up to their WTP, because seed sellers (whether they are dealers, public institutions, or other farmers) may be in a better bargaining position than farmers, implying the need to negotiate the price down so that when farmers buy, they are buying at the highest price they can afford, which is their WTP. The estimate employs both ordinary least squares (OLS) and two-stage least square (2SLS). The 2SLS method is used to correct for potential endogeneity, such as the possibilities that the timing of seed purchases t_ℓ is affected by the price w_ℓ, or some unobserved factors such as the weather affects both the price w_ℓ and planting time, which is embedded in t_ℓ.

SP–Choice Experiment Model

In the SP choice experiment model, each respondent is asked to imagine a hypothetical situation in which he or she buys the same variety seeds that has similar attributes to what they have been growing, and is presented with five different pairs of hypothetical options. For each pair, the respondent answers which option he or she prefers. Each option consists of the attributes of the seeds, the timing at which the seeds can be bought, and the price of the seeds (Table 1). The attribute of each option is defined by modifying the yield, growth length, and the prices of the varieties currently grown by the respondent. Similar approaches for using current conditions by the respondent as a benchmark have been used in several studies (Chattopadhyay, Braden, and Patunru 2005; Patunru, Braden, and Chattopadhyay 2007). Each farmer is asked to compare up to five pairs of options randomly picked from Table 2, and state their preferred options[3]. The 24 options in Table 2 are orthogonal choices selected out of the 96 possible choices (= 2 x 2 x 2 x 3 x 4) using the fractional factorial design[4].

Table 1: Choice experiment

Categories		Values
Base attributes		Varieties grown by the respondent
Modified attributes	Attributes 1 (yield)	Same, +25%
	Attributes 2 (growing length)	-25%, Same
	Timing	1. On the day of planting 2. 1 month before planting 3. 3 months before planting
	Channel	1. Other farmers 2. Government or ADP 3. Agrodealers; 4. Village chief
	Price	Same, -25%

Source: Authors.

sellers' offer curves, the specification in which observed price is regressed on various attributes provides the correct WTP for seeds with given attributes (Chattopadhyay, Braden, and Patunru 2005).

[3] This study did not include the status quo option as it was not clear whether enough variations in responses could be obtained if the status quo option was used. The estimate in this paper therefore omits the alternative specific constants (ASC) from the specification, as choice sets presented to interviewees are purely random and no fixed effects are expected. Some studies exclude the ASC in such cases (Meyerhoff, Liebe, and Hartje 2009). The inclusion of ASC may also trivialize the impact of varying levels of the attributes on respondents' choices (Bennett and Blamey 2001, p55). In addition, it is not feasible to ask interviewees to choose among 24 options. Thus, the number of options is reduced to five. While many studies block all choice sets to a few groups, and ask the same set of options to interviewees who are assigned to the same block, this study randomly selects five options from 24 options for each interviewee. This approach is still acceptable (Bennett and Blamey 2001, p18).

[4] We use *oa.design* command in statistical software R version 2.8.0, which is an open-source software developed by the R Development Core Team.

Table 2: Orthogonal choice set from fractional factorial design

	Yield	Length	Price	Timing	Channel
1	Same	Same	Same	On the day of planting	Government or ADP
2	+25%	–25%	–25%	3 months before planting	Village chief
3	Same	Same	–25%	3 months before planting	Agrodealer
4	Same	–25%	Same	On the day of planting	Other farmers
5	+25%	Same	Same	On the day of planting	Agrodealer
6	Same	Same	Same	On the day of planting	Village chief
7	Same	–25%	Same	3 months before planting	Government or ADP
8	+25%	–25%	–25%	On the day of planting	Agrodealer
9	Same	Same	–25%	1 month before planting	Village chief
10	Same	–25%	Same	3 months before planting	Other farmers
11	+25%	Same	–25%	3 months before planting	Government or ADP
12	+25%	Same	Same	1 month before planting	Village chief
13	Same	–25%	–25%	1 month before planting	Government or ADP
14	+25%	Same	Same	1 month before planting	Other farmers
15	Same	Same	–25%	1 month before planting	Other farmers
16	Same	–25%	–25%	On the day of planting	Village chief
17	+25%	–25%	Same	3 months before planting	Village chief
18	+25%	–25%	Same	1 month before planting	Government or ADP
19	+25%	Same	–25%	On the day of planting	Government or ADP
20	+25%	–25%	Same	1 month before planting	Agrodealer
21	+25%	Same	–25%	3 months before planting	Other farmers
22	Same	–25%	–25%	1 month before planting	Agrodealer
23	+25%	–25%	–25%	On the day of planting	Other farmers
24	Same	Same	Same	3 months before planting	Agrodealer

Source: Authors.

The conditional logit model is then used to estimate the WTP from the choice experiment data. A farmer i with characteristics z_u is presented with a pair of choices, for J times with different combinations of choices each time. Given the random utility theory, assuming that the utility of farmer i from choosing λ-th choice (λ = 1 or 2) from j-th pair of choices is (notation i is included for clarity),

$$U_{ij\lambda} = \beta_t \cdot t_{j\lambda} + \beta_{t,income} \cdot (t_{j\lambda} \cdot \ln(\text{income}_i)) + \beta_{\hat{w}} \cdot \ln(\hat{w}_{j\lambda}) + \beta_\mu \cdot \mu_{j\lambda} + \gamma_\lambda \cdot z_{u,i} + \eta_{j\lambda} \quad (3)$$

