Variety Demand in an Integrated Agricultural Household Model with Attributes: Implications for Emerging Crop Biotechnologies

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1. Introduction

Theoretical formulations and empirical approaches to modeling adoption of agricultural innovations abound (Feder, Just and Zilberman, 1985; Feder and Umali, 1993). Most commonly, models have examined the choice between two types of crops or varieties (i.e. subsistence vs. cash, modern vs. traditional) rather than the multi-crop, multi-variety scenarios often observed on farms. An underlying feature of the early adoption models has been a focus on profit maximizing behavior and expected utility maximization (Herath, Hardaker and Anderson, 1982; Smale, Just and Leathers, 1994), inevitably shifting attention towards factors affecting the production side of farmer decisions. An implicit assumption of complete and perfectly competitive input and output markets has also marked theoretical and empirical modeling. Although household characteristics were later included by some authors, and the semi-subsistent nature of farm households and imperfect markets in developing countries recognized, there has been limited effort to formally integrate production and consumption decisions into a single model of variety choice among smallholder farmers. Furthermore, extension of the analysis to incorporate intrinsic consumption and production characteristics of the crops or varieties studied has been limited (Adesina and Zinnah, 1993; Smale, Bellon and Aguirre Gomez, 2001), with greater attention given to exogenous physical characteristics and other household related variables.

This paper derives the demand for planting material of specific varieties from the demand for their attributes using an agricultural household model that can be applied to systems of modern, traditional or mixed crop varieties. The economic model of the agricultural household recognizes the semi-subsistent nature of farmers in developing countries and integrates consumption and production decisions in a framework of market imperfections. We estimate a crop variety demand system, gaining efficiencies in estimation and exploiting cross-equation relationships. When farmers consume at least a portion of what they produce, the relevance of this technique for improved prediction of planting decisions is apparent. The approach may also be adapted to more commercialized systems where consumers are willing to pay price a premium for special qualities or enhanced output traits. We supplement the data on current production of the set of available varieties with data on past "exposure" to address selection bias problems associated with only modeling the demand for currently grown varieties.

These advances have implications for predicting variety demand in the context of seed technical change. With gene insertion (transgenic) technology as compared to breeding through conventional crossing, any crop variety is a potential host for crop improvement. Variety specific demand systems are a finer tool for predicting adoption and diffusion with emerging technologies, disentangling the role of specific consumption and production attributes to farmers planting decisions.

Our application focuses on banana producing households in Uganda using primary household-level data collected in 2003[1]. Uganda is one of the largest banana producing and consuming countries in the world. Banana production is primarily undertaken by semi-subsistent households, with most bananas consumed locally for cooking and beer production, or eaten raw. Banana diversity in Uganda is large, with an estimated 233 distinct clones of the endemic (traditional) highland banana, a number of exotic types introduced from Southeast Asia, and a few recently developed hybrids. Variety-specific production traits (e.g. yield; resistance to pests and diseases) and consumption attributes (e.g. cooking and beer quality) play an important role in the planting decisions of farmers. Nonetheless, efforts to understand their implications at the

[1] Our paper is part of a larger research effort to identify constraints to adoption of disease and pest resistant banana varieties currently under development by the National Agricultural Research Organization (NARO) in Uganda, and to ascertain complementary investments that may be necessary to support their diffusion.

farm level have thus far been modest. The identification of traits highly valued by potential adopters is relevant for guiding applications of genetic engineering, given the limitations in conventional breeding of the vegetatively propagated crops such as bananas.

The goal of this paper is to theoretically derive and estimate a crop variety demand system for semi-subsistence agriculture that exploits the interrelationships among multiple varieties and their intrinsic consumption and production attributes. To model household decisions we specify variety-specific derived demands, expressed in mat counts (or "trees"), and employ a hurdle/count data system model for the econometric analysis. We use a complete taxonomy of banana varieties[2] currently grown by households, as well as past information on variety choice decisions.

The econometric results underscore the importance of variety attributes in estimating variety demand equations, suggesting that their omission could bias predictions in semi-subsistence agriculture. Our findings also confirm hypothesized trade-offs for semi-subsistent farmers in choosing varieties with differential performance for disease resistance and consumption quality.

The remainder of the paper is organized into several sections. We begin with an overview of the economic importance of bananas in Uganda. Next we provide a conceptual framework that summarizes the agricultural household model with attributes and formulates the derived variety demand relationship. Following this, the link between the theoretical framework and a reduced form empirical specification based on a system of Poisson equations for variety demands is discussed. We then present an overview of data collection methods and summary of

[2] We drew on both accepted scientific banana taxonomy (Karamura and Karamura, 1994) and farmer taxonomy (in the survey data) to list the banana varieties in Uganda. In our analysis both definitions are used to formulate a choice set of banana varieties, where farmer names are collected into synonym groups according to taxonomic classification.

variables used in the analysis, followed by a discussion of the estimation results. We conclude with discussions of the important findings and observations on policy implications and directions for future research.

2. Economic importance of bananas in Uganda

Uganda is one of the largest producers and consumers of bananas in the world. Bananas occupy 38% of total planted area, the largest cultivated area among staple food crops in Uganda (NARO, 2001), with more than 75% of all farmers growing bananas (Gold *et al*., 1993). Most banana production takes place on small subsistence farms of less than 0.5 ha with low input farming methods (Gold *et al*., 1998). The life span of banana groves depends on agro-ecological conditions and management practices, ranging from as low as 4 years in central Uganda to over 30 years in western Uganda (Speijer *et al.*, 1999). Per capita annual consumption of bananas in Uganda is the highest in the world at roughly 0.70kg/person/day (INIBAP, 2000; NARO, 2001). Bananas are typically consumed as fruit, prepared by cooking or roasting or drying, and fermented for the production of alcoholic beverages (beer, wine and gin) as well as for non-alcoholic banana juice (Ssemwanga, *et al.*, 2000). Bananas are primarily grown as a subsistence crop with excess production sold in local markets (Mugisha and Ngambeki, 1994).

