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Assessing the Adoption of Improved Bean Varieties in Rwanda and the Role of Varietal Attributes in Adoption Decisions

Catherine Larochelle[1], Dorene Asare-Marfo[2], Ekin Birol[2], and Jeffrey Alwang[1]

ABSTRACT

Beans are grown by nearly all rural households in Rwanda, provide a large share of calorie intakes, and are a vital source of proteins and micronutrients. Because of the importance of this crop, significant research efforts have been devoted to select, breed, and disseminate bean varieties with superior production, consumption, and market attributes, while addressing challenges related to climate changes and food insecurity. As a result, nearly 100 bean varieties have been released in Rwanda over the last four decades. This study aims at documenting this effort; it assesses adoption of improved bush and climbing bean varieties, identifies determinants of and barriers to adoption, and analyzes farmers' preferred variety attributes. Based on recent household data, 86 and 50 percent of households have adopted improved climbing and bush bean varieties, respectively. Adoption is positively associated with membership in farmers associations and size of landholding devoted to bean cultivation. Agro-climatic factors are strong predictors of adoption in general and of specific popular improved varieties. Varietal attributes most associated with high adoption rates are high yield, early maturity, storability, and taste. Findings from this study can serve to inform future breeding and dissemination efforts of improved bean varieties in Rwanda.

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CONTENTS

I. INTRODUCTION

Common bean (*Phaseolus vulgaris*) is a widely produced and consumed legume in Africa south of the Sahara. Beans are vital sources of micronutrients, such as iron, and can help reduce iron deficiency caused by the lack of diversity in the starch-based diets of the poor.

Rwanda is no exception when it comes to high rates of bean consumption. Several studies have illustrated the importance of beans as a crop and in the diets of Rwandans. Beans are the second-most popular crop (after banana) cultivated in Rwanda; they are grown by about 86 percent of farmers (CIAT 2004) and occupy about 40 percent of cultivatable land area (CIAT 2008). Often referred to as the "meat" of the poor because of their high protein content and affordability, beans are believed to provide up to 65 percent of the country's national dietary protein intake and 32 percent of caloric intake (CIAT 2004). Rwanda's population is also characterized by high rates of anemia, which particularly affects women and young children (NISR, MOH, and ICF International 2012). These factors make Rwanda a global top priority for biofortification of high-iron bean (HIB) varieties (Asare-Marfo et al. 2013).

Beans are grown twice a year in diverse farming systems throughout Rwanda. They are intercropped with banana, cassava, maize, pea, and other crops, and are cultivated under various agro-ecological conditions. As a result of this environmental diversity, two major bean technologies are available to farmers: bush and climbing beans. Climbing beans grow vertically, requiring staking material, and are harvested over a more continuous period compared with bush beans. This vertical-growth property gives climbing beans a yield advantage over bush beans and makes them less likely to be intercropped. Climbing bean varieties, first released in the 1980s, were most suitable for higher-elevation areas. Bean research efforts subsequently led to the release of climbing varieties suited for diverse climate and environmental conditions, now including low- and mid-altitude zones. Consequently, climbing bean varieties, originally most important in the North, have spread to most of the country's regions (Katungi et al. 2015).

Important research efforts have been devoted to select, breed, and disseminate bean varieties that suit various production, consumption, and market needs of the Rwandan population. Research has also addressed challenges related to climate change, such as more frequent flooding and drought and emergence of new diseases. The bean research program at the Rwanda Agriculture Board (RAB), in collaboration with such international partners as the International Center for Tropical Agriculture (CIAT), has released nearly 100 bean varieties over the last four decades (RAB 2012). Widespread adoption of high yielding varieties, along with the shift from bush to climbing beans, has moved Rwanda from a position of net importer to self-sufficiency, and now to being an exporter of dry beans. These changes have improved the livelihoods of millions of smallholder farmers (Larochelle et al. 2015; RAB 2012).

Selection criteria for improved varieties have included adaptability to low soil fertility, seed size, marketability, taste, shorter cooking time, tolerance to heavy rain, resistance to common bean diseases, and shorter production cycles. Recognizing the need to reduce iron deficiency levels among women and children, RAB has also collaborated with HarvestPlus to breed bean varieties that are high in iron content. HarvestPlus uses a conventional breeding method known as biofortification to develop staple crops that are high in micronutrients to help reduce micronutrient deficiency in developing countries. In Rwanda, five fast-track HIB varieties (two bush and three climbing varieties) were released in 2010, and five second-wave climbing varieties were released in 2012. Consumption of these beans at conventional levels could meet 45 percent of daily iron needs (Bouis et al. 2011).

HarvestPlus aims to have millions of Rwandan households growing and consuming HIB varieties by the end of 2020. Large-scale dissemination activities started in 2012, and delivery records reveal that by the end of 2013, more than 500,000 farm households had bought HIB seeds. A feedback study conducted in 2012 revealed that a large proportion (25 percent) of farmers who received HIB seeds shared the grains of their harvest with other farmers, and more than two-thirds recommended these varieties (Murekezi et al. 2013). Moreover, studies in rural and urban markets revealed that HIB grains are widely available (Murekezi 2013). Since farmers often use grains as planting material, it was expected that by the end of 2014 around 700,000 bean-farming households (that is, more than 40 percent of all farming households growing beans) would have purchased HIB varieties.