in which $t_{j\lambda}$, $\hat{w}_{j\lambda}$, and $\mu_{j\lambda}$ are MPD, price, and other attributes of choice $j\lambda$, respectively, while $\eta_{j\lambda}$ is the idiosyncratic errors, and β's and γ are the estimated coefficients. Importantly, $\hat{w}_{j\lambda}$ is different from WTP (w), which is calculated as the function of $\beta_{\hat{w}}$. It is then assumed that $\eta_{j\lambda}$ follows type I extreme value distribution, meaning that its distribution function $F(\eta_{j\lambda}) = \exp[-\exp(-\eta_{j\lambda})]$. Then, the probability that the farmer i chooses λ-th choice from j-th pairs of choices is expressed in conditional logit form $\exp(A_\lambda) / [\exp(A_1) + \exp(A_2)]$ in which $A_\lambda = \beta_t \cdot t_{j\lambda} + \beta_{t,income} \cdot (t_{j\lambda} \cdot \ln(\text{income}_i)) + \beta_{\hat{w}} \cdot \ln(\hat{w}_{j\lambda}) + \beta_\mu \cdot \mu_{j\lambda} + \gamma_\lambda \cdot z_{u,i}$.

The variables $z_{u,i}$ are common across all j interact with dummy variables for each choice (d_λ), as suggested in Greene (2003). The coefficient γ_λ measures the effect of farmers' characteristics on their choices of certain varieties. The utility for different choice λ is affected by household characteristics ($z_{u,i}$) in different ways (through γ_λ). Although γ_λ is not the main interest, its inclusion leads to consistent estimates of β's.

The premium ε for farmer i (ε_i) to obtain seeds one month closer to the planting date in the SP framework, as counterpart of (2), can be expressed as[5],

$$\varepsilon_i = [\beta_t + \beta_{t,income} \ln(\text{income}_i)] / \beta_{\hat{w}} \quad (4)$$

[5] The expression $\beta_t + \beta_{t,income} \ln(\text{income}_i)$ is the marginal utility from having to receive seed one month earlier (MU_t). Assuming that the coefficient for price ($\beta_{\hat{w}}$) measures the marginal utility of income, the ratio – $[\beta_t + \beta_{t,income} \ln(\text{income}_i)] / \beta_{\hat{w}}$ is the premium in WTP for having to receive seed one month earlier (implicit price ratio). Since ε_i is the premium WTP for receiving seed one month closer to the planting time, the negative sign in front drops off.

Data

This study uses the dataset from IFPRI (2010) on rice, cowpea, and maize growers in Kano, Kaduna, and Ebonyi states in Nigeria. The three states are selected for their comparative advantages in each crop (Kano for cowpea, Kaduna for maize, and Ebonyi for rice), and because they represent different agroclimatic zones (Kano for dry savannah, Kaduna for moist savannah, and Ebonyi for humid forest). The data are collected from a total of 420 farmers who grow rice, maize, cowpea, or some combination of the three. The study team collected 120 from Ebonyi and 150 each from Kaduna and Kano state. These three states were selected because of their dominance in production of these crops in Nigeria (Kano for cowpea production, Kaduna for maize production, and Ebonyi for rice production - although all three crops are grown in all three states), and differences in their agro-ecological conditions (Kano is mostly dry-savannah, Kaduna is mostly moist-savannah, while Ebonyi is humid-tropic). The data were not collected through strict random sampling procedures and thus the interpretation of the results is only applicable to farmers with the characteristics described in the study. The local government areas (LGAs) were selected in consultation with the ADP offices in each of the three states with the objective of covering diverse geographical zones, from which farmers were randomly selected.

The general household characteristics of surveyed farmers are summarized in Table 3, which shows the median and standard deviation of values of various categories across states. At the median of the sample, farmers are generally low income with an annual income of US$2000, a farm size of 3.5 ha, and household head who has seven years of formal or Koranic education. Most households are headed by males, although about 20 percent are headed by females from Ebonyi state. Median income farmers have the storage space of 6 tons of grain, are located 5 km away from the nearest food market, and 2 km away from the nearest all-weather road.

Table 3: Descriptive statistics (median with standard deviation in parentheses)

		Total	Ebonyi	Kaduna	Kano
Household size		12 (10)	10 (5)	10 (7)	15 (12)
Income (US$/year)		2000 (11209)	2500 (4473)	2400 (12177)	1667 (14251)
Farm size (ha)		3.5 (11)	4 (3)	3 (18)	4 (8)
Household head age[a]		50 (11)	52 (11)	48 (10)	53 (14)
Household head years of education (formal)[a]		7 (5)	6 (5)	7 (5)	7 (6)
Household head years of education (koranic)[a]		7 (6)	6 (5)	7 (6)	7 (6)
% of female household head		10	18	5	5
Storage space (ton)[b]		6 (232)	9 (3)	5 (134)	3 (417)
Distance (km)					
nearest food market		5 (24)	5 (7)	4 (28)	6 (29)
nearest all-weather road		2 (31)	2 (6)	0.5 (36)	2 (38)
Asset					
Bicycle	Own (%)	69	69	70	68
	Value (US$)	40 (86)	40 (25)	47 (43)	53 (141)
Motorcycle	Own (%)	76	73	82	74
	Value (US$)	433 (318)	533 (216)	400 (260)	400 (433)
Car / truck	Own (%)	19	19	24	15
	Value (US$)	5000 (5000)	5333 (4184)	3333 (4430)	2333 (6640)
Wheel barrow	Own (%)	57	71	68	28
	Value (US$)	40 (31)	43 (28)	33 (30)	33 (42)
Radio	Own (%)	90	94	97	76
	Value (US$)	27 (46)	40 (36)	20 (57)	20 (36)
TV	Own (%)	54	55	72	35
	Value (US$)	120 (96)	160 (85)	100 (80)	67 (126)
Mobile phone	Own (%)	82	83	92	68
	Value (US$)	40 (150)	40 (49)	40 (62)	47 (281)
Cattle	Own (%)	19	15	22	21
	Value (US$)	667 (2870)	533 (187)	567 (568)	2667 (4300)
Bull	Own (%)	20	7	28	26
	Value (US$)	800 (1270)	533 (211)	800 (998)	1333 (1593)
Goat	Own (%)	72	74	71	69
	Value (US$)	140 (280)	100 (100)	121 (190)	334 (390)

[a]Some respondents only gave information of their own, and not of their household heads, which are excluded.