Uganda is recognized as a second center of diversity for bananas. Most of the cultivars[3] grown in Uganda (85%) are endemic to the East African highlands (NARO, 2001). The 233 distinct clones of the endemic banana cultivars in the country consist of two use-determined types: cooking and beer bananas (Karamura and Karamura, 1994). The non-endemic bananas

[3] Banana variety and banana cultivar are used interchangeably in the paper. Banana variety names are used locally for banana planting materials and are differentiated based on observable characteristics. The biological uniqueness of a banana variety is defined by its cultivar, while genetic uniqueness is defined by its genotype.

are primarily naturally occurring hybrids introduced to the country from Southeast Asia. Among them are exotic beer and sweet bananas.

A number of pests and diseases affect banana production, leading to significant production and income losses. Their incidence has intensified, eliminating susceptible cultivars altogether in some parts of the country (Karamura, *et al.*, 1998). Included among the most widespread problems are weevils, Black Sigatoka disease, and Panama disease or *Fusarium* wilt. Weevils are insects that attack banana cultivars and can cause yield reductions of up to 60%. Different levels of susceptibility among cultivars have been observed and the intensity of weevil damage has been found to decrease with elevation (Gold *et al.*, 1994).

Black Sigatoka is an airborne fungal disease that can cause yield losses of around 50% and reduce the longevity of banana farms from 30 years to as little as 2 years (Craenen, 1998). Although it is believed that the potential damage of Black Sigatoka may be limited by altitude, its virulence in highland situations remains unknown (Gold *et al*., 1993). East African highland bananas are highly susceptible, while exotic beer cultivars are found to exhibit some resistance to the disease (Gold *et al.*, 1993).

Fusarium wilt is another fungal disease that attacks the roots of banana plants. The disease develops in a single plant in as little as two months and causes extensive damage, with the pathogen persisting in the soil for years. The spread of the disease is further facilitated by the use of infected planting material by farmers (Gold *et al.*, 1993). The exotic brewing cultivars are particularly susceptible to the disease, with the extent of wilt incidence reported to be as high as 67% on some farms. The endemic highland banana cultivars are believed to exhibit a greater degree of susceptibility to this disease (Gold *et al.*, 1993).

3. Conceptual framework

Our model borrows from literature considering the role of goods attributes in the utility function (Lancaster, 1966; Ladd and Suvannunt, 1976) and inputs attributes in the production function (Ladd and Martin, 1976), placing variety attribute choice within the decision-making framework of the agricultural household. A static risk-free agricultural household mode (Singh, Squire and Strauss, 1986), which explicitly incorporates variety attributes and accounts for market imperfections in rural environments, is used to derive reduced form variety demand equations (Edmeades, 2003). The model describes banana consumption and production decisions by rural, semi-subsistence households in Uganda.

The household derives utility from the set of intrinsic attributes of the bananas it consumes (rather than from the bananas themselves), the consumption of other goods, and leisure or home time. Let the utility function *U* be defined as

$$U\left[\mathbf{Z}^{C}(\mathbf{X},\mathbf{d}^{C}), X^{G}, H \mid \Omega_{HH}, \Omega_{M}\right],$$

where $\mathbf{Z}^C$ is a *J*-dimensional vector of consumption attributes, $\mathbf{X}$ is an *N*-dimensional vector of banana bunches consumed from each available cultivar, $\mathbf{d}^C$ is an $N \times J$ matrix of input/output coefficients where each element d_{ij}^{C} maps consumption of a unit of cultivar *i* to a unit of attribute *j*, X^G is the consumption level of other goods, *H* is household leisure, $\mathbf{\Omega_{HH}}$ is a vector of exogenous household characteristics and $\mathbf{\Omega_{M}}$ denotes market characteristics that influence consumption preferences. While the household can vary the type and amount of banana bunches it consumes, the input-output coefficients associated with the different banana cultivars are exogenous to the decision process. That is, the variety-specific intrinsic consumption attributes are fixed from the perspective of an individual household.[4]

The agricultural household also engages in production. Variable inputs including labor and cultivar-specific planting materials are used to produce banana bunches on an amount of land pre-allocated for banana production. The mix of cultivars planted is dependent on the farmer's perceptions of the intrinsic agronomic traits each provides. Define the production function *G* as:

$$G\left[\mathbf{Q}, \mathbf{Z}^P(\mathbf{V}, \mathbf{d}^P), L \mid \Omega_F, \Omega_M\right] = 0,$$

where **Q** is an *N*-dimensional vector of bunches grown for each cultivar, $\mathbf{Z}^P$ is a *K*-dimensional function defining the relationship between the *N*-dimensional vector **V** of mats grown of each cultivar and the relative proportions of production attributes they yield, $\mathbf{d}^P$ is an $N \times K$ matrix with fixed elements d_{ik}^P defining this mapping[5], *L* is household labor input, $\mathbf{\Omega_F}$ denotes exogenous farm characteristics, while $\mathbf{\Omega_M}$ captures market-related characteristics that influence production decisions. A fixed physical relationship exists between land area allocated to banana varieties and the total count of banana mats from different banana varieties grown by the household.[6]

Household participation in market transactions is conditional on the existence and completeness of markets and the type and magnitude of transactions costs encountered (de Janvry, Fafchamps and Sadoulet, 1991). Input and output markets for bananas are often incomplete or not readily available in rural areas in Uganda. Planting material is either reproduced on-farm or obtained through informal networks in which money is typically not

[4] Intrinsic attributes are variety characteristics defined by the genetic make-up of different banana varieties and the interactions between genotypes and surrounding environment. They are often expressed as the morphological (observable) characteristics of different banana varieties.
[5] See Ladd and Martin (1976) for the role and marginal valuation of production attributes in the production function.
[6] In Uganda, a standard spatial density of banana cultivars is 3m×3m.

exchanged. Instead, a shadow price for banana varieties captures their marginal valuation to the household. Similarly, family labor is widely used for banana production, implying that leisure is valued by its marginal worth to the household rather than as an opportunity cost derived from a market wage rate.