As the benefits of adopting and consuming HIB varieties could help to substantially reduce malnutrition, it is necessary to understand current adoption patterns of improved bean varieties and their determinants. To our knowledge, no study to date has extensively examined the adoption of improved bush and climbing bean varieties in Rwanda. For example, Larochelle et al. (2015) investigate the impact of improved bean varieties on yield, poverty, and food security in Rwanda. While their study reports adoption rates of improved varieties, their focus is on improved varieties released in 1998 and afterward. In addition, the emphasis of that study is on the impact of adoption, rather than the determinants of adoption. Similarly, Sperling and Muyaneza (1995) and Katungi et al. (2015) examine the adoption and impact of improved climbing beans in Rwanda, also focusing on impacts and not considering bush bean cultivation. Therefore, questions remain regarding determinants of adoption of improved[1] bean varieties and how they vary across bush and climbing varieties. This paper fills this gap by documenting adoption rates, spatial patterns of adoption, and factors influencing adoption of improved bush and climbing bean varieties in Rwanda. More precisely, the three objectives of this study are to (1) document and explore the diffusion patterns of improved bush and climbing bean varieties, (2) identify facilitators and constraints of adoption of improved and most popular improved bush and climbing bean varieties, and (3) examine the varietal attributes of the most popular improved varieties that have contributed to their widespread adoption.

The information from this study is expected to signal to HarvestPlus the adoption patterns of improved bean varieties across Rwanda. It will also indicate "hot spots" where improved varietal adoption already takes place on a fairly large scale and the socioeconomic characteristics of adopting households. It is expected that fewer advertising efforts will be required for HIB varieties in such areas, but also that there could be competition with other popular and well-established improved varieties. Conversely, in areas characterized by low adoption rates, greater delivery and advertising efforts will be required. Information on preferred trait attributes of the popular varieties will inform HarvestPlus about which traits in addition to high iron content need to be improved on and emphasized when marketing HIB varieties to farmers. By improving on complementary traits, farmers will be able to perceive the HIB variety as a "valued-added" improved bean variety, rather than a competitor to their existing varieties.

The remainder of this paper proceeds as follow. Section 2 describes the study design and data collection, section 3 presents the theoretical and empirical models, section 4 includes the descriptive analysis and econometric results, and the last section presents our conclusions.

2. STUDY DESIGN AND DATA

To achieve the study objectives, we combined two data sources collected in Rwanda. The first dataset is from a bean varietal adoption study carried out by HarvestPlus. The second source is from a study conducted under the Dissemination and Impact of Improved Varieties in Africa (DIIVA) project, where CIAT, the International Potato Center, RAB, and Virginia Tech partnered to document the adoption and impact of improved bean, potato, and sweetpotato varieties in Rwanda.

The HarvestPlus study (Asare-Marfo et al. 2011) was conducted from January to March 2011, corresponding to the end of cropping season A. In Rwanda, cropping season A refers to the first harvest of the year, and in this case corresponds to the September 2010 to February 2011 growing season. A total of 1,283 households, located across all 30 districts, were randomly selected for interviews. Information was gathered on household demographics and socio-economic characteristics, and agricultural production activities—including bean varieties cultivated, production and harvest, bean sales, trait assessment and preferences, and food consumption frequency.

Data collection under the DIIVA project occurred in two rounds (Larochelle et al. 2015). The two rounds were necessary because of the length of the questionnaire, but their use also helped reduce potential recall bias. The targeted cropping season in this study was season B 2011, which runs from March to August, and corresponds to the second harvest of the year. The first round of data collection took place following planting—that is, during April–May 2011—and the second round was performed in September–October 2011, following bean harvest and marketing. A total of 1,440 households, among which slightly more than 90 percent cultivated beans, were surveyed. The survey covered household and housing characteristics; production and consumer assets; knowledge and adoption of improved bean varieties; production activities, including cultivated area, input use, and harvest; market participation and access; food security; and access to agricultural inputs.

Both studies are nationally representative and have overlapping survey modules with key socio-economic and bean production activity variables consistently measured. Three major differences are worth highlighting. First, despite both being nationally representative, their sampling designs differ. While this cannot be corrected ex post, a larger sample size is obtained by combining the two datasets, both of which have randomized household selection at the last stage. Second, even though the surveys were conducted within the same year, they targeted different cropping seasons. Third, the questioning approach to assess bean varietal adoption differed. Under the HarvestPlus study, respondents were directly asked about the three most important bean varieties cultivated by land area in the season of interest.

[1] Improved varieties in this study refer to varieties that have been enhanced through either careful selection or breeding process. It includes all the varietie ever released by the Rwanda bean research program.

In the DIIVA study (Larochelle et al. 2015), respondents were first asked about their bean plots. They were then asked to list the bean varieties grown on each plot.

Despite these differences, the improved bean varieties that were identified are similar across studies[2] . The 10 most popular improved bush and climbing bean varieties—in terms of number of farmers cultivating a given variety—were identified and compared. Seven improved climbing varieties were common to both studies' top-10 improved varieties lists, while six improved bush bean varieties consistently appeared in the lists (Table A1). The consistent picture of popular improved varieties supports the merging of the two datasets. Combining the two datasets further allows us to fill in coverage gaps in some cases and increases the precision in estimates that results from the nearly doubled sample size[3]. The merged data also allow examination of adoption over an entire year and over two consecutive cropping seasons. Finally, having household geographical coordinates in both studies, geographic information system-related variables were created to describe agro-ecological and market conditions of households in both datasets. This serves as a common ground for combining the two datasets, as it guarantees that key variables in the analysis are consistently measured.