The information of ownership and values of assets was also collected, mainly to explain the timing of seed purchases, and was used as external instrumental variables for the months-to-planting date (MPD) in the 2SLS estimation. Regarding the transportation assets, most of the farmers in the sample owned a bicycle or motorcycle, while only 20 percent of them owned a car or a truck. Regarding the information assets, the majority of farmers in the sample owned radio and mobile phones[6], while about half of them owned TVs. The ownership and values of transportation and information assets indicate that most farmers had basic means for collecting seed-related information and transporting seeds from the nearby market in small quantities, but their capacities may have been limited for collecting complete information on improved seeds and obtaining seeds when the seeds are the cheapest.

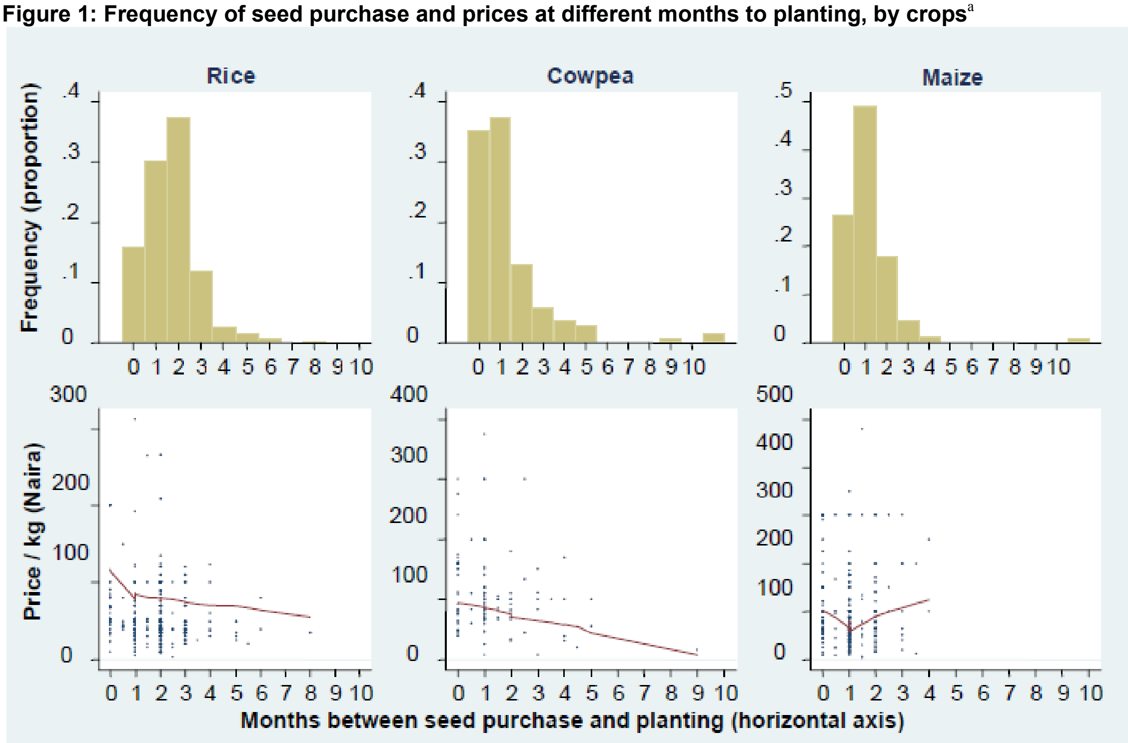
The data on seed purchase behaviors reveal interesting trends.[7] The majority of farmers in the sample purchased seeds within three months of the planting date for all three crops (Figure 1), although purchasing seeds within one month before planting is more common for cowpeas than maize and rice. Prices paid by farmers seem to relate to the months to planting. The price of cowpea seeds exhibits the most negative relationship, and to a lesser extent for rice seeds, while it is ambiguous for maize (Figure 1). Farmers' seed-purchase

[6] Almost no farmer in the sample owned a fixed phone.

[7] This study covers a large number of varieties, and it may be possible that the frequency or the prices of seed purchases vary because different varieties are bought at different times. However, diversity in varieties does not seem to change across different times in the dataset and the variation in aforementioned frequency or price can be attributed to farmers' decisionmaking mechanisms described in the conceptual framework.

behaviors illustrated in Figures 1 roughly indicates that farmers' WTP may vary depending on the timing and crop.

Figure 1: Frequency of seed purchase and prices at different months to planting, by crops[a]



[a]The red lines in the figures are mean of price at different MPD estimated by locally weighted regression with bandwidth = 0.8.