The perishable nature of bananas precludes the possibility of storage, highlighting the importance of meeting immediate household consumption demand either through market participation as buyers or by self-production. Excess production is sold at local markets or given away with no charge. Although markets for bananas exist, it is widely thought that they fail to capture quality differentials between different varieties. This, along with other external factors (e.g., infrastructure inadequacy) may raise the transactions costs of market participation and affect household production and consumption choices. We include the vector of market characteristics in both the utility and production functions to capture the effect of potential market imperfections on the demand and supply sides, respectively.

The household maximizes utility from consumption attributes, other goods, and leisure by choosing the number of bunches from different banana varieties consumed and produced, spending on other goods, and labor hours spent in banana production subject to income and time constraints, the production technology, constraints on planting material and the total number of mats planted, and non-negativity conditions:

$$\max_{\mathbf{X}, X^G, \mathbf{V}, \mathbf{Q}, L} U\left[\mathbf{Z}^C(\mathbf{X}, \mathbf{d}^C), X^G, H \mid \Omega_{HH}, \Omega_M\right] \tag{1}$$

subject to

$$G\left[\mathbf{Q}, \mathbf{Z}^P(\mathbf{V}, \mathbf{d}^P), L \mid \Omega_F, \Omega_M\right] \leq 0 \tag{2a}$$

$$(\mathbf{Q} - \mathbf{X})'\mathbf{P}^B - P^G X^G + I \leq 0 \tag{2b}$$

$$T - L - H = 0 \tag{2c}$$

$$V_i = 0 \ \forall i \notin \tilde{V} \tag{2d}$$

$$\bar{V} \leq \sum_{i=1}^{N} V_i \tag{2e}$$

$$X_i \geq 0, \quad Q_i, V_i \geq 0 \ \forall i \in \tilde{V}, \tag{2f}$$

where T is total household time available, $\mathbf{P}^B$ is a vector of banana output prices, P^G is the price of other goods, I is exogenous income, $\tilde{V}$ is the set of cultivars for which planting material is available at the village level, and $\bar{V}$ total number of mats that can be planted on the household's farm.

The full income constraint represents the budget limitations to the household, while the production technology establishes the banana production margins. Both constraints are represented as inequalities to reflect that full income can exceed expenditures for consumption goods, as well as to indicate possible decreasing returns to scale due to the presence of a fixed input. Missing markets for labor are depicted by the explicit lack of wage labor as a possible production input or an alternative source of household income. Rather, the time constraint captures the total time available to production and home activities. There are two planting material constraints. Equation (2d) captures the effect of the number of banana cultivars available at the village level. Equation (2e), the total mats constraint, is equivalent to a land constraint and captures the physical limitations of available land for banana production[7]. The set of banana varieties planted need not be the same across households, hence variety-specific corner solutions are possible.

Acknowledging the possibility of corner solutions, the following reduced form derived demand relationship for cultivar varieties arises from the Kuhn-Tucker formulation of the optimization problem:

[7] Alternative uses of land are ignored because they add little to the analysis and, considering the perennial nature of bananas, banana area is plausibly treated as separable from other land allocation decisions. Although intercropping is possible, bananas are regarded as the major crop for most households in the sample.

$$V_i = \begin{cases} V_i(\mathbf{d}^C, \mathbf{d}^P, \mathbf{P}^B, P^G, I, T, \bar{V}, \tilde{V} \mid \Omega_{HH}, \Omega_F, \Omega_M) \text{ for } V_i > 0 \\ 0 \quad \text{otherwise.} \end{cases} \tag{3}$$

Derived variety demand is defined as the number of banana mats (or "trees") from a given banana variety grown by the household. It is determined by variety-specific consumption and production attributes, exogenous prices and income, household characteristics, production technology and market-related variables. This derived demand is used as an estimating equation in the empirical analysis.

4. Empirical model

Our data provide information on whether or not the household has exposure different banana cultivars, and if so, how many mats they currently grow. Given this the production decision can be modeled using a hurdle-type econometric approach consisting of two stochastic specifications. In the first, or hurdle, stage a logit model is used to assess the probability that a household has obtained experience with a given cultivar. In practice this means that the household currently grows the cultivar, has in the past, or otherwise possesses knowledge of the cultivar's attributes. Variety experience is an important distinction that provides a more complete representation of the choice set upon which current observed planting decisions are based. Past use of a cultivar or knowledge of its attributes, however, does not imply that it is currently grown. Thus, the hurdle stage is defined over knowledge of cultivar attributes, either through present or past experience with the cultivar or by observation in neighboring farms. The probability is calculated as a function of household characteristics and attitudes. The decision of interest in this stage is whether a household has obtained knowledge or familiarity with a specific cultivar's attributes, rather than a revealed preference for growing the cultivar (the latter used extensively in the adoption literature).

Conditional on the outcome in the first stage, the second, or cultivar demand stage uses a count distribution to model the decision on how many mats of the cultivar are grown. For the households that possess knowledge of cultivar-specific attributes the expected number of mats grown is estimated as a function of household-level and cultivar-specific characteristics. While only households possessing knowledge of cultivars' attributes are included in the second stage, some may reveal zero mats grown for a subset of available cultivars. These households have past experience with the cultivar or otherwise possess knowledge of its attributes, but currently do not grow the variety. Thus, a non-zero observed outcome for mats of a variety grown implies the household has cleared two hurdles: it has obtained information about the variety, and chosen to produce it in positive quantities.