3. METHODS

We present a theoretical framework describing adoption decisions, and link it to empirical models of facilitators and constraints to adoption of improved and popular improved bush and climbing varieties. The decision to adopt improved bean varieties can be modeled in a random utility framework. Under this framework, the adoption decision is driven by the expected utility of the technology, compared with alternatives given household constraints, such as financial resources, and information and knowledge about the new technology and its attributes (Marenya and Barrett 2007). Let's assume that the i^{th} farmer considers a bundle of bean varieties, and the net benefit associated with this bundle is y^*_i, expressed as:

$$y^*_i = x_i' \beta + \varepsilon_i \qquad (1)$$

where x_i is a matrix of variables reflecting household constraints and preferences for bean varieties and β is a vector of parameters to be estimated. The error term ε_i is normally distributed with mean 0 and variance equal to 1. While net benefits associated with adoption are not observed, individual adoption decisions are. Under the revealed preferences assumption, the (latent) continuous net benefits associated with adoption can be expressed using discrete variables. Farmer i^{th} will adopt 0 (y_i=0), 1 (y_i=1), or 2 or more (y_i =2) improved varieties if

$$\begin{aligned} y_i &= 0 \text{ if } y^*_i \le \alpha_1 \\ y_i &= 1 \text{ if } \alpha_1 < y^*_i \le \alpha_2 \\ y_i &= 2 \text{ if } y^*_i < \alpha_2 \end{aligned} \qquad (2)$$

where α_j $(j=1,2)$ are unobserved thresholds of the latent variable that, when exceeded, the number of improved bean varieties cultivated increases by 1. In this situation, the ordered probit is the most appropriate model specification. Ordered probit models are more appropriate than Poisson models when count data take mainly values of 0, 1, or 2, with few observations greater than 2, and a multinomial logit specification would result in loss of information (Cameron and Trivedi 2013). Ordered probit models have been used previously in the literature to explain adoption and its determinants (Teklewold, Kassie, and Shiferaw 2013; Wollni, Lee, and Thies 2010).

Given that we are also interested in factors affecting adoption of the most popular improved varieties, unobserved benefits associated with adoption of a particular variety j can be expressed as:

$$y_{ij}^* = x_{ij}' \beta_j + \varepsilon_{ij} \qquad (3)$$

If the net benefits of adoption are greater than those of not adopting, farmer i^{th} will adopt improved variety j $(j=1, 2, 3)$—with j representing one of the top-three most popular improved varieties. When adoption occurs, the unobservable continuous latent variable y_{ij}^* is greater than

[2] Difficulties arose when identifying improved varieties, as farmers do not always refer to a variety using its official released name. Instead, an improved variety can be given several different local names. For this reason, the list of variety names was cross-checked across both surveys and with several other secondary sources. We are confident in the identification of the most popular improved varieties across the two studies. However, given the large number of local varieties cultivated by Rwandan farmers and the possibilities of several local names given to refer to one particular variety, the ranking of local varieties was not examined across the two studies. In addition, the focus of this study is on improved varieties.

[3] The HarvestPlus study took place in all 30 districts in Rwanda, while the DIIVA study covered 27 districts. We eliminated a few observations because of outliers and missing values. Our combined sample comprises 2,577 observations: 1,256 observations from the HarvestPlus study and 1,321 observation from the DIIVA project.

0, and under the revealed preference assumption can be expressed as a binary variable taking the value of 1 ($y_{ij}=1$), and 0 otherwise ($y_{ij}=0$). The discrete adoption decision can be modeled using a probit model. However, we expect that the decision of adopting one improved variety is correlated with other household adoption decisions. To capture this possible correlation, we used a multivariate probit model. Model assumptions are that the error terms follow a multivariable normal distribution with 0 conditional mean, variance of 1, and correlation ρ_{jk} $\forall j \neq k$. ρ_{jk} represents the covariance between the errors of variety j and variety k and is expected to be nonzero if varietal adoption decisions are correlated within household. The error covariance matrix Ω can be expressed as:

$$\Omega = \begin{bmatrix} 1 & \rho_{12} & \rho_{13} \\ \rho_{21} & 1 & \rho_{23} \\ \rho_{31} & \rho_{32} & 1 \end{bmatrix} \qquad (4)$$

Previous studies making use of a multivariable probit model to estimate determinants of adoption among correlated agricultural technologies include Marenya and Barrett (2007) and Teklewold, Kassie, and Shiferaw (2013).