Results and Interpretation

Determinants of the months-to-planting date (MPD)

Although the main focus of the study is the WTP, the determinants of the timing of seed purchase are also estimated. The determinants of MPD were estimated by two-sided Tobit with truncation at 0 and 12 months (Table 4). The results indicate that farmers with less storage space tend to buy seeds later (smaller MPD), possibly because they have to store seeds outside the storage facility where seeds are more vulnerable to various damages. Farmers located further away from all-weather roads may also buy seeds earlier, possibly because they do not have easy access to itinerant seed sellers and perceive it as more risky to leave seed purchasing to the last minute. Rice farmers are also found to buy seeds earlier than maize and cowpea farmers, possibly because of the relative ease of storing rice. High-yielding varieties of each crop are bought earlier, possibly because the expected profit can compensate for the cost of the potential loss during storage. The MPD seems to be affected by relatively few household characteristics and its variation is relatively small within each crop, indicating that the timing of seed purchase may be relatively fixed and determined by the availability of seed sellers.

Table 4: Determinants of timing (OLS and Tobit)[abc]

Dependent variable: Month to planting date (MPD)	OLS		Two-sided tobit	
	Coefficient	Std.err	Coefficient	Std.err
ln(income)	.179	(.165)	.152	(.173)
Household size	-.005	(.016)	-.006	(.018)
Male only	-.155	(.139)	-.181	(.161)
Number of extension contacts per year	-.001	(.002)	-.000	(.002)
Distance to all-weather road (km)	.008	(.007)	.010	(.007)
Distance to nearest food market (km)	-.006	(.006)	-.007	(.007)
Storage space (ton)	-.012†	(.007)	.018*	(.008)
Transportation assets owned (US$1000)	-.023	(.028)	-.027	(.033)
Information assets owned (US$1000)	-.168	(.356)	-.278	(.393)
Ebonyi (=1 if the farmer is in Ebonyi)	.136	(.330)	.258	(.391)
Kaduna (=1 if the farmer is in Kaduna)	.066	(.336)	.165	(.403)
Rice (=1 if the crop is rice)	.345†	(.187)	.425*	(.195)
Cowpea (=1 if the crop is cowpea)	.286	(.303)	.244	(.347)
Ln (yield)	.184**	(.061)	.243**	(.075)
Maturity length	.003	(.003)	.004	(.003)
Constant	-2.431	(2.155)	-2.881	(2.336)
Σ			1.508**	(.182)
p-value for overall fit	.000		.000	
Observation	512		512	

[a]The asterisks indicate the level of significance level, with ** as 1%, * as 5% and † as 10%, respectively.
[b]This regression is a reduced form. Endogeneous factors such as price are excluded. The standard error is adjusted for household cluster.
[c]The transportation assets include car, truck, motorcycle and bicycle, while the information assets include radio, mobile phone and TV.

Results from RP and SP models

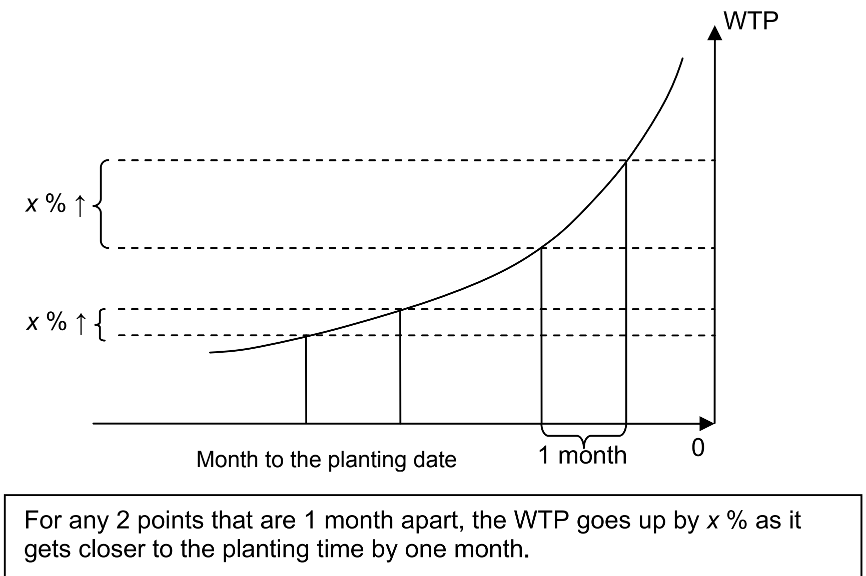
Table 5 shows the results of the RP model (1) under various specifications. The OLS specification is based on the most restrictive assumption that the WTP equals the prices paid and that the timing of purchase is exogenous to the price. The estimated coefficients on MPD indicate the percentage premium a farmer is willing to pay for receiving seeds one month closer to the planting date (in our specification, this applies to any two points in time that are one month apart (Figure 2)). In the first specification under the OLS, the month to planting has a negative effect on the price with the coefficient estimated at -.046. More specifically, the results indicate that the price paid increases by 4.6 percent if the seeds are purchased one month closer to the planting date.

Table 5:Results of RP hedonic-price model[a]