To formally derive the empirical model, consider first the hurdle stage. Under the logit specification, the probability of observing the outcome for household *h* and cultivar *i* is defined as

$$\pi_{hi} = \frac{\exp(\delta_i Z_{hi})^{I_{hi}}}{1 - \exp(\delta_i Z_{hi})}, \quad h = 1, \ldots, H, \quad i = 1, \ldots, N, \tag{4}$$

where I_{hi}=1 if the household has familiarity with the cultivar and zero otherwise, δ_i is a vector of coefficients to be estimated for cultivar *i*, and Z_{hi} is a matrix of household specific explanatory variables thought to influence the decision on whether or not to obtain information about cultivar *i*.

Familiarity with a cultivar is marked by a respondent household being able to give information pertaining to specific cultivar attributes, regardless of whether they currently grow it or not. The data generating process for these households accounts for two behavioral responses: the household currently grows the variety and has knowledge of its attributes, or the household has knowledge of the cultivar from past experience or observation but does not grow it. For those households, the participation hurdle is crossed and variety demand is estimated, conditional on participation as a non-negative derived demand for mats (Gurmu and Trivedi, 1996). Corner solutions are, therefore, present in the analysis.

Conditional on the household possessing knowledge of the cultivar attributes, we specify the distribution for the number of mats grown of cultivar *i* to be Poisson with conditional mean parameters specified as

$$\lambda_{hi} = \exp(\beta_i X_{hi}), \tag{5}$$

where β_i is a vector of parameters to be estimated for cultivar *i* and X_{hi} is a set of household and cultivar specific factors hypothesized to influence the number of mats the household chooses to grow. Under the Poisson distribution the probability that household *h* grows m_{hi} mats of cultivar *i* is given by

$$pr(M_{hi} = m_{hi}) = \frac{\exp(-\lambda_{hi})\lambda_{hi}^{m_{hi}}}{m_{hi}!}, \quad h = 1,..., H_i, \quad i = 1,..., N, \tag{6}$$

where H_i is the sub-sample of households who have knowledge of cultivar *i*.

We estimate the model simultaneously using maximum likelihood to allow for cross equation restrictions. The contribution to the likelihood function for household *h* is

$$L_h(\delta, \beta; X_{hi}, Z_{hi}) = \prod_{i=1}^{N} \pi_{hi} \times pr(M_{hi} = m_{hi})^{I_{hi}}. \tag{7}$$

This form of the likelihood function makes clear that households contribute to the identification of the cultivar demand equation only if they previously have gained knowledge of the cultivar's attributes, while all households contribute to identifying the hurdle equation.

5. Data

Research methods

The data for our empirical analysis are drawn from a statistical survey of randomly selected banana-growing households in rural Uganda, conducted between February and May 2003 with personal interviews and a supervised team of trained enumerators. The sample domain was selected to represent major banana producing areas in eastern, central, and southwestern Uganda. The sample was stratified according to low and high elevation (below and above 1400 meters above sea level, respectively). Prior biophysical information suggests that elevation is correlated with soil fertility and the incidence and severity of pests and diseases, which are factors contributing to variation in productivity and relate to the potential yield savings available from the adoption of resistant banana varieties.

Primary sampling units (PSU) were defined at the sub-county level, the lowest administrative entity possible to map. Budget and logistical considerations restricted the total number of PSU to 27. They were allocated proportionately with respect to elevation. Secondary sampling units (SSU) were defined at the village level. One SSU was randomly selected per PSU from a list of rural villages with more than 100 households, according to the 1991 Uganda census. A total of 20 households with access to land were selected per village, using a number generator or systematic random sampling depending on whether or not there was periodicity in the list.[8] These efforts provided a sample of 540 rural households in Uganda, of whom 517 are banana-growing and provide the basis for our study.

Variable construction

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[8] A farm household includes female-headed and child-headed (orphaned) households, as well as male-headed households with more than one wife.

A total of 95 banana varieties were grown by households in our sample. A high level of variety diversity was observed at the household level, with farmers growing on average six different cultivars. The proportion of households growing a particular cultivar and its share of total mats planted across households comprise the selection criteria used to identify thirteen banana varieties used in this study.[9] The selected cultivars are distributed across three use-driven types: seven cooking (endemic) varieties, four beer (endemic) varieties, and two sweet (non-endemic) varieties.

Our econometric approach uses two sets of dependent variables for the hurdle (participation) and the variety demand (mat count) stages of the model. The hurdle stage models the probability that a household has knowledge of the attributes of each cultivar. Of the 6721 (517×13) household-cultivar combinations, 45% indicate familiarity with the variety's attributes. Among these approximately three-fourths have knowledge from currently growing the cultivar, with the remaining having knowledge from past experience or observation. Individual cultivars vary substantially in the proportion of households that are familiar with their traits, ranging from approximately 70% of households for the most familiar varieties (a sweet and a cooking type) to 17% for the least familiar variety (a beer type). The largest number of cultivars familiar to a single household is eleven, and the fewest is one.

The hurdle stage is estimated as a function of household-specific factors thought to influence knowledge gathering for the set of thirteen banana varieties. Among the variables hypothesized to affect the participation decision are: gender (capturing preferences associated with culturally defined consumption and production responsibilities), relative experience[10] (an

[9] The 13 selected varieties represent 60% of the sample observations at the household-cultivar level. They are the most popular (across households) and dominant (across varieties) cultivars in the sample.