In sum, ordered probit models are estimated to identify determinants of adoption and intensity of adoption of improved bush and climbing bean varieties. A model is estimated for each type of bean. Adoption of popular improved bush and climbing bean varieties is investigated using multivariate probit models. For both models, variables reflecting variety performance and constraints to adoption are (1) household head characteristics (gender, age, education, and main occupation); (2) access to information (membership in farmers association and population density); (3) agro-climatic conditions (elevation, average yearly rainfall, average drought severity index, and type of soil texture); (4) market factors (distance to nearest town, and ratio of that distance not on main road); and (5) household endowment (Tropical Livestock Unit [TLU [4]], land planted to beans, and number of working adults). Finally, probabilities of adopting each of the top-three improved varieties are predicted based on the multivariate probit estimated coefficients. The predicted probabilities are regressed against variety attributes (for adopting households) to identify attributes that have contributed to variety popularity.

4 The following conversion factors were applied: cattle = 0.7, sheep = 0.1, goats = 0.1, pigs = 0.2, chickens = 0.01, and were then summed to get household TLU.

Since the two data sources are combined for model estimations, a dummy variable is included to distinguish between datasets and cropping seasons. This is an intermediary between the two extreme cases of separate estimation—assuming all model coefficients are different—and pooled estimation—assuming all model coefficients are the same. [5] In the pooled estimation, the common intercept represents the average of the two cropping seasons. Adding a dataset-specific dummy variable captures changes in variety choice per cropping season. Since we combine two independent cross-sectional datasets, each representing a random sample from the population, potential correlation between survey error terms is not a concern.

4. RESULTS

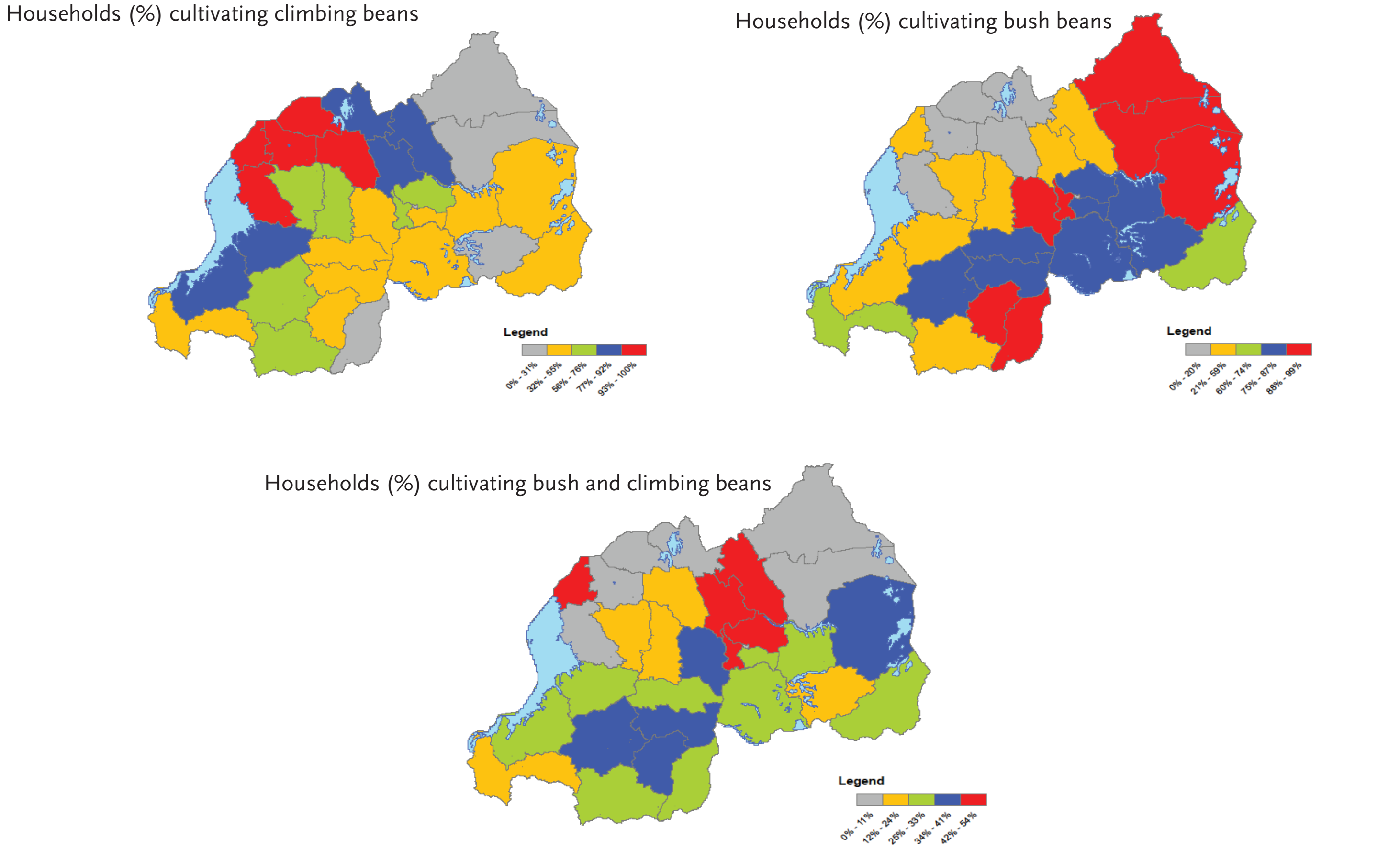
4.1 Descriptive Analysis and Adoption Patterns

Our data reveal that a similar proportion of households cultivates bush and climbing beans: nationally, 62 percent of households grow climbing beans compared with 64 percent for bush beans. Twenty-six percent of households grow both types of beans. Important regional patterns exist (Figure 1). Climbing bean cultivation dominates in the Northern Province, which is characterized by high elevation, cooler temperatures, and precipitation throughout the year (Katungi et al. 2015). The Northern Province was also the point of introduction for climbing beans in Rwanda (Sperling and Muyaneza 1995).