Dependent variable: ln(price)	OLS				2SLS[b]	
	Coef	Std.err	**Coef**	Std.err	**Coef**	Std.err
Month-to-planting date (MPD)	-.046†	(.026)	.125	(.276)	***-.110***	***(.524)***
MPD*rice			.336	(.395)	***.990***	***(.678)***
MPD*cowpea			-1.595*	(.656)	***-1.918***†	***(1.094)***
MPD*ln(income)			-.012	(.018)	***.005***	***(.033)***
MPD*ln(income)*rice			-.025	(.028)	***-.061***	***(.039)***
MPD*ln(income)*cowpea			.123**	(.049)	***.162***†	***(.086)***
ln(yield)	-.011	(.048)	-.024	(.048)	-.185**	(.051)
ln(yield)*rice	-.141†	(.078)	-.118	(.078)	.080	(.100)
ln(yield)*cowpea	-.060	(.082)	-.104	(.084)	.035	(.088)
Channel – other farmers	-.141	(.121)	-.132	(.118)	-.216†	(.131)
Channel – ADP / Government	.041	(.121)	.056	(.117)	-.068	(.131)
Channel – agrodealer	.292*	(.145)	.309*	(.144)	.172	(.143)
Cowpea	.608	(.585)	.959	(.595)	-.249	(.705)
Rice	.787	(.575)	.562	(.571)	-1.014	(.963)
Maturity (days)	-.002	(.002)	-.002	(.002)	-.002	(.002)
Size (large = 1, small = 0)	-.064	(.059)	-.061	(.058)	-.013	(.067)
Palatable (1 if yes)	.156†	(.090)	.153	(.093)	.139	(.101)
Household size	-.004	(.004)	-.005	(.004)	-.001	(.004)
ln(farmsize)	-.013	(.048)	.001	(.047)	-.003	(.060)
Kaduna	.022	(.093)	.015	(.094)	-.104	(.121)
Ebonyi	-.275**	(.090)	-.300**	(.091)	-.540**	(.164)
Intercept	4.632**	(.407)	4.702**	(.408)	5.904**	(.466)
p-value (overall fit)	.000		.000		.000	
R^2	.214		.234		.200	
p-value (overidentification)					.473	
Observation	642		635		549	

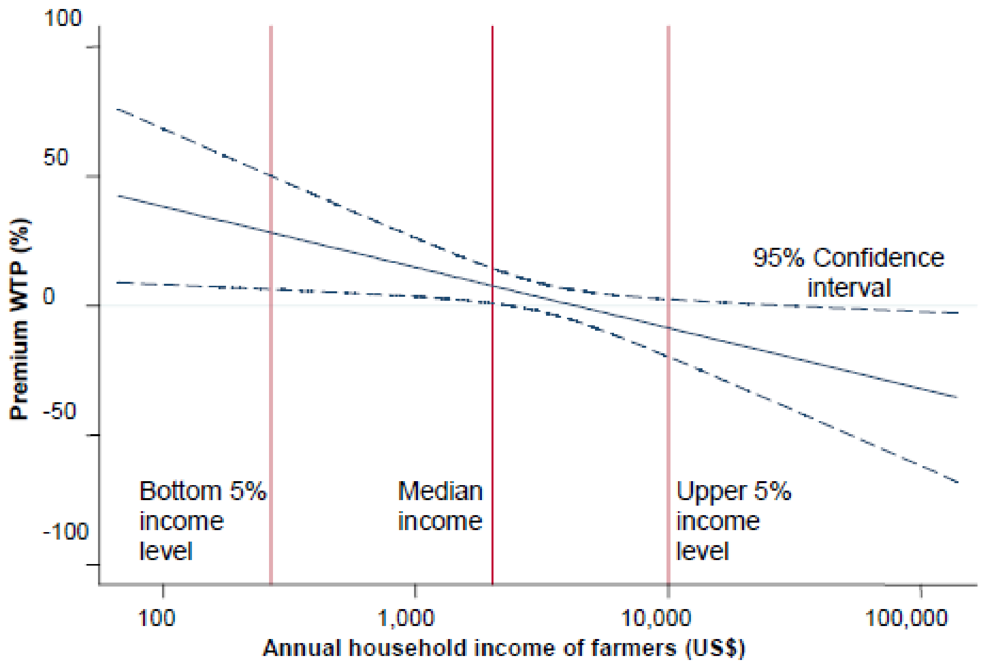
[a]The asterisks indicate the level of significance level, with ** as 1%, * as 5% and † as 10%, respectively. The standard error is adjusted for household cluster.
[b]Italic bold numbers are variables considered endogenous in 2SLS specification.

Figure 2: Illustration of premium WTP



The other models, however, indicate that there are variations in premium WTP across crops and farmers' income levels. The strongest link between timing and WTP may be observed for cowpea. The results also indicate that low-income farmers exhibit a higher WTP for cowpea seeds closer to the planting date, while the opposite holds for high-income farmers, with more than 95 percent statistical significance for most income ranges (Figure 3). More specifically, the lowest income farmer in the data exhibits a 40 percent higher WTP for cowpea seeds one month closer to the planting date, while the highest income farmer exhibits a 30 percent lower WTP. Similar evidence is not found for rice and maize. While the endogeneity of purchase timing is suspected, the 2SLS results are qualitatively similar to the OLS, indicating that the main implications of the OLS results could be valid.