[10] Typically, age and experience, both measured in years, tend to be correlated such that older people are more experienced for a given task. Population dynamics in Uganda make this general rule not applicable to the country.

indicator of acquired human capital in banana production), time needed to travel to a banana market (capturing the effect of transaction costs on behavior), risk factors such as the perceived frequency of occurrence of Black Sigatoka (BS), Fusarium wilt (FW) and weevils (WE), and elevation (as a proxy for physical and climate characteristics).

The dependent variable in the variety demand stage is the number of mats planted of each cultivar that the household is familiar with. On average households grow 68 total mats, with cooking type mats (42) comprising the largest component of the mean, and beer (17) and sweet (9) type mats comprising the remainder. This division is an indication of the subsistence importance of bananas in Uganda. Conditional on the hurdle stage the largest average for a single cultivar is 28 mats (a beer type grown by 74 households) and the smallest is 6 mats (for a sweet type grown by 212 households).

The determinants of variety demand include household and farm characteristics, market-related characteristics, and variety-specific banana attributes. Household characteristics include the relative experience of the banana production decision maker[11], household size (an indicator of consumer demand) and livestock assets (a proxy for household wealth). Among the farm characteristics are banana production area, the stock of banana planting material at the village level and elevation.

Market-related characteristics include household specific prices and transaction cost proxies. Because the majority of households selling bananas engage in supply transactions at their farm gate, the farm-gate price is an appropriate proxy for the cultivar-specific marginal valuation of bananas net of transactions costs. The farm gate price is spatially dependent and is

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This is attributed to high mortality rates of the active population due to disease pressures causing young people to be more experienced for a given task.

[11] The banana production decision maker is not necessarily the household head, but the person in charge of banana production and management decisions in the household. In Uganda, this person is often a female.

not an equilibrium price for bananas. The purchase price of bananas at local markets is perhaps closer to an equilibrium price for bananas given market imperfections. The farm-gate price is household specific and collected at the cultivar level and the market price is village specific and elicited at the use type (i.e. cooking, beer, sweet) level. Household transaction costs are represented by a measure of the time needed to get to the nearest banana market.

Consumption and production attributes of banana varieties are categorical variables at the cultivar level, with the exception of bunch size (yield), which is a continuous variable. The categorical variables are the consumption attributes cooking quality and beer making quality, and production attributes measuring perceived resistance to BS, FW and WE. Farmers were asked to rate each familiar cultivar according to its supply[12] of each attribute where: 1=good; 2=neither good nor bad; and 3=bad. In order to minimize potential recognition problems, farmers were presented with colored photographs of each attribute of interest. Bunch size is measured as a continuous variable.[13] Farmers were asked to estimate bunch size (in kilograms) for each familiar cultivar in the presence and absence of BS and FW. The expected yield and the expected yield loss were calculated by means of the triangular distribution (Anderson, Dillon, and Hardaker. 1977). Although these constructed variables were constructed for the three biotic constraints, they were only used in the case of FW and BS. This was done to avoid the multicollinearity problems between the FW and WE variables, attributed to farmer recognition problems on the distinction between the cause and effect of the two constraints.

[12] Information on the demand for attributes, defined as the rating of the importance of each attribute, is also available. An equilibrium attribute rating was formulated from a matrix over the supply and demand for each attribute. However, this representation of attribute rating significantly reduced the variation in the data. Moreover, the definition of attribute demand could compromise the results due to potential endogeneity problems.

[13] Banana yield per tree is measured in kilograms and it is the product of the number of bunches per "tree", and the weight of each bunch. It is widespread practice in Uganda to grow a single bunch per "tree", in which case banana yield and bunch size can be regarded as equivalent measures.

A list of variables used in the analysis is given in tables 1 and 2, along with descriptive information and summary statistics. For clarity of presentation table 1 summarizes cultivar-specific information, while table 2 presents the variables defined at the household level. The comparative statics of a non-separable agricultural household model are complex, and unambiguous signs on the direction of effects cannot in general be derived. In light of these theoretical limitations, empirically determined effects supported by observations from the banana literature or findings from the variety choice literature are required for establishing directional associations of variables in the analysis.

6. Results

Estimation Approach

A system of thirteen independent hurdle Poisson (derived demand) equations was simultaneously estimated using maximum likelihood formulated in GAUSS. Cross-equation parameter restrictions are imposed a priori across the three use-types of banana cultivars in both stages of the empirical analysis. The restrictions serve two related purposes. First, estimation of household specific effects at the use-group level provides a convenient base for comparing the relative importance and substitute/complement relationships between attributes of use groups for different types of households. Likewise the use groups parallel the taxonomic classification of genomic groups, allowing indirect inference on household preference for the genetic traits of the three use groups.[14] Second, identification of the parameters of interest is facilitated by restrictions that take advantage of the variability in responses across both households and cultivars.

[14] The sweet types are non-endemic bananas, while the cooking and beer types are endemic cultivars. The genetic construct differs between non-endemic and endemic (typically sterile) cultivars.

The model is specified to include cultivar-specific intercepts for the hurdle and derived demand stages, use group specific parameters for most of the household characteristics, and single parameters for the market characteristics. The parameters on consumption variety characteristics in the variety demand equations are restricted[15] as follows:

$$\beta^i_{cook} = \beta_{cook} \ \ \forall i \in \text{cook}, \quad \beta^i_{cook} = 0 \ \ \forall i \notin \text{cook}$$
$$\beta^i_{beer} = \beta_{beer} \ \ \forall i \in \text{beer}, \quad \beta^i_{beer} = 0 \ \ \forall i \notin \text{beer},$$

where beer and cook in this case denote the set of cultivars in this use group. The parameters on production attributes are constrained based on a priori knowledge of disease and pest risks. Because BS does not attack sweet (non-endemic) cultivars we impose the restriction $\beta^i_{rbs} = \beta^i_{bs} = \beta^i_{bsloss} = 0 \ \forall i \in \text{sweet}$. Likewise, because FW is not a problem for the cooking and beer (endemic) varieties we restrict $\beta^i_{rfw} = \beta^i_{fw} = \beta^i_{fwloss} = 0 \ \forall i \in \text{cook,beer}$.