Bush beans are most frequently cultivated in the Eastern Province, a low-altitude area with warmer temperature and less rainfall. Bush beans are also commonly grown in areas surrounding Kigali and in a few districts in the Southern Province, which is mostly a low-altitude zone. Cultivation of both climbing and bush beans is common in few districts—that is, in some districts in the center of the country and one in the North—adjacent to Kivu Lake. Most of these districts overlap with the mid-altitude zone, where temperature is lower than in the low-altitude zone, but higher compared with the high-altitude zone (Katungi et al. 2015).

Household profiles are provided in Table 1, by type of beans grown. The average bean-growing household head is about 46 years old and, in most cases, is male (73 percent) with some level of primary education (65

5 Separate and compiled regression results were compared. Some estimated coefficients are statistically different between models, while others are not, suggesting that the reality probably lies in the middle between complete separation and pooled estimation. We consider a model with a varying intercept a good intermediary, considering the advantages of combining the two data sources.



Source: Authors, based on the HarvestPlus adoption study and the DIIVA study

Figure 1: Bean cultivation by district, Rwanda 2011

percent). Male-headed households are more prevalent among climbing bean than bush bean growers and households cultivating both types of beans. The proportion of household heads who attended secondary school is lower among climbing bean growers compared with the other groups. About 90 percent of household heads farm as a main economic occupation, and no statistical differences in occupation are found across groups.

The average bean-producing household is composed of 5.2 members and has fewer dependents than working adults. About 22 percent of households belong to a farmers association, and this proportion is statistically greater for climbing than bush bean producers (23 versus 19 percent). Households cultivating only climbing beans reside in more densely inhabited areas than those cultivating only bush beans (640 versus 548 population/0.8 square kilometers [km2]). As expected, households cultivating only climbing beans reside at higher altitudes and experience higher yearly rainfall, compared with households growing both types of beans and those cultivating only bush beans.

Land planted to climbing beans is about 0.5 hectares for those growing only climbing beans, while bush bean producers allocate about 1 hectare to bush bean cultivation. The smaller amount of land per household under climbing beans reflects that they are frequently grown in the North, where population density is high and land is scarce. Growers of both types of beans allocate about 0.7 hectares to each. About 30 percent of households sold beans in the market, regardless of the types of beans they grow. Distance to the nearest city of a minimum of 20,000 inhabitants is greater for households cultivating only bush beans, compared with those cultivating only climbing beans or both types of beans.

Adoption of Improved Climbing and Bush Bean Varieties in Rwanda

The vast majority of climbing bean producers have adopted improved varieties, as improved varieties are

Table 1: Descriptive Statistics by Bean Producer Type, Rwanda, 2011

Producer characteristics	Climbing beans growers	Bush bean growers	Both	Sample
HH head gender (1 = male)1,2	0.77	0.72	0.70	0.73
HH head education				
None	0.26	0.26	0.24	0.26
Primary	0.67	0.64	0.65	0.65
Secondary 1,2	0.07	0.09	0.11	0.09
HH head age	46.02	45.66	46.87	46.11
HH head is a farmer (1 = yes)	0.91	0.90	0.89	0.90
Household size	5.16	5.20	5.33	5.22
Dependency ratio (Dep/working adult)	0.88	0.95	0.92	0.92
Farmers association (1 = yes) 1	0.23	0.19	0.22	0.22
Population density (pop/0.8 km2) 1	640.21	518.85	610.93	588.71
Elevation (meters) 1,2,3	1,820.64	1,583.26	1,691.55	1,701.19
Long-term average yearly rainfall1,2,3	1,252.90	1,053.21	1,139.43	1,151.14
Land planted to bush beans (ha)	–	1.06	0.71	0.92
Land planted to climbing beans (ha)	0.50	–	0.67	0.57
HH sales beans (1 = yes)	0.29	0.31	0.31	0.30
Distance to city with ≥ 20,000 people (min) 1,3	175.05	200.04	169.22	182.56
N	**972**	**938**	**667**	**2,577**

Source: Authors, based on 2011 HarvestPlus adoption study and DIIVA study

Notes: 1, 2, and 3 indicate that means are statistically different at the 5 percent level between (1) Climbing and bush bean growers, (2) climbing and climbing-bush bean growers, and (3) bush and climbing-bush bean growers. ha = hectare; HH = household; km2 = square kilometers; min = minutes; pop = population; dep = dependents.

cultivated by 86 percent of climbing bean-growing households: [6] 55 percent grow one improved variety, 25 percent grow two, and 6 percent grow three or more improved climbing bean varieties. Adoption of improved climbers is higher in districts where climbing bean cultivation is more common (in the North) and in two districts surrounding the capital.

