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VARIETY DEMAND WITHIN THE FRAMEWORK OF AN AGRICULTURAL HOUSEHOLD MODEL WITH ATTRIBUTES: THE CASE OF BANANAS IN UGANDA

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ABSTRACT

Ugandan smallholder farmers produce the nation's major food crop using numerous banana varieties with distinctive attributes, while coping with important biotic constraints and imperfect markets. This empirical context motivates a trait-based model of the agricultural household that establishes the economic association between household preferences for specific variety attributes (yield, disease and pest resistance, and taste), among other exogenous factors, and variety demand, or the extent of cultivation. Six variety demands are estimated in reduced form, each in terms of both plant counts ("absolute" or levels demand) and plant shares ("relative" demand). Two salient findings emerge from the analysis: 1) the determinants of both absolute and relative demands are variety-specific and cannot be generalized across groups of cultivars; and 2) the determinants of absolute and relative demand are not the same in sign or significance. These findings raise questions about commonly used econometric specifications in the adoption literature. Grouping varieties together masks individual differences, and differences may be important for predicting the adoption of new technologies such as genetically transformed, endemic or local varieties. The development of methods to estimate a complete variety demand system might permit resolution of cross-variety relationships. The purpose of this research is to contribute information of use in identifying suitable local host varieties for the insertion of resistance traits through genetic transformation, and the factors affecting their potential adoption.

KEYWORDS: variety demand; variety attributes; agricultural household model; bananas; Uganda

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VARIETY DEMAND WITHIN THE FRAMEWORK OF AN AGRICULTURAL HOUSEHOLD MODEL WITH ATTRIBUTES: THE CASE OF BANANAS IN UGANDA[1]

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1. INTRODUCTION

Uganda is one of the largest banana producing and consuming countries in the world, and a second center of diversity for bananas. Banana production is primarily undertaken by semi-subsistent households and most bananas are locally consumed as cooking or beer bananas. An estimated 233 distinct clones of the endemic (traditional) highlands banana are grown in Uganda, as well as a number of exotic types from Southeast Asia and a few recently developed hybrids. Variety-specific production attributes (e.g. yield, disease resistance) and consumption attributes (e.g. taste) play an important role in the planting decisions of semi-subsistent farmers.

In recent years there have been pronounced changes in the location and intensity of banana production in Uganda. Geographic shifts in the locus of production,

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[1] This paper is the first of a set of products of joint research undertaken by project partners in Uganda and Tanzania. The social science research is led by the Banana Research Programme of the National Agricultural Resource Organization (Uganda) and the Agricultural Research and Development Institute, Lake Shore-Maruku District (Tanzania), with the International Network for Improvement of Banana and Plantains (INIBAP) and the International Food Policy Research Institute (IFPRI). Doctoral students and professors participate from the University of Makerere, Uganda, University of Sokoine, Tanzania, University of Pretoria, South Africa, University of Wageningen, the Netherlands, and North Carolina State University, USA. Social science research is supported by the U.S. Agency for International Development, and the Rockefeller Foundation.

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declining output, and changes in preferences from endemic to other banana types have been observed. The incidence and severity of pests and diseases, particularly black Sigatoka air-borne disease, have increased.

Efforts to understand these changes and their implications at the farm level have been modest. This paper addresses two related, practical objectives. The first is to contribute information that might be useful in identifying suitable host plant cultivars for insertion of resistance traits through genetic transformation. The second is to better understand the determinants of variety demand and factors affecting potential adoption. Many of the impediments to use of improved varieties are common to those improved by either conventional or non-conventional means.

Banana improvement by means of conventional plant breeding techniques (based on seed production or vegetative propagation) has proved extremely difficult (Persley and George 1999; Johansen and Ives 2001). Most banana varieties are triploid genotypes that are almost or fully sterile. This has constrained the application of conventional breeding methods and has increased interest in the potential of genetic engineering to tackle pressing biotic problems in banana production. Whether plant biotechnology can effectively address production constraints and consumption requirements of poor farmers in developing countries depends on the expression of targeted genetic traits in plant varieties as bundles of desirable phenotypic (observable) attributes, farmers' perceptions of these attributes, and the role of their perceptions in land allocation decisions. We argue that attribute-based models are particularly well suited to predicting the adoption of transgenic varieties.

The research summarized here, drawn from a doctoral thesis (Edmeades 2003), also contributes to the variety choice and adoption literature. The agricultural household model enables the testing of hypotheses about the economic association between a household's choice of varieties and variety-specific attributes. This model is an integrated framework of production decisions and consumption choices of rural households in developing countries. Variety choice is a revealed preference by farmers for a set of variety attributes that best responds to production constraints, satisfies consumption preferences and fulfills specific market requirements (Smale, Bellon and Aguirre Gomez 2001). We consider variety attributes as the performance characteristics of plant varieties as perceived and evaluated by farmers, encompassing both the production (agronomic) capacity of the plant and the consumption attributes of the product. Variety attributes are determined by genetic traits in interaction with farm-specific agro-ecological features and management practices. Social factors may also contribute to the perception of variety attributes. For example, some organoleptic attributes (taste, color, feel of food) are strongly influenced by ethnicity. The economic association between the extent of household's choice of a variety and variety-specific attributes is defined as variety demand.

The next section summarizes the economic importance of banana as a food crop in Uganda and current production problems. The empirical context of banana production in Uganda motivates a variety demand model that considers both multiple varieties and multiple variety attributes. The theoretical approach is then presented, against the background of previous models of adoption and variety choice. The design of the survey research and selected descriptive statistics follow. Econometric findings are reported in Section 6, and policy implications are drawn in the concluding section.

2. BANANAS IN UGANDA

Bananas occupy the largest cultivated area among staple food crops in Uganda (1.4 million hectares or 38% of total planted area (NARO 2001)) with more than 75% of all farmers growing the crop (Zake et al. 2000; Gold et al. 1993). *Per capita* annual consumption of bananas in Uganda is the highest in the world, estimated at around 250kg or, roughly 0.70kg/person/day (INIBAP 2000; NARO 2001). They are consumed as fruit, prepared by cooking, 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).

Banana production is characterized by a continuous growing season due to the all-year-round fruiting nature of the crop. Most banana production takes place on small subsistence farms (plots 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 and it ranges from as low as 4 years in Central Uganda to over 30 years in Western Uganda (Speijer et al. 1999).

Geographic shifts of banana production towards new growing areas (Southwestern Uganda) and the abandonment of the crop in traditional areas (Central Uganda) have occurred in recent years. Declining soil fertility, pest and disease pressures and socio-economic constraints (reduced labor availability and management of the plants) have been cited as causal factors[6] (Gold et al. 2000; Kangire et al. 2000). In the traditional banana growing areas of Central Uganda, the relocation of production of endemic East African highland bananas has stimulated an increase in the production of non-endemic bananas and other food crops (e.g. maize, sweet potato, cassava). Meanwhile, two thirds of Uganda's bananas are being produced in the Southwestern highlands of Uganda, displacing millet as the key staple in this region (Kangire et al. 2000).

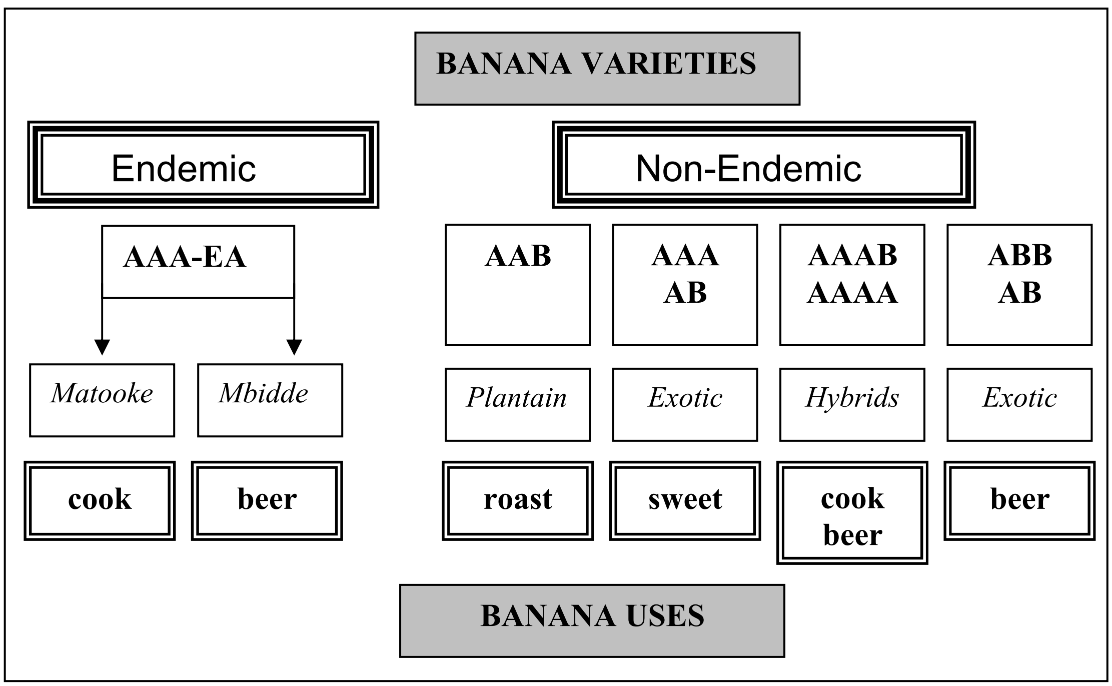
Most of the banana varieties grown in Uganda are endemic to the East African highlands - a region recognized as a secondary center of banana diversity[7]. NARO (2001) estimates that as much as 85% of bananas grown in the country are East African highland bananas. The endemic banana varieties (AAA-EA genomic group) consist of two use-determined types: cooking bananas (*matooke*) and beer bananas (*mbidde*). They are classified by morphological (or observable) characteristics into five clone sets: Musakala, Nakabululu, Nakitembe, Nfuuka and Mbidde (Gold et al. 1998; Karamura and Pickersgill 1999). The non-endemic bananas grown in Uganda are cultivated varieties, which have their origins in South-East Asia. They include exotic beer and sweet bananas (AB, ABB and AAA genomic groups) and roasting bananas or plantains (AAB genomic group). During the last decade, a number of new banana varieties were

[6] Data are not available to allow for the separation between causes and the evaluation of their magnitude on the decline in banana production in Uganda (Gold et al. 1993). There is also lack of information allowing for comparisons between past and current cultivar distribution and cultivar shifts (Karamura et al. 1996).