Estimation Results

A complete table of parameter estimates for both the hurdle and derived demand stages is provided in the Appendix. Here, we briefly summarize estimates for the household characteristics included in the hurdle stage before focusing primarily on inferences for variety demand. Gender, relative experience, and time to market are included with coefficients restricted to be equal across use types. We find that a male with primary banana production responsibility is more likely to acquire familiarity with beer varieties and less likely with sweet varieties, while gender has little effect on cooking varieties. These results confirm the anecdotal observation that men are primarily involved with beer production. For all use types higher relative experience implies a higher likelihood of having familiarity with a cultivar. This effect

[15] Restrictions are imposed based on separability in use of the thirteen banana cultivars. While some banana varieties are recognized as multi-use varieties (i.e. they can be used for both cooking or beer making), the thirteen varieties used in this study have a commonly agreed upon single use.

is significantly greater for sweet cultivars relative to cooking and beer cultivars. Since sweet bananas are the most likely use type to be sold for profit this is consistent with the notion that experienced producers are more likely to supply bananas off-farm. Finally, a greater time needed to get to market increases the likelihood that a cooking cultivar will be familiar and decreases the likelihood for sweet and beer varieties. The effect is particularly strong for sweet cultivars. These estimates illustrate the importance of transactions costs. More distant households are primarily subsistence and rely on cooking cultivars for consumption rather than sweet (and to a certain extent beer) varieties for sale off-farm.

The results for the derived variety demand estimates are given in table 3. There are differences in the effects of explanatory variables by type of cultivar, which is suggestive of the importance of examining sub-groups of cultivars with similar genetic construct and use characteristics, rather than aggregating them into one homogeneous group. Among the household characteristics, relative experience of the representative household member is positively related to variety demand for all three types of banana cultivars. As a farmer gains more experience over time, she has better knowledge of the characteristics of the groups of cultivars grown and plants more mats of each type. The effect of household size varies by type of cultivar. The larger the number of household members, the greater the consumption needs of the household, and the more cooking cultivars are planted, which is consistent with the subsistence nature of most rural households in Uganda. Household demand for beer bananas is reduced with household size, which can be explained by intra-household differences in beer consumption: only men of certain age consume homemade beer. The positive association between sweet bananas and household size could be explained by larger household consumption needs, both in terms of direct consumption of the fruit, as well as for income generating purposes for semi-subsistent households. Sweet cultivar bunches are the most widely sold bananas in local markets in Uganda. The effect of assets (measured in terms of the value of livestock) is only statistically relevant for cooking bananas. The negative relationship is perhaps associated with land allocation tradeoffs between grazing land and banana producing land, and income effects driving substitution away from home production of cooking bananas. To the extent that this is the case improvement in the resistance of cooking cultivars to pests and disease would generate benefits primarily for lower wealth, subsistence households.

As expected, banana area is positively related to variety demand for all varieties. The stock of planting material has a negative effect on variety demand for all types of cultivars. The greater the variety of cultivars available in the community (or village), the lower the number of mats of a given cultivar planted on-farm. This likely reflects complementarity in the bundles of consumption and production attributes provided by different banana varieties, which motivates farmers to plant smaller numbers of more cultivars on the available land.

Regional differences across types of cultivars are also identified. Households in low elevation areas tend to grow a lower number of cooking-type cultivars and a larger number of beer and sweet cultivars. This supports observations in the banana literature that physical constraints to production (e.g. incidence and severity of pests and diseases, reduced soil fertility, lower average rainfall) have affected the extent cooking-type cultivars planted, with households substituting towards beer and sweet types. Cooking bananas are particularly susceptible to BS, the severity of which is confined to low elevation areas.

Market price is, as expected, positively related to variety demand. The higher the market price, the less likely a household is to purchase bananas at the market place, producing instead a greater proportion of consumption needs on-farm. The interaction of market price and the transaction cost variable (time taken to get to the nearest banana market) shows that the responsiveness of households to market price is not homogeneous across geographical locations. Households further from banana markets are less responsive to price due to the higher transaction cost of market access, which limits interaction with the market and results in more autarkic behavior. Households closer to the market respond to market price as expected, providing evidence of market participation when transaction costs are low. The interaction of market price and banana area also yields an interesting result. Households with a larger scale of banana production are less responsive to market price, since immediate household needs can be met from own production rather than purchasing bananas at market. These results provide further evidence that infrastructure improvements allowing greater market participation may allow smaller farmers to increase income by greater specialization.

The farm gate (or supply) price is net of transaction costs to the household and impacts behavior at the point of sale. Contrary to expectations, a higher farm-gate price is associated with a smaller number of mats planted for any cultivar. This effect could be associated with the semi-subsistent nature of most households, in which only a fraction of bananas produced are sold. Responsiveness to farm-gate price is exhibited by the relatively few households that produce substantially more than subsistence levels, while the majority of households are unable to expand production when prices rise due to land and other constraints.[16] Interaction with the scale of production does not alter the direction of the response, while regional differences appear to influence behavior. Households in low elevation areas are more responsive, with higher farm-gate prices inducing greater variety demand.

[16] In an alternative empirical specification we included farm-gate price interacted with a dummy variable indicating if the household sold bananas at the farm gate. The results showed that farmers who produce bananas for sale respond to price as expected; that is, they increase the number of mats planted when the sale price increases. This specification is not reported since ‘sell’ is likely endogenous.