Figure 3: Estimated premium WTP for cowpea seeds at different income levels



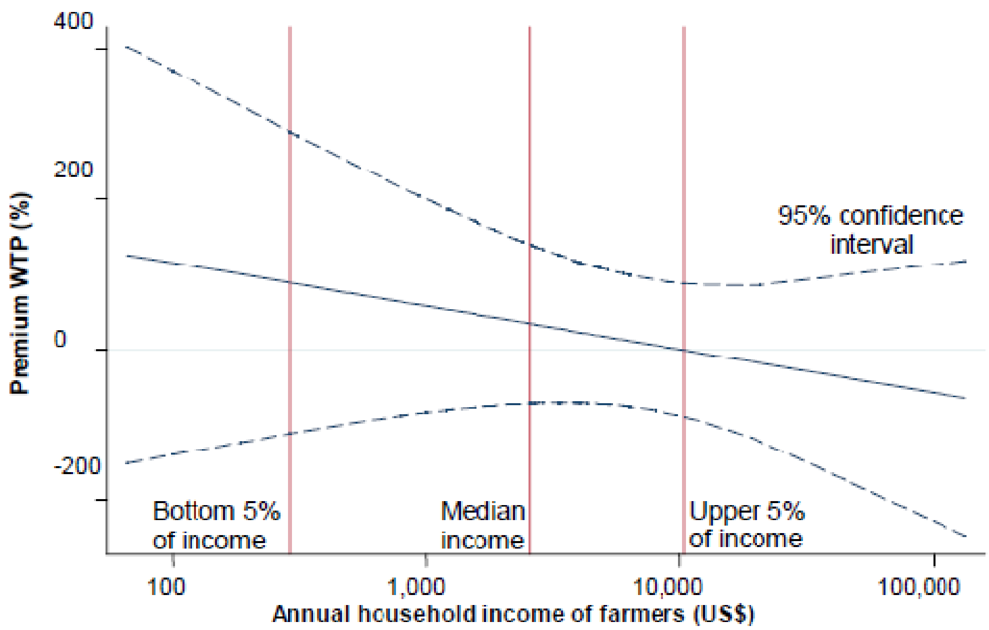
The results from the SP choice experiment model are similar to those of the RP hedonic price model, but different in some respects (Table 6). The results indicate that the preference for the timing may vary for households at different income levels, which is similar to the RP model. The difference across crops is insignificant. It is worth noting that the WTP estimated by the equation (4) depends on the coefficients on price. In order to obtain a robust estimate of WTP, the coefficients of price in the second model are used (-.485) although it is not statistically significant. Figure 4 shows the WTP expressed as premium (percent) in proportion to the current price, in which low-income farmers may be willing to pay almost a 100 percent higher price on average albeit lower estimation accuracy.

Table 6: Results of SP choice experiment

Dependent variable = 1 if the choice is selected, 0 otherwise	Coef	Std.err	Coef	Std.err	Coef	Std.err
MPD	.014	(.055)	-1.405†	(.743)	-1.470†	(.788)
MPD × ln(income)			.111†	(.059)	.115*	(.062)
ln(price)	-.471	(.374)	-.485	(.437)	-12.564*	(5.334)
ln(price) × ln(income)					.924*	(.187)
ln(yield)	4.522**	(.664)	4.373**	(.683)	4.369**	(.693)
Maturity (days)	-.012*	(.005)	-.011*	(.005)	-.010†	(.006)
Channel - other farmers	.208	(.193)	.266	(.193)	.266	(.195)
Channel – ADP / Government	.398†	(.210)	.377†	(.212)	.369†	(.214)
Channel - agrodealer	.311	(.201)	.325†	(.193)	.326†	(.197)
Log-likelihood	-279.406		-265.896		-263.380	
p-value						
Overall fit	.000		.000		.000	
Pseudo-R^2	.096		.097		.106	
Observation	892		850		850	

[a]The asterisks indicate the level of significance level, with ** as 1%, * as 5% and † as 10%, respectively.

Figure 4: Percentage premium for receiving seeds one month closer to planting date



[a] Confidence interval (CI) was estimated by the Delta-method

Overall, the SP model suggests a sharper increase in WTP for low-income farmers, but with larger confidence interval than the RP model. A sharper increase in WTP in the SP model may be partly because the RP model takes into account the market constraints that farmers may actually face, while the SP model does not. The more noise in the estimated premium in WTP by the SP model may be because the formula for WTP in the SP model includes a division by additional estimated coefficients $\beta_{\hat{w}}$ as in (4), while the formula for the RP model in (2) does not. Each of the RP and SP models, however, has its advantage, as discussed earlier. Both models suggest variations in WTP depending on MPD and income indicating the robustness of such results. Altogether, the results from the RP and SP models roughly support the proposition 1 and, to a lesser extent, the proposition 2.

Limitations of the study and future research needs

The results suggest various important issues for future research. First, while time-varying WTP is suggested by the results, more studies are required to identify the causes described in the conceptual framework, including liquidity constraints and seed storage skills, which are approximated by the household's income level in this study. Future studies examining the impacts of these two factors on the premium can make the findings of this study more robust. From the perspective of policy on the seed sector , relaxing those constraints may be as important as supporting the timely delivery of seeds.

Second, it is difficult to assess whether the estimated WTP is high or low at this point, due to various reasons. For example, the information is scarce in Nigeria and many other African countries on the responsiveness of seed supply to higher prices (such as price elasticity of seed supply). In addition, the estimate of such responsiveness is also complicated because the seed supply chain consists of diverse actors (private companies, farmers, seed producers, distributors), basic marketing infrastructures (urban center and rural areas), with different short-term adjustment capacities. The failure to incorporate such complicated structures leads to an incorrect estimate of the aggregate responsiveness of seed supply to higher price by the entire seed sector, thereby leading to inappropriate policy suggestions for public support among each actor in the seed sector.

There are various limitations to the results obtained in this study. First, the sample of farmers is not representative of the country and the generalization of the results is limited. There are also potential sampling biases, which could lead to the overestimation or underestimation of the premium WTP. Secondly, the obtained results are applicable only for specific cases in which the farmer buys the same varieties he or she has been growing. The results do not consider the case in which farmers who have been using traditional varieties switch to improved varieties or to different varieties. Thirdly, the WTP is assumed the same for all varieties within the same crop, and do not distinguish the difference across cross-pollinated, open-pollinated, or self-pollinated, or other attributes (they are used as shifters but not interacted with WTP).

Conclusion

Seed demand in Africa has complicated factors, which often leads to slow adoption of improved varieties by farmers. Among the many factors, various empirical studies point out that farmers do not adopt improved seeds partly because these seeds are often not available at planting time, indicating the possibility that adoption of improved seeds may increase significantly if they are available at planting time. The empirical evidence has been scarce with respect to whether and how much more farmers are willing to pay to obtain seeds at the right time. Given the capacity constraints faced by the public sector in many African countries, the information on WTP for timeliness can aid the government in achieving optimal resource allocation.