[7] By banana cultivars or banana varieties we refer to cultivated banana varieties that retain distinct, uniform characteristics when propagated.

introduced in the region (FHIA and IITA hybrids – AAAA, AAAB and other tetraploid genomic groups - developed by breeders in Honduras and Nigeria). These hybrids are grown at selected sites, primarily for the purposes of on-farm evaluation of their agronomic performance and farmer acceptance[8]. Figure 1 (below) summarizes this information by type of variety, genomic classification and most common use.

Figure 1--Banana varieties and uses



The total number of banana cultivars in East Africa has not been determined and it is a subject of on-going debate among breeders. One source of confusion is multiple local names. The same name may be given to more than one clone, or a single clone may have several different names in different parts of the country (Ddungu 1987).

[8] Although the production of big bunches is a typical characteristic of hybrids, they have poor cooking quality, which renders their consumption attributes non-desirable to rural households and in urban markets (NARO 2001).

Karamura and Karamura (1994) identify a total of 233 East African highland banana cultivars (*Musa spp*., genome group AAA-EA), of which 145 are cooking bananas and 88 are beer bananas.

Farmers growing 10 to 15 different banana cultivars in stands of less than 200 banana mats are frequently encountered (Gold et al. 1998; Karamura et al. 1998; INIBAP 2000). Farmers perceive different banana cultivars to be associated with distinct consumption and production advantages and disadvantages. Cultivar selection criteria are found to vary among farmers in a given region and across regions according to household production objectives (sale and domestic consumption) (Gold et al. 1998). Insight into the specific traits that motivate farmer selection of a cultivar is limited and primarily derived from on-station research trials rather than on-farm research. The relationship between morphological or trait diversity and the utility of these traits to farmers is also poorly understood (Gold et al. 1998; Karamura et al. 1999).

A number of pests and diseases affect banana production and lead to significant food and income losses. Among them are nematodes, weevils, Black Sigatoka disease and Panama disease (or *Fusarium* wilt). The incidence of pests and diseases has intensified, eliminating susceptible cultivars altogether in some parts of the country (Karamura, et al. 1998). Weevils attack banana cultivars and can cause yield reductions of up to 60%. The traditional highland bananas are characterized by a great degree of susceptibility to weevils as compared to the more resistant exotic cultivars. Different levels of susceptibility among cultivars have been observed and the intensity of weevil damage has been found to decrease with elevation (the most severe being between 1000-1100 masl) (Gold et al. 1994; Abera et al. 2000).

Black Sigatoka is an airborne fungal disease that can cause yield losses of around 50% (due to the reduction in the number of fruit per bunch and lower fruit weight) 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, the virulence of this pathogen 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; Stover 2000).

Panama disease (Fusarium Wilt) is another fungal disease, which attacks the roots of banana plants. The development of the disease in a single plant is rapid (2 months) and the damage it causes is extensive, with the pathogen persisting in the soil for a long period of time. 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).

A common observation in the literature is the widespread confusion and error in the recognition of pest and disease problems by farmers. Farmers tend to attribute damage to the causal agent they can readily observe. Visible symptoms from *Fusarium* wilt and Black Sigatoka have often been attributed to other pest or soil problems (Gold et al. 1993). Added to the "recognition" problem is the limited availability of information regarding the effects of agro-ecological characteristics and farming practices on pest and disease type and spread of damage. This has led to divergence between the cause of the problem, as perceived by farmers, and effective control strategies against pests and diseases adopted by farmers. Traditional practices for pest control are widely used. Often, farmers simply accept low yields or opt for substituting bananas with other crops or more tolerant banana varieties (Gold et al. 1993; Sserunkuuma 2001). These findings have implications for banana breeding and adoption of resistant cultivars. They also underscore the importance of socio-economic variables in analyzing determinants of demand for varieties.

3. THEORETICAL MODEL

PREVIOUS MODELS OF ADOPTION AND VARIETY CHOICE

Theoretical formulations and empirical approaches to modeling the partial adoption of agricultural innovations by farmers abound (Feder, Just and Zilberman 1985; Feder and Umali 1993), though the framework within which variety choice is examined has not been uniform. Most commonly, models have treated the choice between two types of crops or varieties (modern vs. traditional or subsistence vs. cash) rather than the multi-crop, multi-variety scenarios often observed on farms. Within a portfolio selection framework, variety choice is determined by trade-offs between the level of expected yields and the variance (or variability) in yield performance. Within the framework of safety-first behavior, adoption is conditional on the variety fulfilling the food requirements of the household (Herath, Hardaker and Anderson 1982; Smale, Just, and Leathers 1994). Variety choice has also been addressed from the viewpoint of economies of scope, where adoption is driven by trade-offs between the joint products of a given crop variety rather than by intrinsic input characteristics (Traxler and Byerlee 1993; Renkow and Traxler 1994).

The importance of intrinsic consumption and production variety attributes, as perceived by farmers, has received some attention in the more recent adoption and variety choice literature (Knudsen and Scandizzo 1982; Adesina and Zinnah 1993; Bellon and Taylor 1993; Smale, Just, and Leathers 1994; Barkley and Porter 1996; Smale, Bellon and Aguirre Gomez 2001; Hintze 2002).

An underlying feature of the historical adoption literature has been the focus on farmers' profit maximizing behavior and expected utility maximization (when risk and uncertainty play a role in decision making), inevitably shifting attention towards factors affecting the production side of farmer decisions. The response of yield to a set of exogenous factors (e.g. agro-ecological conditions) and endogenous determinants (e.g. aversion to risk) was the preoccupation of the early adoption literature. Although household characteristics were later included in the decision equation by some authors and the subsistent (or semi-subsistent) nature of farm households in developing countries recognized, there have been limited efforts to formally integrate production and consumption decisions into a single model that examines the adoption by smallholder farmers of agricultural innovations.

Most of the economic relationships established in the adoption literature hinge on a general assumption of the existence of complete and perfectly competitive input and output markets (i.e. households are price-takers). Although it has been recognized that some markets are imperfect or missing altogether in rural areas (e.g. markets for credit) few attempts were made in the early adoption literature to formally model the impact of such market imperfections. These were subsumed by assumptions about the risk-averse behavior of the farm household.

By contrast, the agricultural household model has extensively been used to analyze different household-level decisions of semi-subsistent households in developing countries (Singh, Squire and Strauss 1986). This framework explicitly recognizes market imperfections and their impact on household decision-making. Market "failure" arises when the costs of transacting at the market place exceed the benefits from participating in it (de Janvry, Fafchamps and Sadoulet 1991), and it is characterized as being household-specific (Goetz 1992).

The agricultural household model with attributes (Edmeades 2003), summarized next, is a complex but transparent method for deriving optimal relationships from sequential, as well as from simultaneous household production and consumption decisions.

A HOUSEHOLD MODEL OF VARIETY CHOICE WITH ATTRIBUTES

The model (Edmeades 2003) borrows from frameworks that consider the role of goods attributes in the utility function (Lancaster, 1966; Muellbauer, 1974; Ladd and

Suvannunt, 1976) or inputs attributes in the production function (Ladd and Martin, 1976), placing variety choice within the decision-making framework of the agricultural household (Barnum and Squire, 1979; Singh, Squire and Strauss 1986; Sadoulet and de Janvry *199*5). The derivation of a reduced form relationship between optimal land allocations and household preferences, technology and other exogenous factors parallels the formulation of land shares in the analytical framework developed by Smale, Bellon and Aguirre Gomez (2001). This relationship is examined within a static risk-free model under the case of attribute uncertainty associated with the performance of agronomic traits (yield and resistance to biotic factors). The approach presented here addresses uncertainty with respect to outcome (i.e. observed yield) and not behavior (e.g. risk aversion).

The novel insight is the use of an agricultural household model with attributes as a modeling tool for the formal derivation of the association between household preferences for specific variety attributes and variety demand, expressed as mat counts or mat shares. The variety-specific approach expands the simplistic traditional variety-modern variety dichotomy in the adoption literature. This is important for transgenic as compared to conventional breeding technologies, which involve trait insertion into any one or several of a number of potential host cultivars. Variety demand is expressed in mat counts and mat shares (the share of all mats in a particular variety)[9]. The crop area allocated to a variety, or crop area share, was commonly used in the adoption literature for high-yielding cereals such as rice, wheat, or maize.

[9] Bananas and plantains are not true trees, but rather herbaceous plants that grow in stems called mats.