Improved bush varieties are grown by about half of households growing bush beans. About 42 percent of adopters cultivate one improved bush bean variety, while only 8 percent cultivate two. Less than 1 percent of bush bean growers cultivate three improved bush bean varieties at a time. While cultivation of bush bean is most widespread in the eastern region (Figure 2), none of the districts there has the highest adoption level for improved varieties. The highest rates of adoption of improved bush bean varieties are found in two southern districts, and in one district near Lake Kivu, where climbing bean cultivation is most important.

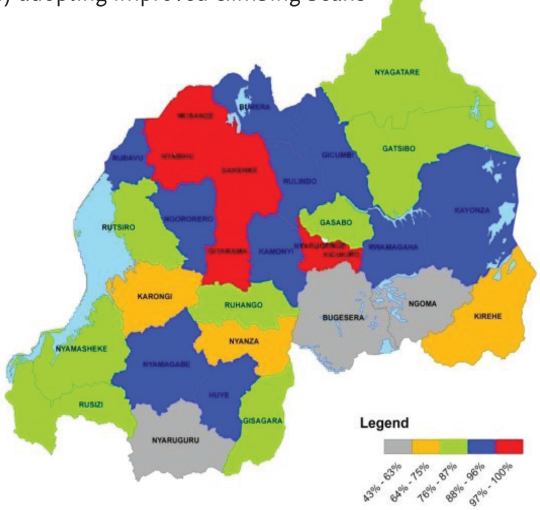
Adoption of Most Popular Improved Bean Varieties

The three most popular [7] improved varieties are Decelaya, Kaki, and Vuninkingi for climbing beans and Mutiki, Shyushya, and Kiryumukwe for bush beans (Figure 3). Decelaya is grown by about 23 percent of households adopting improved climbing beans; Kaki, by 20 percent; and Vuninkingi, by 18 percent. These varieties were released over three decades ago, with the exception of Kaki, which was first released in Rwanda in 2010. However, Kaki was released in the neighboring country Burundi in 1987, meaning that this variety could have been informally available among Rwandan farmers for a

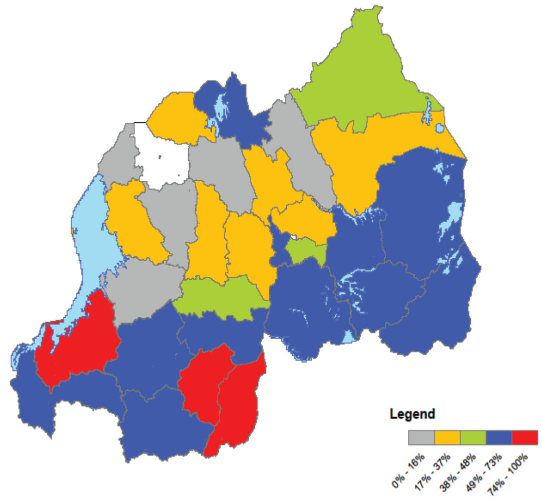
6 Statistics reported are conditional on households growing climbing beans.

7 Popular refers to varieties cultivated by the greatest number of farmers in both datasets, which can be considered a proxy for land area under each variety.

Households (%) adopting improved climbing beans



Households (%) adopting improved bush beans



Source: Authors, based on the HarvestPlus adoption study and the DIIVA study

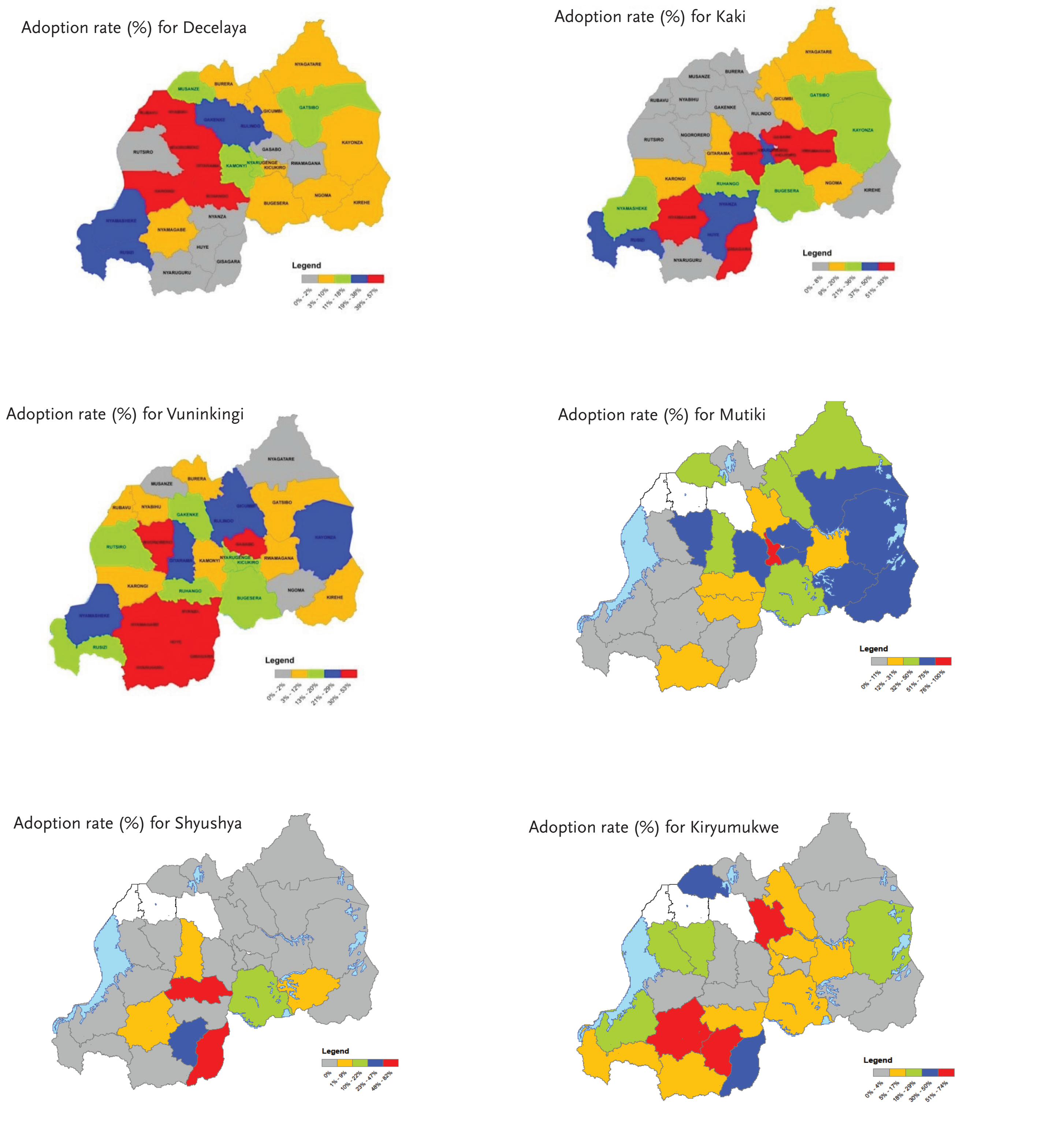
Figure 2: District Profile of Improved Bean Adoption, Rwanda, 2011