This study attempts to narrow such knowledge gaps by assessing how farmers' WTP for seed changes over time, particularly toward the planting time, by applying both RP and SP models. The results provide important insights into the possibility of raising the adoption rates through timely distribution of improved seeds. The timing of farmers' seed purchases seems relatively rigid, meaning their current seed purchase timing may be determined largely by seed supply-side factors such as the availability of sellers and that farmers may have little flexibility. The results indicate that the Nigerian farmers surveyed exhibit different WTP at different times. Most importantly, the results of the RP model indicate that low-income farmers may have significantly higher WTP for seeds closer to the planting season for certain crops like cowpea, while such effects are not significant for high-income farmers and crops like rice and maize. The findings from the RP model are consistent with the hypotheses that farmers' WTP for seed at different times is highly influenced by the susceptibility of seeds to damage during storage and challenges typically faced by low-income farmers such as the high risk of seed stock loss, few seed sales opportunity, and liquidity constraints, which discourage paying for seeds ahead of planting time. The results from the SP model also generally point to a similar tendency by low-income farmers, although the evidence is weaker. From the policy perspective, making improved seeds available closer to planting time is more likely to assist in an improved adoption rate, especially among low-income farmers

The findings also have implications for the direction of future research. First, the analysis may need to be conducted with a larger nationally representative sample, which will provide adequate information about the varieties available at various times in the market, but are not actually purchased by the farmers. This will help improve the robustness of the findings by allowing for testing diverse alternative hypotheses. Second, more empirical studies may also be useful in identifying more clearly the causes of higher WTP at planting time, and whether low-income farmers are more constrained by their lack of good seed storage facilities or limited seed resale opportunities at planting time. Finally, future empirical studies should also investigate the liquidity constraints that lower-income farmers face. The findings may help in designing more specific public support systems to mitigate liquidity constraints faced by low-income farmers in the purchase of improved seeds regardless of the timing of their availability.

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Appendix A: Detailed conceptual frameworks

In this paper, the seed purchase behavior during the planting season among agricultural households in Nigeria is expressed as a utility maximization problem in a two-period model[8]. The two time periods considered are t = 0, which is substantially ahead of the planting date, and t = 1, which combines seed purchases made immediately before planting and subsequently during crop production. In the model, a farmer purchases seed either at t = 0 or 1 but not at both periods.

The focus of this research is to map a farm household's transactions of seeds during or before planting season and the willingness to pay at these two periods of time. In this framework, K represents all the goods relevant for crop-production purposes, where K = {k, ℓ}. Here the goods k are produced without using seed as a direct input into the production process (such as livestock and other non-farm products), and goods ℓ are produced using seed for crop production. While the focus here is a farm household's purchases of seeds for crops ℓ, goods k are also included in the model because decisions on goods k also affect the decisions on seeds for crops ℓ. We define the farm household's behavior as follows:

$$\max_{w_{\ell t}, s_{\ell t}, \psi_{\ell t}, q_{Kt}, x_{Kt}, m_{Kt}, c_{Kt}} \quad \sum_{t=0}^{1} u_t \left[c_{Kt}(p_{Kt}, I_t, \Omega_t, A_{Kt}, F_\ell, \pi_\ell, \omega_{\ell t}, G, \sigma); z_u \right] \cdot \delta^t \qquad (5)$$

Here, a farm household's utility at time t (u_t) is a function of the consumption of goods K at t (c_{Kt}) and other residual factors (z_u). Consumption c_{Kt} is determined by a set of exogenous factors, which are explained below. The farm household's utility is maximized subject to a set of constraints (6) through (15).

$$\sum_K p_{Kt} m_{Kt} + I_t + \Omega_t + \sum_\ell \left\{ \left[-w_{\ell t} - (1-t)\cdot\theta_\ell + \pi_\ell \right] s_{\ell t} + \omega_{\ell t}\psi_{\ell t} \right\} \geq 0 \quad \forall\, t \qquad (6)$$

Condition (6) refers to the farm household's liquidity constraint in which the net revenue from the sales of the goods they produce (the net sales of goods K at time t (m_{Kt}) times its prices (p_{Kt})), income from other sources at time t (I_t), and non-productive liquid assets (Ω_t) must cover net seed purchase. The net seed purchase is determined by the seed price for ℓ at t ($w_{\ell t}$) and the quantity of seed purchased at t (s_t), along with the costs incurred towards seed storage (per-unit cost θ_ℓ), net profit (π_ℓ) per unit of seed bought at t = 0, which realizes at t = 1, through means like reselling it to others at t = 1, and any income from net sales of farmer-owned seed of the same variety (its price at t ($\omega_{\ell t}$) times net sales at time t ($\psi_{\ell t}$))[9]. While it is possible for the farm household to borrow seeds instead of purchasing them (van Wijk 1996), seed sellers do not easily provide credit to buyers due to high transaction costs for monitoring repayments (van Bastelaer and Leathers 2006).

Importantly for crop ℓ, $\psi_{\ell t}$ denotes net sales as 'seed', which is different from '$m_{\ell t}$' which is comprised of net sales of the all the outputs that include grains. Subsistence farm households often sell surplus grains as seed (farmer owned) before the planting season along with grains depending on the market conditions or demand.

[8] In reality farmers can purchase seed at any time up to t = 1 instead of either at t = 0 or t = 1. For simplicity, the presentation here, focuses on two discrete periods while maintaining the essential illustration of how WTP can vary over time given the characteristics of farmers' constraints.