Following Lancaster's (1966) approach to consumer theory, the household derives utility from the set of "intrinsic" properties of the goods it consumes, rather than from the goods themselves. Different goods (or inputs) contain different relative (fixed) proportions of the various "intrinsic" attributes (or joint-outputs). Household utility is defined over the set of consumption attributes conferred by different banana cultivars. Adapting the notation used by Muellbauer (1974) and Ladd and Suvannunt (1976), the vector of consumption attributes represents the total amount of all banana consumption attributes ($j = 1, \ldots, J$) conferred by the different banana bunches consumed ($i = 1, \ldots, N$): $\mathbf{Z^C} = [\mathbf{Z_1}^{\mathbf{C}}(\mathbf{X}; \mathbf{x_1}), \ldots, \mathbf{Z_J}^{\mathbf{C}}(\mathbf{X}; \mathbf{x_J})]$. The vector $\mathbf{X} = (X^1, \ldots, X^N)$ comprises all banana bunches from different banana varieties consumed by a given household, including cultivars used for cooking, beer brewing, eaten as fruit or roasted. The vector $\mathbf{x}$ encompasses the input-output coefficients that establish the technical link between the different banana bunches consumed (the inputs) and the level of the consumption attributes (the outputs) they possess: $\mathbf{x} = (x_1^i, \ldots, x_J^i)$. These coefficients convert each banana bunch into units of consumption attributes that it provides. Bunches from different banana varieties produce different levels of consumption attributes. While the household can vary the type and amount of banana bunches it consumes, it has no control over the input-output coefficients embodied in the different banana bunches it consumes (i.e. $\mathbf{x}$ are fixed parameters, exogenous to the household) (Ladd and Suvannunt, 1976).

The household derives utility from the attributes of banana bunches it consumes $\mathbf{Z^C}(\mathbf{X}; \mathbf{x})$, from the consumption of other (purchased) goods ($\mathbf{X^{AOG}}$) and leisure (or home time, H). Embodied in the vector of exogenous household characteristics ($\mathbf{\Omega_{HH}}$) is the ratio of active household members to total household size, value of animal assets, years of experience with banana production as a proportion of age, and gender of the representative household member. The utility function has the following general form:

$$U[\mathbf{Z}^{C}(\mathbf{X}; \mathbf{x}), \mathbf{X}^{\mathbf{AOG}}, H \mid \mathbf{\Omega_{HH}}]$$

The household engages in the production of banana bunches on its farm. Variable inputs (labor (L), planting material (mats from banana variety, **V**)) and land allocated to banana production (A^B) are used for the production of banana bunches (**Q**), given a vector of exogenous farm characteristics ($\mathbf{\Omega_F}$). Analogous to the role of attributes in the consumption side, the choice of planting material (both in terms of type of varieties and number of mats per variety) is associated with the farmers' perceptions of the "intrinsic" agronomic traits it provides. Bunches from different banana varieties (or inputs) are associated with different relative (fixed) proportions of production attributes (or joint-outputs).

Banana output is stochastic. There is uncertainty associated with the average levels and variability of production attributes, v_k^i (e.g. yield, disease and pest resistance), as perceived by farmers. There is also uncertainty associated with agro-ecological conditions (e.g. average seasonal levels of rainfall) and the occurrence of adverse biotic factors (e.g. frequency of disease occurrence), defined as a vector of risk characteristics ($\mathbf{\Omega_R}$).

The farmer faces two states of nature: "occurrence of disease", denoted by θ_1, and "non-occurrence of disease", denoted by θ_2. The farmer is uncertain about the occurrence of either state of nature, but is able to assess expected output outcomes by observing the levels of production attributes of banana cultivars they grow. For a given state of nature, the farmer formulates a variety-specific subjective distribution of yield and disease resistance based on previous experience. If the farmer has not experienced the "occurrence of disease", he or she would be unable to assess the potential effects of the disease on the production attributes. In that case, the farmer's subjective beliefs are determined by their knowledge of the attributes when disease does not occur.

Following the approach developed by Ladd and Martin (1976), the household's production function is defined over a set of production attributes ($\mathbf{Z^P}$) derived from variety-specific inputs, rather than over the inputs themselves. With two states of nature (θ_1, θ_2) and two production attributes of interest (v_1, v_2), the stochastic nature of output is captured through the vector of production attributes: $\mathbf{Z^P}$=[$\mathbf{Z_1}^\mathbf{P}$($\mathbf{V}$; d($v_1^i \mid \theta_1$)), $\mathbf{Z_2}^\mathbf{P}$($\mathbf{V}$; g($v_2^i \mid \theta_2$))]. The vector $\mathbf{V} = (V^1, \ldots, V^N)$ comprises the number of mats planted by the household from a set of different banana varieties. The stochastic elements are represented as subjective distributions of the input-output coefficients conditional on a given state of nature, respectively d($v_1^i \mid \theta_s$) and g($v_2^i \mid \theta_s$). By explicitly incorporating the two moments of the subjective distributions of the two attributes, the vector of production attributes adopts the following form:

$$\mathbf{Z^P}=[\mathbf{Z_1}^\mathbf{P}(\mathbf{V}; E(v_1^i \mid \theta_s), Var(v_1^i \mid \theta_s)), \mathbf{Z_2}^\mathbf{P}(\mathbf{V};\ E(v_2^i \mid \theta_s), Var(v_2^i \mid \theta_s))]$$

Labor (L) represents the time the household dedicates to on-farm banana production. Embodied in the vector of farm characteristics ($\mathbf{\Omega_F}$) are farm size, location, and the stock of banana planting material available at the village level. The land allocated to banana production (A^B) is fixed for a given growing season. Its composition varies according to household preferences for different banana varieties. There is a one-to-one physical correspondence between allocation of land to banana varieties (a^i) and the count of banana mats from different banana varieties grown by the household (V^i) on the banana production area (A^B).

By taking into consideration agro-climatic uncertainty (represented by $\mathbf{\Omega_R}$) and risk associated with disease occurrence (reflected in the definition of $\mathbf{Z^P}$), the expected cultivar specific banana output is formulated as a stochastic function of its determinants:

$$E[Q^i] = \int_1^S \int_1^N (Q^i \mid \theta_s) f(Q^i \mid \theta_s) d(Q^i \mid \theta_s)$$

where

$$(Q \mid \theta_s) = G[Z_1^P(V, E(v_1^i \mid \theta_s), Var(v_1^i \mid \theta_s)), Z_2^P(V, E(v_2^i \mid \theta_s), Var(v_2^i \mid \theta_s)), L \mid \Omega_F, \Omega_R]$$

for $i = 1, \ldots, N$ and $s = 1, 2$

Whether a household participates in market transactions is determined by the existence and completeness of markets and the transactions costs involved in market participation (e.g. time taken to get to a market). Both input and output markets for bananas are often incomplete or not readily available in rural areas in Uganda. On the input side, planting material is either re-produced by farmers or obtained through informal networks. Therefore, no market price is typically charged. Instead, there is a shadow price for banana varieties ($\mathbf{p_v}$) that represents 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 imputed from a market wage rate.

Although markets for banana bunches exist in Uganda, they tend to be incomplete, inducing different household-specific market participation behavior. The perishable nature of bananas precludes the possibility of storage, highlighting the importance of meeting immediate household consumption demand either through market participation or by self-production. Production of banana cultivars for household consumption is widespread in Uganda, suggesting that although banana markets exist, they either fail to capture quality differentials between bunches from different banana varieties, or other transactions costs prevent households from participating in them.

The household maximizes utility by consuming a non-tradable (X^{NT}) and a tradable (X^{T}) banana bunch it produces on its farm[10], a number of other goods it purchases at the marketplace ($\mathbf{X^{AOG}}$) and leisure (H), subject to a full income constraint, a time constraint, a variety constraint, a non-tradability constraint and a production technology:

$$\max_{\psi} U[\mathbf{Z^{C}}(X^{T},X^{NT};\, x^{T},x^{NT}),\, \mathbf{X^{AOG}},\, H|\mathbf{\Omega_{HH}}]$$

$$\text{for } \psi = (X^{T}, X^{NT}, \mathbf{X^{AOG}}, H, E[Q^{T}], E[Q^{NT}], V^{T}, V^{NT}, L^{T}, L^{NT})$$

s.t.

a) Full income constraint (for the tradable banana cultivar, X^{T}):

$$P(Q^{T} - X^{T}) - \mathbf{P^{AOG}X^{AOG}} + I = 0$$

[10] Referring to single tradable and non-tradable banana cultivars is a simplification, for exposition purposes only. The extension to more than one goods is straightforward by considering X as a vector rather than a scalar. Different banana cultivars may be sold at the market, while others are kept for own consumption.

b) Time constraint:

$$T - L^{T} - L^{NT} - H = 0$$

c) Variety constraint:

$$V - V^{T} - V^{NT} = 0$$

d) Non-tradability constraint (for the non-tradable banana good, X^{NT})[11]:

$$E[Q^{NT}] - X^{NT}\,(\boldsymbol{\Omega_M}) = 0$$

e) Production function (for the tradable and non-tradable banana goods, X^{T}, X^{NT})[12]:

$$G[E[Q^{T}], E[Q^{NT}], \mathbf{Z}^{\mathbf{P}}(V^{T}, V^{NT};\ E(v_k^{T}), Var(v_k^{T}), E(v_k^{NT}), Var(v_k^{NT})), L^{T}, L^{NT} \mid \boldsymbol{\Omega_F}] = 0$$

Optimal mat counts and mat shares are derived from the agricultural household framework, by variety. The number of mats per unit of area is constant over a growing season, and an input to banana production both in terms of planting material used (variety chosen) and in terms of land used (number of mats of each variety planted). Therefore, considering only the variety constraint (and no land constraint) suffices for the analytical purposes of the model.