Our results demonstrate the importance of consumption and production attributes in understanding variety demand. The perception of good cooking quality in a cooking-type cultivar increases the number of mats of that variety. Similarly, demand for a beer-type variety increases if the farmer perceives the cultivar is good for beer making.

The production trait estimates illustrate trade-offs between banana types, but also reflect the difficulties that farmers have in recognizing and attributing yield losses to pests and diseases. Perceptions of good resistance to BS are related to growing more mats for cooking cultivars and fewer mats of beer cultivars. Considering that both types of cultivars belong to the same genomic group, this result suggests there are important trade-offs between cooking and beer cultivars. Good resistance to FW is related to a lower number of mats of sweet cultivars planted, which is opposite to expectations. This could be due to the fact that farmers confuse the effect of FW with that of WE. As expected, resistance to weevils increases variety demand for most banana types, except in the case of cooking bananas.

The result for unconditional expected yield in the case of BS is as expected. The bigger the bunch size, the greater the number of cooking and beer cultivars grown. In the case of FW bigger bunch size is associated fewer trees of sweet cultivars grown. This may be explained by efficiency effects, where farmers obtain greater yield through the size of the bunch rather than the number of mats grown. In the case of expected yield loss, higher proportional loss is associated with lower levels of resistance of the cultivar to the specific biotic constraint, which in turn is expected to reduce the numbers of mats grown of this cultivar. This is only observed in the case of BS for cooking cultivars. This expectation is not supported for the other two cases, which could be associated with farmers responding to loss in bunch size by planting more to beer and sweet cultivars.

7. Conclusions and future research

Studying household banana selection and planting decisions is of interest for several reasons. Implicit in the number and mix of planted cultivars are household perceptions and attitudes about cultivar-specific production traits, risk diversification strategies when biotic constraints are binding, subsistence requirements and preferences for specific consumption attributes. Disentangling the role of farmers' attitudes and perceptions of specific production and consumption attributes is essential for the understanding of farm level banana production decisions. Omitting attribute information has important implications for the statistical validity of the results, as well as for the identification of important trade-offs in household choices of banana varieties.

Our approach provides useful information for the selection of suitable local host plants and the targeting of specific traits of interest for future banana improvement research seeking to develop resistant banana varieties with bundles of desirable attributes. It complements scientific efforts to improve banana cultivars by providing socio-economic analysis identifying subsistence needs, production and consumption attribute requirements, and constraints on production decisions for banana farmers in rural Uganda. Improved living standards for smallholder banana farmers through more sustainable food provision and cash inflow from banana selling are among the potential implications of this research.

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Table 1: Cultivar Specific Summary Statistics[a]

Variables	Total	Individual Cultivars: S-sweet, C-cook, B-beer												
		S	C	C	S	C	C	C	B	C	C	B	B	B
KNOW[b] Indicator of respondent familiarity.	0.45	0.70	0.60	0.58	0.60	0.52	0.45	0.43	0.39	0.39	0.28	0.27	0.25	0.17
COUNT[b] Number of mats grown by households.	67.98 (83.8)	6.78 (14.5)	9.29 (23.6)	6.46 (13.8)	2.51 (6.2)	4.97 (13.1)	4.35 (10.3)	6.45 (20.2)	4.03 (11.3)	3.93 (16.7)	6.11 (20.3)	4.84 (22.4)	4.11 (24.5)	4.08 (15.5)
COOK[c] Subjective rating of cooking quality.	1.17 (0.42)		1.13 (0.38)	1.19 (0.45)		1.12 (0.33)	1.16 (0.39)	1.15 (0.38)		1.21 (0.45)	1.33 (0.60)			
BEER[c] Subjective rating of beer brewing quality.	1.15 (0.51)								1.12 (0.45)			1.27 (0.66)	1.09 (0.42)	1.11 (0.44)
RBS[c] Subjective rating of black Sigatoka resistance.	1.87 (0.63)	1.73 (0.58)	1.96 (0.68)	1.91 (0.58)	1.76 (0.62)	2.00 (0.60)	2.08 (0.72)	1.92 (0.60)	1.79 (0.70)	2.02 (0.63)	1.87 (0.49)	1.73 (0.54)	1.70 (0.52)	1.44 (0.58)
RFW[c] Subjective rating of Fusarium wilt resistance.	2.00 (0.76)	2.41 (0.67)	1.75 (0.73)	1.65 (0.65)	2.32 (0.71)	1.75 (0.66)	1.83 (0.76)	1.68 (0.61)	2.41 (0.73)	1.82 (0.68)	1.75 (0.65)	1.98 (0.70)	2.52 (0.62)	2.46 (0.75)
RWE[c] Subjective rating of weevil resistance.	2.25 (0.76)	2.19 (0.83)	2.30 (0.69)	2.11 (0.75)	2.26 (0.77)	2.40 (0.67)	2.32 (0.70)	2.26 (0.74)	2.24 (0.85)	2.28 (0.65)	2.24 (0.69)	2.34 (0.75)	1.95 (0.91)	2.46 (0.72)
BS[c] Expected bunch size (kg) given BS	12.30 (6.33)	7.95 (3.93)	12.46 (6.33)	11.33 (5.65)	15.54 (7.00)	14.07 (6.34)	15.09 (6.04)	14.17 (7.01)	10.58 (6.01)	13.98 (6.09)	13.43 (6.12)	11.47 (4.69)	8.44 (3.65)	9.24 (3.44)