[9] The availability of farmer-saved seed plays an important role in determining how much the farmer is willing to pay for the same varieties purchased from others, and thus included in the conceptual framework. The empirical analysis in this paper, however, does not explicitly use information on farmer-saved seed because of the following reasons. First, the information on farmers' income used in the empirical specification may partly reflect the availability of own saved seed. Second, depending on how long farmers have saved the seed, attributes may have been altered, and it is difficult to obtain information on the changed attributes .

The non-productive liquid assets at t = 1 (Ω_1) is a carryover of its balance in t =*0* (Ω_0) as in (7).

$$\Omega_1 = \sum_{K} p_{K0} m_{K0} + I_0 + \Omega_0 + \sum_{\ell} \left[(-w_{\ell 0} - \theta_\ell + \pi_\ell) s_{\ell 0} + \omega_{\ell 0} \psi_{\ell 0} \right] \geq 0 \qquad (7)$$

Condition (8) states that the quantity of goods k produced at t (q_{kt}) plus the initial endowment (A_{kt}) must cover its allocation as inputs at t (x_{kt}), net sales at t (m_{kt}) and consumption (c_{kt}) at both time periods.

$$q_{kt} - x_{kt} + A_{kt} - m_{kt} - c_{kt} \geq 0, \qquad \forall\, k, t \qquad (8)$$

The initial endowment A_{k1} is simply the sum of initial endowment at t = 0 (A_{k0}) and the net physical balance of goods at t = 0, leading to

$$A_{k1} = q_{k0} - x_{k0} + A_{k0} - m_{k0} - c_{k0}, \qquad \forall\, k, t \qquad (9)$$

For crops ℓ, the physical balance and initial endowments are similar to (8) and (9), except that they are also affected by their sale as seed at t ($\psi_{\ell t}$), distinguished from their sale as grain ($m_{\ell t}$) as in (10) and (11).

$$q_{\ell t} - x_{\ell t} + A_{\ell t} - m_{\ell t} - c_{\ell t} - \psi_{\ell t} \geq 0, \qquad \forall\, \ell, t \qquad (10)$$

$$A_{\ell 1} = q_{\ell 0} - x_{\ell 0} + A_{\ell 0} - m_{\ell 0} - c_{\ell 0} - \psi_{\ell 0}, \qquad \forall\, \ell, t \qquad (11)$$

in which $q_{\ell 0}$ = 0 for all crops ℓ grown by the farm household.

The total quantity of traditional seed used as inputs in production at t = 1 (x_ℓ^*) is

$$x_\ell^* = x_{\ell 0} + x_{\ell 1} \qquad \forall\, \ell \qquad (12)$$

The total quantity of purchased seed usable for production of ℓ at t = 1 (s_ℓ^*) is

$$s_\ell^* = s_{\ell 1} + s_{\ell 0} \cdot F_\ell(\theta_\ell) \qquad \forall\, \ell \qquad (13)$$

in which s_ℓ^* is the sum of seed purchase at ℓ = 1 ($s_{\ell 1}$) and the seed purchase at t = 0 minus those lost during storage, depending on the per-unit cost spent for preservation, which is expressed as $s_{\ell 0} \cdot F_\ell(\theta_\ell)$. The purchased seed available at planting date is the initial purchase quantity at t = 0 times F_ℓ, which is a function of θ_ℓ (per unit cost spent for preserving seed).

The production technology set G is expressed as the relationship between inputs and outputs as

$$q_{\ell t} = G(X_t, x_\ell^*, s_\ell^*; z_q),\ q_{kt} = G(X_t; z_q), \qquad \forall\, k, \ell, t \qquad (14)$$

where goods k and ℓ are produced by a vector of all inputs k other than seeds at t (X_t), quantity of recycled seeds (x_ℓ^*) and purchased seed (s_ℓ^*), and other factors that affect the total factor productivity (z_q).

The non-negativity condition required for the choice variables are

$$c_{Kt}, q_{Kt}, x_{Kt}, w_{\ell t}, s_{\ell t}, \psi_{\ell t} \geq 0 \qquad \forall\, K, \ell, \qquad (15)$$

We include in the above formulation, the farm household's perceptions as a 'relative risk' resulting from not having sufficient quantity of seeds during or before planting time relative to not obtaining other agricultural and consumption (non-seed) goods. This is defined as 'σ', reflecting the farm household's perceptions at time t, and affects whether the farm household prefers to cut down on seed purchases at t due to higher risks for obtaining non-seed goods. The σ could, as is noted below partly explain how the farm household's liquidity constraints may lead to a higher WTP at t = 1.

Following the utility maximization, the WTP at $t = 0$ ($w_{\ell 0}$*) and $t = 1$ ($w_{\ell 1}$*) can be expressed in the following reduced forms which are the functions f of relevant exogenous factors,

$$\text{WTP (at } t = 0) = w_{\ell 0}^* = f\,(p_{K0}, I_0, \Omega_0, A_{K0}, G, z_u, F_\ell, \pi_\ell, \sigma) \tag{16}$$

$$\text{WTP (at } t = 1) = w_{k1}^* = f\,(p_{K1}, I_1, \Omega_1^*, A_{K1}^*, G, z_u) \tag{17}$$

in which Ω_1* and A_{K1}* are the levels of Ω_1 and A_{K1} determined by decisions at $t = 0$ and become exogenous at $t = 1$. In (16) and (17), assuming that p_K, I, Ω, A_K, G, and z_u vary little between $t = 0$ and 1, the premium ε can be roughly explained by F_ℓ, π_ℓ and σ.