Assuming an interior solution (such that the household consumes both the tradable and the non-tradable banana good), the following optimal reduced form variety demand relationship in the case of incomplete markets is derived from the first order conditions:

$$(1) \qquad \mathbf{V}^* = \mathbf{V}(x, E[\mathbf{v_k}], Var[\mathbf{v_k}], \mathbf{P}, \mathbf{P}^{\mathbf{AOG}}, I \mid \boldsymbol{\Omega_{HH}}, \boldsymbol{\Omega_F}, \boldsymbol{\Omega_M}, \boldsymbol{\Omega_R})$$

Equation (1) is used as an estimating equation in the empirical analysis.

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[11] Market failure is assumed to be on the demand side. Because household consumption demand for attributes cannot be met through market transactions, household production of banana cultivars with the desired attributes is induced. Market failure on the supply side would be captured by the inability of the household to sell bananas with specific attributes (because of transactions costs or lack of price differentials for quality). If market failure is observed on the production side, then the non-tradability constraint can be represented as $Q^{NT}(\boldsymbol{\Omega_M}) - X^{NT} = 0$.

[12] The production function is defined over the unconditional mean and variance of the *k* attributes.

4. DATA

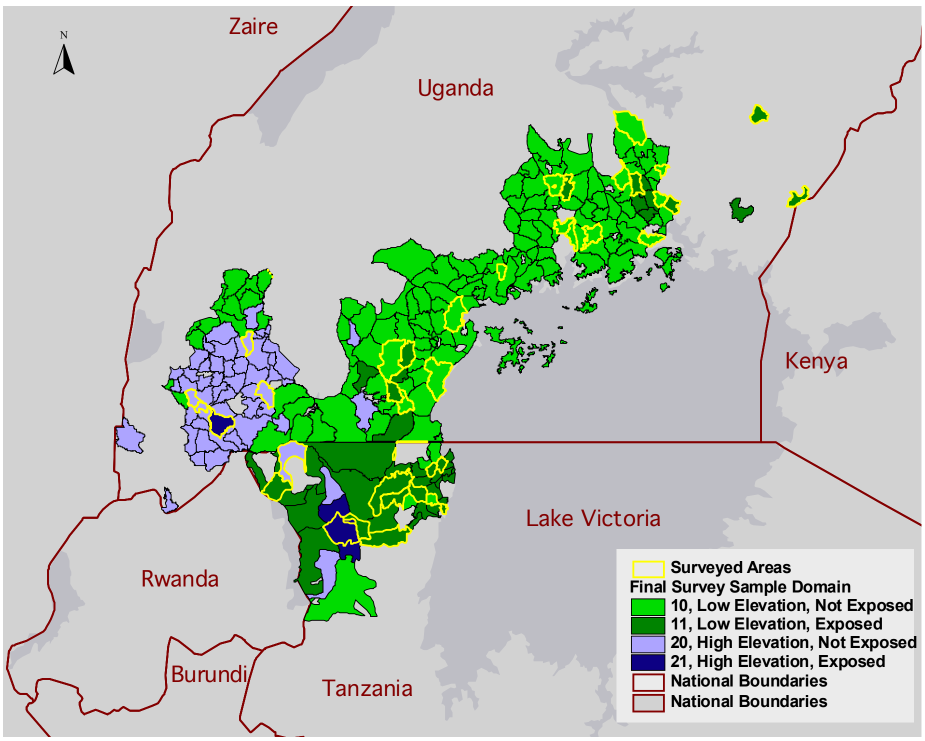
Data are drawn from a multi-stage, stratified random sample of households in a domain that was purposively selected to represent major banana growing areas in Uganda and Tanzania, including districts in Eastern, Central, and Southwestern Uganda and a contiguous banana growing area of Northern Kagera region in Tanzania. The domain was stratified according to elevation (above and below 1,400 meters above sea level) and previous "exposure" to improved banana varieties. 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, as well as in the potential yield savings associated with adoption of resistant banana varieties.

Exposed areas were defined as administrative units where improved planting banana material (e.g. banana suckers) had been formally introduced by researchers, extension or other programs to at least one community[13]. Areas with no exposure are those where no formal mechanism exists for the diffusion of improved planting material to communities. Exposed areas constitute the factual, while non-exposed areas represent the counterfactual in predicting the impact of improved banana varieties. Four strata were delineated (*i=elevation, j=exposure*): 1) low elevation, with exposure (i=1, j=1); 2) low elevation, without exposure (i=1, j=0); 3) high elevation, with exposure (i=2, j=1); and 4) high elevation, without exposure (i=2, j=0). Other factors known to

[13] Improved planting material includes hybrid varieties introduced to Uganda from Honduras (e.g. FHIA hybrids) and endemic cooking varieties, identified as superior varieties (e.g. Mpologoma), domestically transferred from one, exposed to this variety, region to another non-exposed region.

contribute to variation in adoption probabilities (e.g. market access, agro-ecological zone) were not used as criteria for stratification because of difficulties in defining them meaningfully for small administrative units. A map of the stratified sample domain and the selected surveyed areas is presented in Figure 2.

Figure 2--Map of the stratified sample domain and selected surveyed areas



PSUs are sub-counties (LC3 or local council, level 3) in Uganda and wards in Tanzania, the lowest administrative levels possible to map. Information about underlying population parameters was minimal, and budget and logistical considerations restricted the total number of primary sampling units to 40. PSUs were allocated proportionately with respect to elevation. An equal, minimum sub-sample size of 20 communities each in exposed and unexposed areas was maintained for descriptive statistics related to adoption analysis, and they were drawn using systematic random sampling from a list frame with a random start[14]. PSU sampling fractions (*s.f.*) vary by stratum, and are defined as the ratio of stratum-specific sample size (n_{ij}) and stratum-specific population size (N_{ij}), expressed as (n_{ij}/N_{ij}). The final sample in Uganda consists of 27 PSUs (18 in non-exposed areas and 9 in exposed areas). In Tanzania, there is a total of 13 PSUs (11 located in exposed areas and 2 in non-exposed areas).

The secondary sampling unit (SSU) both in Uganda and Tanzania is a village. In Uganda, in each LC3, there are several parishes (LC2s), and in each parish there are several villages (LC1s). One SSU was selected per PSU. The probability of selection (or sampling fraction) of a SSU varies by PSU and it is denoted as ($1/M_p$), where M_p represents the number of villages in the p-th PSU (p = 1, …, 40 PSUs in the sample). For most exposed LC3s in Uganda, there was only one exposed LC1 per PSU. In that case a one-to-one correspondence exists between a PSU and a SSU (a village). Where there was more than one exposed village per PSU, and in the case of non-exposed villages, a decision rule for selection was used. The SSU was drawn with a random number from the list of only those villages with over 100 households according to the 1991 census. Because of population changes and related administrative adjustments, some villages had been subdivided, thus reducing the total number of households per selected village below 100 (but above 80). A number of villages (from the area around Kampala) were also excluded from the selection criteria because they were identified as

[14] Of the 40 primary sampling units, 3 PSUs in Uganda were purposively selected (Ntungamo, Bamunanika, and Kisekka) to complement soil sample collection and analysis as part of the research of other project partners.

urban areas with minimal or no banana production undertaken. Whether or not a community selected in the sample had been properly classified as exposed or non-exposed was then verified at the site. Two randomly selected villages were replaced because they were fishing villages with little banana production.

A total of 20 households were selected per village from a current census of all households with access to land, using random number generator. The probability of selection (or a sampling fraction) of a household varies by village and it is denoted as ($20/H_s$), where H_s is the number of households in the s-th village ($s = 1, \ldots, 40$ SSUs in the sample).

The units of observation for the sample survey are the village (defined administratively) and the farm households[15] selected within a village. Although the total number of households in the stratified sample is 800, the research reported here is based on the Uganda sub-sample of 540 households because data collection is ongoing in Tanzania. Among these, 23 households reported they did not grow bananas. The overall probability of selecting a household in the sub-sample (denoted as PSH) is a unique number, and it is defined as the product of the sampling fractions at each level. PSH = $[(n_i/N_i)\text{x}(1/M_p)\text{x}(20/H_s)]$. For descriptive analysis, survey weights (w) were calculated as the ratio of the inverse PSH and the sum of the inverse PSH's for all 27 PSUs, or equivalently, all 27 SSUs:

[15] A farm household is culturally defined as a social entity that includes all members of a common decision making unit (usually within one residence) that are sharing income and other resources. It includes female-headed and child-headed (orphaned) households, as well as male-headed households with more than one wife. It does not include workers or servants who reside in the household.

$$w = \frac{\left(\frac{1}{PSH}\right)}{\sum_{p=1}^{27}\left(\frac{1}{PSH}\right)_p}$$

The survey instruments were implemented in all selected households across the selected villages. A total of 10 questionnaires (or schedules) were designed for the survey, and the analysis presented here is based on 5 of them for which data collection and cleaning has been completed: Household, General Plot (a), Banana Plot, Banana Cultivar, and Expenditure-Income Schedules.

5. DESCRIPTIVE STATISTICS

HOUSEHOLD-LEVEL CHARACTERISTICS

As expected, no significant differences were found between elevation strata in dependency ratios[16] and the value of assets held by the household. Nor are there significant differences in the characteristics of the banana production decision-maker, other than proportion who are women. In high-elevation areas, the scale of banana production is larger and more commercially oriented than in low elevation areas, enforcing the role of men in banana production management decisions (Table 1).