long time as well. Varietal adoption clusters, defined as a high concentration of households in close proximity growing a particular variety, are observed for all popular improved varieties. This clustering may indicate that the intensity of adoption depends on the suitability of the variety to local conditions. Studies from the Green Revolution show that adoption occurred in clusters (Feder, Just, and Zilberman 1985). While the adoption rate for Kaki is greatest in the mid-altitude zone, geographical adoption patterns for this variety are not as clustered as for the other two varieties. High adoption in the Southern Province may be explained by the release of Kaki in Burundi.

Among households growing improved bush varieties, 33, 18, and 16 percent reported cultivating Mutiki, Shyushya, and Kiryumukwe, respectively. These popular improved bush varieties have spread to fewer districts than the popular improved climbing bean varieties (Figure 4). Adoption of Mutiki is the greatest near Kigali and is also high in the Eastern Province. The largest share of Shyushya adopters is in a few districts in the Southern Province. Similarly to Mutiki, adoption of Kiryumukwe spreads to about half of the districts. High-adoption clusters of Kiryumukwe are found in different districts, again providing evidence of environmental specificity.

Attributes of most popular improved bean varieties

Popular improved varieties performed best on several attributes compared with other improved and local varieties (Table 2). Among climbing bean varieties, Kaki performs statistically better for yield, early maturity, marketability, cooking time, and taste compared with Decelaya, Vuninkingi, and other improved and local varieties. Contrary to findings from other studies, local climbing varieties do not perform better for taste than improved varieties (Lunduka, Fisher, and Snapp 2012; Timu et al. 2012). For bush bean varieties, popular improved varieties are outperformed by other improved and local varieties only for drought tolerance, suggesting their superiority. Tests for the equality of attribute scores between the three most popular improved bush varieties indicate that Mutiki, Shyushya, and Kiryumukwe perform similarly for yield, marketability, and taste. Shyushya is statistically superior to the two other popular bush improved varieties for early maturity and cooking time, but is inferior for grain size. Mutiki performs significantly better for grain color than Shyushya and Kiryumukwe, but performs worse than Shyushya for drought tolerance. For storability, Shyushya and Kiryumukwe are statistically equal and superior to other bush bean varieties.



Source: Authors, based on 2011 HarvestPlus adoption study and DIIVA study

Figure 3: District profile of cultivation of Decelaya, Kaki, Vuninkingi, Mutiki, Shyushya, and Kiryumukwe, Rwanda 2011

Table 2: Variety Attributes Performance as Stated by Farmers for Popular, Improved, and Local Climbing and Bush Bean Varieties, Rwanda, 2011

Varieties	Yield	Early maturity	Grain size	Market demand	Grain color	Storage	Cooking time	Taste	Drought tolerance
Climbing varieties									
Decelaya	3.94	3.89	3.62	3.81	3.75	3.69	3.74	3.86	3.05
Kaki	**4.37**	**4.13**	3.78	**4.31**	**4.00**	3.83	**4.23**	4.35	3.23
Vuninkingi	4.07	3.87	**3.85**	4.03	3.95	**3.88**	4.02	4.16	3.21
Other improved	4.00	3.90	3.80	3.95	3.87	3.85	3.94	4.06	3.21
Local[1]	3.90	3.64	3.78	3.68	3.79	3.70	3.85	3.96	**3.26**
Bush varieties									
Mutiki	4.52	4.34	**4.21**	**4.53**	**4.40**	3.87	4.31	4.52	2.83
Shyushya	**4.50**	**4.66**	3.88	4.44	4.26	4.08	**4.73**	**4.57**	3.22
Kiryumukwe	4.45	4.18	4.11	4.37	4.28	**4.09**	4.27	4.51	2.91
Other improved	4.25	4.13	4.16	4.32	4.21	3.86	4.25	4.36	**3.31**
Local[2]	4.28	4.08	3.75	4.23	3.93	3.78	4.11	4.29	3.06