Table 1 continued

FW[c]														
Expected bunch size (kg) given FW	11.96 (6.33)	7.23 (3.66)	12.22 (5.87)	11.69 (5.69)	14.14 (7.19)	13.78 (6.35)	15.37 (6.29)	14.35 (6.73)	9.47 (6.18)	14.43 (5.82)	13.16 (6.08)	11.33 (4.72)	7.74 (3.17)	8.17 (3.11)
BSLOSS[c]														
Expected bunch size loss (kg) given BS	11.13 (9.58)	9.07 (8.48)	14.21 (10.5)	12.80 (9.30)	11.32 (10.0)	6.74 (7.79)	10.95 (9.31)	12.26 (10.8)	9.40 (7.68)	16.03 (11.2)	7.69 (5.06)	9.18 (8.09)	11.92 (8.52)	2.48 (1.88)
FWLOSS[c]														
Expected bunch size loss (kg) given FW	10.82 (11.8)	15.80 (13.3)	6.68 (8.51)	4.48 (6.31)	13.28 (13.9)	7.60 (9.27)	5.95 (5.73)	3.86 (3.48)	17.66 (14.8)	5.87 (5.44)	8.36 (9.19)	9.22 (7.40)	12.30 (10.8)	10.68 (11.2)
MKTP[a,d]														
Village-level market (demand) price in 1000's USh/bunch.	1.39 (0.96)	0.72 (0.47)	2.01 (0.81)	2.01 (0.81)	0.72 (0.47)	2.01 (0.81)	2.01 (0.81)	2.01 (0.81)	0.63 (0.51)	2.01 (0.81)	2.01 (0.81)	0.63 (0.51)	0.63 (0.51)	0.63 (0.51)
FGP[a]														
Household-level farm gate (supply) price in 1000's USh/bunch.		0.53 (0.22)	1.93 (0.71)	2.31 (0.66)	1.59 (0.68)	2.45 (0.88)	2.04 (0.47)	2.22 (0.80)	0.52 (0.60)	2.47 (0.64)	1.92 (0.35)	1..06 (0.67)	0.71 (0.21)	0.38 (0.21)

[a]standard deviations in parentheses.
[b]summaries calculated for full sample of 517 households.
[c]summaries calculated using households that have knowledge of the cultivar.
[d]summaries given at use-type level.

Table 2: Household Specific Summary Statistics

Variable	*Mean*
GENDER Gender of representative household member (male =1)	0.62
RELEXP Ratio of years of experience to age of representative household member	0.24 (0.20)
TIME Time (in hours) to nearest banana market	1.00 (0.53)
PBS Perceived probability of occurrence of Black Sigatoka	0.18 (0.29)
PFW Perceived probability of occurrence of Fusarium Wilt	0.20 (0.28)
PWE Perceived probability of occurrence of Weevils	0.39 (0.32)
ELEV Elevation (low =1, high =0)	0.81
HHSIZE Total number of household members	5.78 (2.67)
ASSETS Value of livestock owned by the household in 1000's of USh	42.32 (96.20)
BAREA Area devoted to banana production in acres	1.35 (2.03)
BSTOCK Number of cultivars available at the village level for planting stock	23.39 (5.53)

Table 3: Selected Parameter Estimates

	Use-type restricted parameters		
	Cook	***Beer***	***Sweet***
Selection			
GENDER	0.0132*	0.2513**	- 0.2257**
RELEXP	0.5507**	0.6837**	1.0292**
TIME	0.0974**	-0.0250**	- 0.3322**
Derived demand			
RELEXP	0.5379**	0.5864**	0.4683**
HHSIZE	0.0679**	-0.0068*	0.0318**
ASSETS	- 0.0038**	0.0004	0.0009
BAREA	0.2922**	0.1576**	0.1055**
BSTOCK	- 0.0375**	- 0.0429**	- 0.0443**
ELEV	- 0.1039*	0.0915**	0.6136**
COOK	- 0.1361**	NA	NA
BEER	NA	- 0.6149**	NA
RBS	- 0.1546**	0.0582**	NA
RFW	NA	NA	0.1497**
RWE	0.0624**	- 0.0481**	- 0.0939**
BS	0.0052**	0.0135**	NA
FW	NA	NA	- 0.0083**
BSLOSS	- 0.0030**	0.0147**	NA
FWLOSS	NA	NA	0.0047**
	Restricted parameters		
MKTP	0.2688**		
MKTP×TIME	- 0.0553**		
MKTP×BAREA	- 0.1171**		
FGP	- 0.3336**		
FGP×BAREA	- 0.0195**		
FGP×ELEV	0.1879**		

Notes:
* denotes significance at 5% level
** denotes significance at 1% level

Appendix Table: Remaining Parameter Estimates

	Cooking Varieties							Beer Varieties				Sweet Varieties	
Selection													
Intercept	-0.4132**	-0.2423**	1.889**	-1.4086**	-0.1819**	-1.0051**	0.4123**	-1.9795**	-0.5635**	-0.7882**	-3.7820**	1.4379**	0.4539**
PBS	0.3303**	0.5151**	-0.3894**	0.9274**	-0.4588**	0.1174**	0.0664*	0.7674**	0.2291**	-2.0049**	-0.8240**	0.4667**	-0.2440**
PFW	0.6990**	0.1409**	-0.8433**	-1.1722**	-1.5007**	1.3119**	-0.9143**	0.8984**	0.3833**	-2.0124**	2.2873**	1.0373**	2.5358**
PWE	-0.2199**	-0.2393**	1.1789**	0.3131**	1.0766**	-0.1143**	1.0524**	0.4696**	0.5151**	1.6966**	-1.3373**	0.3572**	0.2736**
ELEV	1.1386**	0.4037**	-2.5896**	1.1419**	-0.4539	0.1149**	-2.4265**	0.8820**	-1.3602**	-0.8367**	2.2673**	-0.8578**	-0.3465**
Derived demand													
Intercept	3.1410**	3.0794**	2.8751**	2.7961**	3.2540**	3.0197**	3.6378**	3.1013**	3.8289**	3.6727**	4.0283**	2.7919**	2.2117**

Notes:

* denotes statistical significance at the 5% level.

** denotes statistical significance at the 1% level.