Table 1--Household-level characteristics, by elevation

Characteristic	Mean	
	Low Elevation (N=419)	High Elevation (N=98)

[16] Population dynamics in Uganda are such that a number of sample households have no members between the ages of 16 and 54. Here, we define the "active" ratio as the number of economically active members who participate in on-farm or off-farm production and are between 16 and 54 years of age. The boundaries of the age cohorts are those used by sociologists in Uganda.

Characteristics of the banana production decision-maker		
Age	41.04	38.55
Gender (1=male)	0.51**	0.82**
Household Characteristics		
Active Ratio	0.46	0.48
Assets (in '0000 USh)	449	328
Farm Characteristics		
Farm Size (in acres)	4.39*	2.55*
Banana Share (in %)	0.34**	0.66**
Stock of Planting Material	22.03**	26.64**
Probability of Black Sigatoka	0.23**	0.01**
Probability of Fusarium Wilt	0.22*	0.15*
Probability of Weevils	0.42*	0.31*
Seasonal Rainfall (in mm)	92.81^	94.34^

Note: ** denotes significance at the 1% level of the difference between the means; * denotes significance at the 5% level and ^denotes significance at the 10% level. Differences in the proportion of males to females across strata are tested with the chi-square distribution in cross-tabulation.

Statistically significant differences are evident between strata for all farm characteristics of interest, as expected. Although mean farm size is larger in low elevation areas, bananas are relatively more important as a crop in high elevation areas. The diversity of the stock of planting material also diverges statistically across strata. A greater range of cultivars is available at the village level in the high elevation areas.

Perceptions of biotic factors[17] differ between elevation levels, consistent with expected differences. The average probability of occurrence of Black Sigatoka, as perceived by farmers, is much greater in low elevation areas, where the spread of this air-borne fungal disease is less constrained. Higher average probability of occurrence

[17] Levels of rainfall are measured yearly as seasonal averages (in mm). The frequency of the occurrence of pests (weevils) and diseases (Black Sigatoka and Fusarium Wilt) is a household-specific subjectively measured variable. It is expressed as the ratio of the number of years of occurrence of the pest/disease, as reported by the farmer, to the total number of years of banana production.

of Fusarium Wilt and weevils in low elevation areas may be associated with increasing soil-related problems and differences in management practices.

There are statistically significant differences between strata in terms of household participation in banana market transactions. Some households choose not to participate. Others participate as only sellers, only buyers, or as both sellers and buyers. The majority of households in both strata report some involvement in banana markets, with roughly a quarter of the households remaining autarkic in either stratum. Market participation appears to be more evenly distributed across the different types for households in low elevation areas. In high elevation areas, market participation is mostly associated with selling of banana bunches, where the point of sale is predominantly the farm gate (Table 2).

Table 2--Household participation in banana markets

Type of Market Participation	Proportion (%) Low Elevation (N=419)	High Elevation (N=98)
No Participation	26	28
Only Sells	28**	56**
Only Buys	27**	7**
Sells and Buys	19*	9*

Note: Differences across strata are tested by cross-tabulation using the chi-square distribution. ** denotes statistical significance at the 1% level, and * - at the 5% level.

Survey data confirm the high level of banana cultivar diversity both in the aggregate (the country) and the micro-level (on single farms). A total of 95 currently banana cultivars are currently grown only in this sample[18]. The majority of these cultivars (86%) are endemic to East Africa (AAA-EA genomic group). The remaining 14% are composed of non-endemic naturally occurring exotic varieties or conventionally bred banana hybrids, introduced to East Africa. Surveyed households grow a large number of different banana cultivars simultaneously on their farms. Both the level of the frequency distribution (min, max, mode) and its mean are higher in high elevation areas (Table 3).

Table 3--Number of Banana cultivars grown per household

Elevation	Number of Banana Cultivars Grown: Min	Max	Mode	Mean
Low (N=419)	1	19	4	6.72**
High (N=98)	2	27	6	9.07**

Note: Using a pairwise t-test, the means in the two locations are found to be significantly different from each other at the 1% level (p-value<.0001).

[18] Banana cultivars were first identified by farmers and then were classified into synonym groups by taxonomists. The banana varieties identified appear to be widely grown across the whole banana production domain rather than location-specific.

Major cultivars appear to be fairly uniformly distributed across households. That is, the cultivars most frequently grown by farmers (percent of households) are generally the same as those most widely planted (percent of mats). Among them, the endemic cooking bananas predominate. Even the most popular banana cultivars occupy less than 10% of mats. The list of the 10 most frequently grown and most dominant cultivars in the sample is summarized in Table 4.

Table 4--Most frequently and most widely gown cultivars

Percent of Households			Percent of Banana Mats		
Cultivar Name	Use Group	(%)	Cultivar Name	Use Group	(%)
Sukali Ndiizi	NES	60.74	Nakitembe	EC	9.18
Nakitembe	EC	57.83	Sukali Ndiizi	NES	6.71
Nakabululu	EC	43.52	Nakabululu	EC	6.39
Bogoya	NES	41.01	Kibuzi	EC	6.38
Mbwazirume	EC	37.33	Nabusa	EC	6.04
Musakala	EC	32.88	Mbwazirume	EC	4.92
Kibuzi	EC	32.50	Mbidde	EB	4.79
Kisubi	NEB	28.43	Musakala	EC	4.30
Ndyabalangira	EC	25.73	Musa	NEB	4.07
Nabusa	EC	22.63	Kayinja	NEB	4.04

Note: The use groups are: EC=endemic cooking; EB=endemic beer; NES=non-endemic sweet and NEB=non-endemic beer. The household share reflects the proportion of households in the sample that currently grows this specific banana cultivar. The cultivar share expresses the proportion

The demand for an attribute is farmer-specific. We asked farmers to express their demand for an attribute in terms of three categories: very important (=1), indifferent (=2) and not important (=3). Descriptive information on the proportion of farmers attributing great importance (=1) to each attribute across elevation strata is summarized in Table 5. Differences across strata in the importance of the consumption attributes may be explained by differences in underlying preferences. Disparity in the relative importance of Black Sigatoka, Fusarium Wilt and weevils may reflect differences in the incidence (constrained by elevation) and severity (constrained by management) of these biotic constraints. Differences in the relative importance of bunch size (yield) may be attributed to differences in the nature of banana plantations, with greater commercial orientation in high elevation areas.

Table 5--Proportion of farmers attributing importance (=1) to banana attributes, by elevation

Attribute	Low Elevation (N=419)	Proportion High Elevation (N=98)	Whole Sample (N=517)
Cooking quality	67.94**	54.49**	66.43
Suitability for beer	51.31**	36.26**	49.62
Bunch size (Yield)[19]	74.55**	97.26**	77.09
Resistance to Black Sigatoka	44.76*	25.09*	42.56
Resistance to Fusarium Wilt	52.42**	58.53**	53.11
Resistance to Weevils	60.41**	76.72**	62.24

Note: Differences across strata are tested by cross-tabulation using the chi-square distribution. **denotes statistical significance at the 1% level, while * denotes statistical significance at the 5% level.

The importance of banana attributes statistically differs between men and women banana farmers for cooking quality (at the 10% level), for beer quality (at the 1% level) and for resistance to Fusarium Wilt (at the 1% level). These differences could be explained by underlying preferences, according to household tasks – cooking

[19] Although bunch size is one component of banana yield, in the text, the two are used interchangeably. Banana yield per mat is the product of bunch size and the number of bunches per mat. If a plantation is well managed, a banana mat would typically produce 1 banana bunch per season. Assuming 1 bunch per mat (which is commonly adopted), the banana yield per mat is equivalent to banana bunch size.

for women and beer production for men. Bunch size and resistance to Black Sigatoka and weevils are equally important for both men and women farmers.

The supply of an attribute is cultivar-specific. We asked farmers to rate each cultivar according to its supply of each attribute (good =1; neither good, nor bad =2; bad=3). The lower the mean score the better the rating of the variety with respect to a given attribute. In both strata, Mbwazirume outperforms the other two endemic cooking varieties in terms of bunch size, while Nakabululu appears to do relatively better in resistance to weevils in both strata. In terms of cooking quality, Nakabululu is scored best in high elevation areas, as compared to Mbwazirume in low elevation areas. The fact that no statistically significant differences were identified among cultivars for resistance to Black Sigatoka and to Fusarium Wilt may reflect either the uniformity in the effects across endemic cultivars, or the inability of farmers to effectively recognize or distinguish the effects (Table 6).

Table 6--Mean scores for relative performance of attributes for 3 endemic cooking cultivars by elevation

Attribute	Mean Score		
	Nakitembe	*Nakabululu*	*Mbwazirume*
		Low Elevation	
Cooking Quality	282.92	302.01	271.40**
Bunch Size (Yield)	277.71	341.99	217.15**
Res. to Bl. Sigatoka	294.91	269.91	297.41
Res. to Fus. Wilt	290.72	274.14	299.84
Res. to Weevils	293.03	257.28**	322.46
		High Elevation	
Cooking Quality	83.07	64.14*	71.01
Bunch Size (Yield)	69.17	101.97	61.67**
Res. to Bl. Sigatoka	67.42	75.00	73.86
Res. to Fus. Wilt	72.32	61.09	77.39
Res. to Weevils	74.33	46.14**	82.73

Note: Two-sided p-values were obtained from a Kruskal-Wallis Non-Parametric Test. ** denotes significance at the 1% level, while * denotes significance at the 5% level.

Farmers were asked to report the incidence of the disease and estimate yields in the presence and absence of Black Sigatoka using triangular distributions (Hardaker, Huirne and Anderson 1997)[20]. Table 7 summarizes the information on the parameters of the subjective yield distributions conditional on the absence of the disease.

[20] Using the triangular distribution, conditional expected yield is calculated for two states of nature (s = 1, 2), as perceived by each farmer: no occurrence of pest/disease, (θ_1), and occurrence of pest/disease, (θ_2): $E[(v^i \mid \theta_s)] = \frac{(a+m+b)}{3}$. The unconditional expected yield is then computed as the sum of the products of the probability of occurrence of a given state of nature, $P(\theta_s)$ and the cultivar-specific conditional expected yield for that state of nature:

$$E[v^i] = P(\theta_1) * E[v^i \mid \theta_1] + P(\theta_2) * E[v^i \mid \theta_2]$$

Table 7--Conditional expected yield parameters in the absence of black sigatoka

Cultivar Name	Low Elevation Mean					High Elevation Mean				
	Min [y]	Mode [y]	E	Var [y]	σ/μ	Min [y]	Mode [y]	E [y]	Var [y]	σ/μ
Sukali Ndiizi	4.64**	7.14*	7.41	2.29	0.16**	6.10**	8.46*	8.51	1.28	0.12**
Nakitembe	7.92	11.51	11.77	3.76	0.15	9.45	13.71	13.87	4.42	0.13
Nakabululu	7.48^	11.32	11.44	3.67^	0.16**	10.02^	13.01	12.93	1.67^	0.10**
Bogoya	9.64*	13.99	14.73	7.21*	0.16**	12.79*	16.68	16.63	3.21*	0.10**
Mbwazirume	8.94*	12.75*	13.16^	4.71	0.15*	11.32*	15.72*	15.61^	3.93	0.12*
Musakala	9.64	13.42	13.91	4.66	0.15	10.18	14.02	14.79	5.94	0.15

Note: Using a t-test, the mean value of the parameters is compared with each other across strata, e.g. min value is compared with min value, etc.;**, * and ^ denote statistical significance at the 1%, 5% and 10% level, respectively.

Expected yield in the absence of the disease, as perceived by farmers, is similar on average across locations, with statistically significant differences identified only for Mbwazirume. Few differences are apparent between the means of the other parameters of the distribution. No statistically significant differences are found for the average maximum bunch size.

Average expected cultivar-specific yield losses[21] in the presence of Black Sigatoka differ across strata for most of the cultivars, which is not surprising given the differences in the incidence and severity of the disease in low and high elevation areas.

[21] The formula used is: $E[yloss^i] = P(\theta_2) * \left(\frac{E[v^i \mid \theta_1] - E[v^i \mid \theta_2]}{E[v^i \mid \theta_1]} \right)$

Table 8--Cultivar-Specific expected yield loss (in %) due to black Sigatoka

Cultivar Name (Type)	Low Elevation Mean	Min	Max	σ/μ	High Elevation Mean	Min	Max	σ/μ
Sukali Ndiizi	2.78*	0	40.82	0.24	0.18*	0	5.00	0.58
Nakitembe	4.94*	0	51.29	0.18	0*	-	-	-
Nakabululu	5.67*	0	44.73	0.21	0.04*	0	1.11	1.00
Bogoya	4.41*	0	68.00	0.26	0.08*	0	2.72	0.80
Mbwazirume	4.80**	0	44.85	0.32	0.22**	0	6.82	0.57
Musakala	5.78	0	52.00	0.23	1.19	0	12.50	0.96

Note: **denotes statistically significant differences between the means at the 1% level; * denotes statistical significance at the 5% level.

In low elevation areas, the disease is perceived to reduce expected yield, on average, by as much as 50%, which supports findings in the banana literature. In high elevation areas, the spread of the disease appears to be small, with average maximum expected yield loss being around 5%, which confirms expectations.

6. ECONOMETRIC ANALYSIS

HYPOTHESES TESTS

Three hypotheses that stem from the model were tested:

1. *Significance of (uncertain) production attributes*. The null hypothesis is that farmers' perceptions about production attributes of banana cultivars (defined by the moments of the subjective yield distribution) have no effect on their demand for these cultivars, as expressed in either observed mat counts or mat shares:
$$\mathbf{H_0:}\ \frac{\partial V^*}{\partial E[v_k^i]} = \frac{\partial V^*}{\partial Var[v_k^i]} = 0 \qquad \forall i,k$$
Rejection of the null suggests that uncertainty in the level and variability of production attributes is important for the extent of the planting decision.
2. *Separability of production and consumption decisions*. In the attribute-based model, the null hypothesis that production and consumption decisions are made separately is expressed as:

$$\mathbf{H_o}: \frac{\partial V^*}{\partial x_j^i} = 0 \qquad \forall i, j$$

Rejection of the null hypothesis is consistent with the proposition that banana market imperfections motivate a farmer to grow banana varieties that provide desirable consumption attributes.

3. *Autarky and transactions costs.* The null hypothesis is that the buying and selling behavior of households, and other transactions costs do not affect households' demand for banana varieties, as expressed in observed mat counts. Market participation (captured by $\mathbf{\Omega_M}$) is defined by the household decision to either sell or buy banana bunches or remain in autarky with respect to banana markets. Another component of $\mathbf{\Omega_M}$ is a transaction cost variable expressed as the time taken to get to a banana market. Farm-gate prices and market prices (**P**) are the supply and demand price for bananas, respectively. Among other things, the supply price of bananas is believed to capture transaction costs borne by buyers at the farm-gate, while the demand price is a proxy for transactions cost variables borne by buyers at the market.

$$\text{(a) } \mathbf{H_o}: \frac{\partial V^*}{\partial \Omega_M} = 0 \qquad \text{and} \qquad \text{(b) } \mathbf{H_o}: \frac{\partial V^*}{\partial P} = 0$$

Rejection of either null hypothesis is consistent with the proposition that transactions costs matter, and they are internalized by the extent of land allocation (either mat counts or mat shares) and the type of banana cultivars grown. Failure to reject both hypotheses (a) and (b) is an indication of autarkic behavior.

DEFINITION OF VARIABLES USED IN THE ANALYSIS

To relate this work to previous specifications in adoption literature, variety demand is formulated in absolute and relative terms. Absolute demand is defined as the count (or number) of mats of each banana cultivar of interest, and it takes on non-negative, discrete, integer values[22]. The relative formulation of variety demand considers the number of mats of each cultivar of interest in relation to the total number of mats of all other cultivars grown by the household, as a mat share. The results are compared within and across formulations of variety demand for cultivars of interest.

The dependent variable in the analysis (in both absolute and relative terms) is formulated for the 6 most popular banana cultivars in the sample (V^{*i} for i=1,…,6). Individual demand equations are estimated for each of the six cultivars, given the econometric difficulties of estimating more than 2-3 regressions with censored dependent variables simultaneously. Explanatory variables are defined and their hypothesized effects summarized in Table 9.

Table 9--Definition of explanatory variables in the variety demand regression and hypothesized effects

Variable	Definition	Expected Effect
Individual Characteristics		
EXPAGE	Ratio of years of experience with banana production to age	0 or +/-
GENDER	Gender (1=male; 0=female)	0 or +/-
Household Characteristics		
ACTHHM	Ratio of active household members to household size	0 or +/-
ASSETS	Value of animals owned by the household (in ’0000 USh)	0 or +/-
Farm, Banana Plantation and Physical Characteristics (in preceding season)		
FARMSZ	Total available land to farmer (in acres)	+
CULTNUM	Number of banana cultivars available at the village level	-
ELEV	Elevation as an indicator of location (1=low; 0=high)	+/-
Market Participation		
SELL	Market participation as a seller (1=sell; 0=not sell)	0 or +

[22] The motivation for using counts of banana mats is associated with the nature of the crop, as well as with the greater objectivity in quantifying the scope of the planting decision.

BUY	Market participation as a buyer (1=buy; 0=not buy)	0 or -
TIME	Time taken to get to nearest market for bananas (in hours)	0 or +
FGPRICE	Average farm-gate (banana supply) price (in '000 USh/bunch)	0 or +
MKTPRICE	Average market (banana demand) price (in '000 USh/bunch)	0 or +
Banana Consumption and Production Attributes		
COOK	Cooking quality (taste, color, softness) (1=good; 0=other)	+
UEBSIZE	Unconditional expected bunch size (in kg)	+
EBSLOSS	Expected bunch size loss (in %)	-

When the null hypothesis of separability is rejected, individual and household characteristics are expected to influence variety demand. The direction of the effects of the characteristics of the representative household member (relative experience[23] and gender) is ambiguous and it depends on the type of cultivar considered. Education is not included because no a priori hypothesis on the effects of human capital to the extent of banana planting can be formulated for endemic bananas. This hypothesis in the adoption literature is related to learning and the role of human capital in technology adoption. Gender hypotheses are motivated by the findings reported above concerning preferences and participation in banana production.

The ratio of active household members to family size is expected to be positively associated with variety demand, representing a standardized indicator of subsistence requirements and consumption demand for bananas. On the other hand, the ratio may express capacity to engage in non-banana producing activities or off-farm

[23] This variable is an indicator of involvement in banana production. Given the unique demographic characteristics in Uganda, it is designed to better capture the effect of years of experience on the extent of planting decisions, as it is normalized by age. Typically, age and experience would be correlated, but in the Uganda sample, they are not.

employment. Data on exogenous income is not available (due to widespread non-response) and this variable has not been included in the analysis.

The value of animal assets is used as a proxy for wealth, but as in the case of education, there is no a priori hypothesis concerning the relationship of wealth to demand for endemic cultivars. Farm size, another indicator of wealth, is also a scale variable. Larger farmer sizes suggest larger absolute demand for any single banana cultivar, other factors held constant.

The stock of distinct cultivars in the community captures the supply of potentially useful planting material. The larger the stock of cultivars, the smaller the area that is likely to be allocated to any particular cultivar. Elevation is used as a proxy for other physical characteristics relevant to banana production (e.g. soil quality, rainfall), the variable used to stratify the domain for sampling and shown to be significant repeatedly in the bivariate statistics.

Market participation is household-specific and characterized by a participation decision in the previous period, net selling, and net buying. Transactions have no effect on variety demand when farmers do not participate in markets. Conditional on participation, the effect on number of mats planted could be positive (if selling) and negative (if buying). The transaction cost variable (time taken to get to nearest banana market) is expected to be positively related to variety demand – the longer it takes to get to a market where bananas can be purchased or sold (i.e. the more geographically isolated the farmer) the greater the incentive to allocate land to bananas on-farm. This variable is calculated at the village level and is imputed for households that do not participate.

The hypothesized effect for both types of prices is also expected to be positive, conditional on participation in market transactions. The higher the farm-gate (supply) price for a specific cultivar, the greater the net benefit for farmers selling bunches from this cultivar, hence the greater the demand for mats of that cultivar. The higher the market price of a specific cultivar, the higher the net cost for farmers purchasing bananas, hence the greater the incentive to plant more mats to this cultivar on-farm. Both prices[24] are calculated at the village level, and are imputed at village level averages for non-participating households. The farm-gate price is cultivar-specific, while the market price is use-specific. No data is available for the price of other goods.

All attribute variables, including one consumption attribute and several production attributes, are cultivar-specific. The consumption attribute is cooking quality, representing a bundle of traits such as taste, softness and color. Better quality is expected to induce farmers to grow more mats. The production attributes are the unconditional expected yield and the expected yield loss from Black Sigatoka. Higher unconditional expected yield is hypothesized to influence demand positively, while expected yield loss is expected to affect it negatively.

Although information on production attributes was collected for the effects of three biotic constraints - Black Sigatoka, Fusarium Wilt, and weevils – this analysis considers only the effects of Black Sigatoka. Since the three biotic constraints are

[24] Both prices are measured in 2003 Ugandan Shillings. When the survey was conducted, March-April 2003, the exchange rate with the US dollar fluctuated between 1,800USh and 1,900USh for 1US$.

highly correlated, variety demands must be estimated separately for each one of the three constraints in order to separate their effects. Secondly, Black Sigatoka has been signaled as a research and extension priority for banana scientists and farmers (Luganda 2003). Thirdly, farmers are found to confuse cause and effect associated with Fusarium Wilt and weevils, making it difficult to analyze their separate effects whether or not equations are estimated separately.

ESTIMATION PROCEDURE

Initially, both absolute and relative demands were estimated with a Heckman model (Heckman, 1979), by variety. For the absolute variety demand the dependent variable takes on non-negative, discrete, integer values. A count selection model was used with a Negative Binomial rather than Poisson distribution because statistical tests suggested over-dispersion[25](Greene 2000). For relative variety demand, mat share equations were estimated with OLS in the second stage instead of Tobit because few observations reached the upper limit of one.

In either case, the choice of a Heckman two-step procedure over other econometric methods reflected a data constraint in the structure of the independent variables. Information on consumption and production attributes is only available for those households who currently grow the cultivars of interest, resulting in sample selection due to missing data in the set of explanatory variables (Wooldridge 2001). A

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[25] The Poisson is a one parameter distribution with equal mean and variance, $(E[V_i^*] = Var[V_i^*] = \lambda)$. The Negative Binomial relaxes this restrictive equality assumption, allowing for $(E[V_i^*] = \lambda_i) \neq (Var[V_i^*] = \lambda_i + \eta = \theta)$, such that over-dispersion is possible (i.e. $\lambda < \theta$).

Tobit model could not be used because it requires the same number of observations for both the dependent and independent variables.

Hurdle and zero-inflated (ZIP) count models were also considered for the absolute demand equations, but were not applied because of limited information about the underlying preference structure. All zeros included in the variety demand regressions reported here originate from the same data-generating process; zero values for the dependent variable imply that the variety was not present in the banana plantation during the survey period. More complex count data models allow for zero values to originate from independent data-generating processes. For example, farmers may not grow mats because they are not aware of their existence or because they have grown them in the past and abandoned them as inferior.

In only one case among all demand equations (mat share of the non-endemic cultivar, Sukali Ndiizi) was the null hypothesis of no selection bias rejected. The factors influencing the decision to grow a cultivar have no statistically significant effect on the number of mats grown or mat shares allocated to it.

As a consequence, all demand equations except that of the relative demand for Sukali Ndiizi were then estimated as a truncated regression in a single stage. The Negative Binomial was again statistically identified as better suited to the data for all six cultivars. The truncated OLS approach internalizes the selection of growers (left-side truncation at 0) and also captures the share formulation of the dependent variable with a maximum value of 1 (right-side truncation at 1). Equations were estimated individually for both count and share equations. A seemingly unrelated systems approach for the truncated, relative demand equations is not feasible because different farmers grow different varieties and the number of observations is not the same across equations.

7. ECONOMETRIC RESULTS

Maximum likelihood estimates for single parameters of relative and absolute variety demand are summarized in Tables 10 and 11. Results of joint tests of significance for sets of explanatory variables are presented in Table 12.

Table 10--Variety demand results for the case of black Sigatoka – absolute variety demand (mat counts)

Variables	Maximum Likelihood Coefficient Estimates by Type of Cultivar and Estimation Method					
	Non-Endemic Cultivars		*Endemic Cultivars*			
	Sukali Ndiizi (Negative Binomial)	Bogoya (Negative Binomial)	Nakitembe (Negative Binomial)	Nakabululu (Negative Binomial)	Mbwazirume (Negative Binomial)	Musakala (Negative Binomial)
Individual and Household Characteristics (Ω_{HH})						
Relative experience	0.1133	0.6461*	0.2543	0.4583	0.9831**	0.4746
Gender (1=male)	0.3882**	0.4296**	0.2705*	0.2453*	0.7468**	0.2578^
Ratio of active members	0.2067	- 0.4615*	- 0.5411*	- 0.2621	0.1317	- 0.2430
Assets (‘0000)	0.0005	0.0006	- 0.0003	- 0.0008	- 0.0005	0.0006
Farm Characteristics (Ω_F)						
Farm area	0.0108	0.0119	0.0173**	0.0086	0.0073	0.0264**
Stock of Planting Material	- 0.0359**	- 0.0118	- 0.0495**	- 0.0518**	- 0.0299*	- 0.0132
Elevation (1=low)	0.4644**	0.4255*	0.5493**	0.6726**	0.5521**	1.0531**
Market Related Characteristics (Ω_M)						
Participation – seller (1=sell)	0.3914**	- 0.0633	0.2925**	0.1350	0.2716*	0.1977^
Participation - buyer (1=buy)	0.0221	- 0.0388	- 0.0142	- 0.1311	- 0.2781*	- 0.3991*
Time taken to get to market	- 0.1785	0.3848**	0.0361	0.1965^	- 0.0450	0.0878
Farm-gate price (‘000)	- 0.6891	0.0031	- 0.2278	0.2942**	0.3223**	0.1171
Market price (‘000)	- 0.8011	- 0.4177	0.1424*	0.4126**	0.0792	- 0.1339
Banana Consumption and Production Attributes (x, v)						
Cooking quality (1=good)	0.3775*	- 0.4419	- 0.0122	0.0737	- 0.3693	- 0.4963
Expected bunch size	0.0082	- 0.0160	0.0103	0.0193*	0.0010	- 0.0393
Expected bunch size loss	0.0191	0.0090	0.0083	- 0.0364**	- 0.0135	0.0013
Log-Likelihood	- 1027.18	- 570.07	- 1098.87	- 793.79	- 658.13	- 585.48

Note: ** denotes statistical significance at the 1% level; * denotes statistical significance at the 5% level and ^ denotes statistical significance at the 10% level.

Table 11--Variety demand results for the case of black Sigatoka – relative variety demand (mat shares)

Variables	Maximum Likelihood Coefficient Estimates by Type of Cultivar and Estimation Method					
	Non-Endemic Cultivars		*Endemic Cultivars*			
	Sukali Ndiizi (Heckman OLS)	Bogoya (Truncated OLS)	Nakitembe (Truncated OLS)	Nakabululu (Truncated OLS)	Mbwazirume (Truncated OLS)	Musakala (Truncated OLS)
Individual and Household Characteristics (Ω_{HH})						
Relative experience	- 0.1082	0.1613^	- 0.2029*	- 0.1717	0.2337**	- 0.0976
Gender (1=male)	- 0.0333	- 0.0418	- 0.0464	- 0.0734^	0.0260	- 0.0392
Ratio of active members	0.0294	- 0.0491	- 0.0825	- 0.1413*	- 0.0187	- 0.0211
Assets (‘0000)	- 0.0003	-0.0000	- 0.0003	- 0.0002	- 0.0002	- 0.0002
Farm Characteristics (Ω_F)						
Farm area	- 0.0022	- 0.0027	0.0018	- 0.0011	- 0.0029	0.0070**
Stock of Planting Material	- 0.0038	0.0044	- 0.0069*	- 0.0098**	0.0006	0.0028
Elevation (1=low)	0.0139	0.0493	- 0.0085	- 0.0403	- 0.2519**	- 0.0516
Market Related Characteristics (Ω_M)						
Participation - seller (1=sell)	0.0358	- 0.0873	0.0177	- 0.1023	- 0.0250	- 0.0029
Participation - buyer (1=buy)	0.0318	0.0832	0.0150	- 0.0288	- 0.0254	0.0799
Time taken to get to market	- 0.0532	0.1214**	- 0.1231	0.1058**	- 0.0082	0.0075
Farm-gate price (‘000)	- 0.1073	0.0192	0.0065	0.0063	0.0240	- 0.0503
Market price (‘000)	- 0.0468	0.0987*	- 0.0307	0.0594*	0.0521^	- 0.0075
Banana Consumption and Production Attributes (x, v)						
Cooking quality (1=good)	- 0.0163	0.1638*	0.0034	0.0807	- 0.0968	- 0.0218
Expected bunch size	0.0001	- 0.0041	- 0.0031	0.0113**	0.0004	- 0.0103
Expected bunch size loss	0.0014	0.0013	- 0.0040*	- 0.0129**	- 0.0044	- 0.0011
Log-Likelihood	- 334.75	175.88	76.42	80.05	80.89	59.86

Note: ** denotes statistical significance at the 1% level; * denotes statistical significance at the 5% level and ^ denotes statistical significance at the 10% level.

Table 12--Joint tests of significance of sets of variables

Null of no joint significance: H_0: $\beta_i=\beta_j=0$ for $i \neq j$

X indicates rejection of the null at the 1% (**), 5% (*) or 10% (^) level of significance, in favor of joint significance

Empty cells indicate that the null is not rejected

Sets of Variables	Degrees of Freedom	Likelihood Ratio Test for the Joint Significance of Sets of Variables, by Type of Cultivar and Demand					
		Non-Endemic Cultivars		Endemic Cultivars			
		Sukali Ndiizi	Bogoya	Nakitembe	Nakabululu	Mbwazirume	Musakala
Mat Shares							
Set of Ω_{HH}	4			X*	X*		
Set of Ω_F	3					X**	X*
Set of Ω_M	5	X^	X**		X**		
Set of x,v	3				X**		X^
Mat Counts							
Set of Ω_{HH}	4	X**	X**	X*	X*	X**	
Set of Ω_F	3	X**	X**	X**	X**	X**	X**
Set of Ω_M	5	X**	X**	X*	X**	X**	X*
Set of x,v	3	X**	X**	X**	X**	X**	X**

Perusal of Tables 10-12 reveals two salient findings: 1) the determinants of both relative and absolute variety demands are cultivar-specific and cannot be generalized across groups of endemic or non-endemic cultivars; and 2) the determinants of relative and absolute variety demand are not the same in sign or significance. These findings raise questions about commonly used econometric specifications in the adoption literature. Statistical results are clearly sensitive to how demand is conceptualized and reduced form equations are specified econometrically. Grouping varieties together clear masks individual differences, and differences may be important for predicting the adoption of new technologies such as genetically transformed, endemic or local cultivars. Development of methods for estimating a complete variety demand system might permit resolution of cross-cultivar relationships.

TESTS OF INDIVIDUAL HYPOTHESES

No direction of effect was hypothesized for the characteristics of households or decision-makers, and various effects are observed. Years of experience, relative to age, is positively related to absolute variety demand for both the non-endemic cultivar Bogoya and the endemic cultivar, but negatively related to mat shares of Nakitembe. Men grow significantly more mats for all cultivars than do women, but only one weak and negative effect appears for mat shares in Nakabulu. For several cultivars, the ratio of active household members to family size is negatively related to both absolute and relative demand, suggesting that this variable may capture participation in non-banana producing activities more than it does consumption demand. As expected, livestock wealth bears no significance in the demand for any local banana cultivar, whether endemic or non-endemic.

One-tailed hypotheses were advanced for farm area and the supply of banana cultivars in the village. Farm area, both an asset and scale variable, has a significantly positive effect on demand in several cases, as hypothesized. Similarly, the greater the supply of distinct banana cultivars in a village, the lower the counts and mat shares allocated to specific cultivars. Elevation is statistically significant in all six absolute variety demand equations, with households in low elevation areas growing more mats than those in high elevation areas. Mat shares are related to elevation only in the case of Nakabululu, with larger mat shares in high elevation areas.

One-tailed tests were also conducted on coefficients of market-related factors. These appear to play an important role in absolute demand for most endemic cultivars, though less so in relative demands. Participation as seller or buyer has the expected sign for absolute demand in all cases, whether or not the effect is significant. The transaction cost variable is positively associated with absolute and relative variety demand in a number of cases. The effects of the farm-gate and market prices are positive and significant in the absolute and relative demands for several cultivars.

Results for banana attributes are also cultivar specific. Positive effects of cooking quality on variety demand are statistically significant in the case of only two cultivars, Bogoya and Sukali Ndiizi, non-endemic cultivars. The overall lack of significance for cooking quality likely reflects its limited variation. Cooking bananas are uniformly considered by farmers to be good for cooking, which makes cooking quality a quasi-fixed attribute—in itself a reasonable indication of strong underlying consumption preferences.

The sign of the unconditional expected bunch size is as anticipated for some cultivars. Higher proportional loss is associated with lower levels of resistance of the cultivar to the specific constraint, reducing the numbers and share demanded in several cases.

JOINT TESTS OF HYPOTHESES

A major difference between the results for the two types of variety demand is the overwhelming joint significance of all sets of explanatory variables for all six cultivars in the count regressions, as compared to the share regressions. In the absolute demand equations, the sole exception is the vector of household characteristics in the case of Musakala (Table 12 in the Appendix).

The data are consistent with the broad notion of non-separability in the absolute demand for individual banana cultivars in Uganda and support the application of the agricultural household model as an analytical tool. The joint significance of market-related factors emphasizes the importance of transactions costs, prices and market participation behavior to variety demand (mat counts). Variety attributes are also found to be jointly statistically significant for all six cultivars, supporting other empirical evidence concerning the limitations of studies that omit these variables. Joint tests of significance indicate that attributes are in general important in explaining mat share variation only for two endemic cultivars, Nakabululu and Musakala.

8. IMPLICATIONS

Adoption analyses typically focus on the improvement status of the variety, grouping varieties into broad categories termed "modern" and "traditional." These categories often mask important genetic differences between varieties, some of which can be expressed in terms of attributes. In predicting the adoption of some biotechnology innovations such as genetically transformed varieties, where specific traits are inserted into host cultivars rather than crossbred, understanding variety-specific demand may be important. Econometric results confirm that no common pattern or grouping of cultivars makes sense for East African Highland bananas, even when cultivars have similar genetic composition. Policy recommendations derived from adoption analysis applied to groups of cultivars may over- or under-state the importance of some explanatory variables by overlooking the underlying nature of association between each individual cultivar and the set of explanatory variables.

Since all cultivars used in the analysis are unimproved, a number of the a priori hypotheses from the adoption literature have little relevance—such as, for example, wealth in livestock assets. Farm physical characteristics and the supply of distinct banana cultivars in the village have strong and significant relationships to variety demand. The significance of market participation reiterates the importance of bananas to households as both a subsistence crop and source of cash, and implies that the composition of variety demands is likely to evolve as market infrastructure changes in these villages.

The weakness of coefficients on the expected yield loss to Black Sigatoka reinforces the notion that the disease is relatively new and is not well recognized by farmers, though regression results should be interpreted with caution. Farmers' perceptions of Black Sigatoka are conditional on its occurrence and their ability to identify its effects. Particularly in the high elevation areas, non-occurrence of the disease is associated with resistance to it. Results associated with resistance to Black Sigatoka may not capture the levels of resistance of cultivars to the disease, but instead, the occurrence of the disease, as perceived by farmers. In any case, if farmers do not recognize yield losses, it is unlikely that simple insertion of resistance will generate adoption. In this complex production system, with so many cultivars grown, adoption will be constrained by numerous, often counteracting, factors.

Though tests of individual hypotheses are relatively weak, joint tests of hypotheses support the application of the model of the agricultural household in analyzing variety demand decisions. The effects of transactions costs variables are found to be binding for some cultivars, and not for others. Therefore, policies targeted at reducing transactions costs may stimulate household participation differentially across cultivars. Profit maximizing behavior is a constraining assumption when modeling behavior in developing countries where production decisions are influenced by household characteristics or preferences for specific consumption attributes. Findings underscore the importance of the agricultural household model in analyzing land allocation decisions in developing countries.

A fuller specification of a variety demand system, in which the error structure of the equations and the trade-offs among cultivars can be adequately treated, may resolve some of the apparent inconsistencies between the absolute and relative variety demand estimations. Estimating systems of large numbers of variety demand equations in which censoring is observed and/or different varieties are grown across different households is not feasible with current econometric packages.

This research initiates the development of an analytical and empirical framework that can be used to predict the adoption of transgenic varieties of bananas in East Africa. The identification of popular varieties as local host varieties is the first step to successful genetic manipulation. This research finds that the most popular and dominant endemic cooking varieties are Nakitembe, Nakabululu, Mbwazirume and Musakala. Only one of these varieties (i.e. Mbwazirume) coincides with the list of nine different varieties that have already been selected in Uganda for future genetic manipulation.

The emphasis on specific locally important variety attributes can help understand the popularity of the cultivars and identify traits for potential genetic transformation. The importance of considering specific variety attributes has important policy implications. Banana hybrids, recently introduced to East Africa, are a good example. Despite the big bunches they offer farmers, they are perceived as inferior in terms of cooking quality and thus not preferred by farmers. Failing to account for the practical importance of cooking quality may impact the usefulness of scientific involvement in transformation of specific agronomic attributes.

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