Source: Authors, based on the HarvestPlus adoption study and the DIIVA study

Notes: For each variety cultivated, farmers were asked to judge attribute performance by providing a score from 1 to 5. A score of 5 indicates that a variety performs "very well" and 1 means it performs "very poorly." A score of 3 indicates average performance. Numbers in bold indicate varieties with the highest scores.

[1]The three most important local climbing bean varieties in the DIIVA study are Umushingiriro, Nyirabukara, and Nyirambohera, and in the HarvestPlus study are Nyirabukara, Gitsimbayogi, and Kenyerempure.

[2]The three most important local bush bean varieties in the DIIVA study are Colta, mixture, and Mukwararaye, and in the HarvestPlus study are Akanyamanza, Kivuzo, and Ibigondo.

4.2 Econometric Analysis

Ordered probit models were estimated to identify the determinants associated with cultivating only local varieties (not adopting), adopting one improved variety, or adopting two or more improved varieties. Marginal effects are presented in Table 3 for climbing beans and Table 4 for bush beans. The marginal effects are specific to each level of adoption and represent changes in probabilities of observing a given adoption level

Adoption of Improved Climbing Bean Varieties in Rwanda

Agro-climatic factors and biophysical constraints are the most important determinants of adoption of improved climbing bean varieties (Table 3). The likelihood of adopting two or more improved varieties is greater in high-elevation areas, where heavy precipitation coexists with dry spells, and soil texture is coarse. These findings suggest that the bean research program has been successful in selecting, breeding, and disseminating varieties that respond well to Rwanda's challenging biophysical production constraints.

Variables reflecting access to information and opportunities to learn from others are strong predictors of adoption of improved climbing beans. Membership in a farmers association significantly raises adoption; the probability of cultivating two or more improved climbing varieties is 4.6 percentage points higher for association members. Membership in a farmers association reduces the likelihood of adopting only one improved variety or none by two and three percentage points, respectively. If population density increases by 100 units (population/0.8 km2), the probability of adopting two or more improved climbing bean seeds increases by 0.5 percentage points.

Variables representing household resource constraints are jointly significant (p-value = 0.0040) in explaining adoption. Individual coefficients are statistically significant at the 5 percent level for land area planted to climbing beans, and the 10 percent level for TLU. Land planted to climbing beans has a positive impact on the likelihood of cultivating two or more climbing improved varieties, supporting the hypothesis that larger land holding facilitates adoption by allowing farmers to experiment with different varieties. Livestock ownership

Table 3: Marginal Effects on the Probability of Not Adopting, Adopting 1, or Adopting 2 or More Improved Climbing Bean Varieties, Rwanda, 2011

	Non-adopters		Adopters of 1 variety		Adopters of 2+ varieties	
Probability Variables	ME	Sd. err.	ME	Sd. err.	ME	Sd. err.
HH head gender (1 = male)	-0.0168	0.0129	-0.0100	0.0072	0.0268	0.0201
HH head age	0.0002	0.0004	0.0002	0.0003	-0.0004	0.0007
HH head education (base = none)						
Primary	0.0215*	0.0126	0.0146	0.0093	-0.0362*	0.0218
Secondary	-0.0048	0.0208	-0.0041	0.0181	0.0089	0.0389
HH head main occupation is farming (1 = yes)	-0.0559**	0.0238	-0.0232***	0.0057	0.0791***	0.0287
Membership in farmers association (1 = yes)	-0.0267**	0.0120	-0.0196*	0.0100	0.0463**	0.0219
Population density (100 pop/0.8 km2)	-0.0032***	0.0008	-0.0021	0.0005	0.0053***	0.0012
Elevation (100 meters)	-0.0067***	0.0025	-0.0043***	0.0017	0.0110***	0.0042
Average yearly rainfall 2004–2010	-0.0004***	0.0001	-0.0003***	0.0001	0.0007***	0.0001
Average drought severity index 2005–2010	-0.2489***	0.0349	-0.1591***	0.0253	0.4080***	0.0559
Soil texture (1 = fine)	0.0476***	0.0111	0.0341***	0.0089	-0.0816***	0.0196
Distance in minute to city with ≥ 20,000 people	0.0003***	0.0000	0.0002***	0.0000	-0.0005***	0.0001
Ratio of distance to city NOT on road	0.0003	0.0008	0.0002	0.0005	-0.0005	0.0013
Tropical Livestock Unit	-0.0127*	0.0072	-0.0075*	0.0042	0.0202*	0.0113
Land planted to climbing beans (ha)	-0.0145**	0.0073	-0.0093*	0.0048	0.0238**	0.0121
Number of adults	-0.0030	0.0038	-0.0019	0.0024	0.0049	0.0062
Season (1 = Season B)	0.1587***	0.0131	0.1287***	0.0140	-0.2874***	0.0209

Source: Authors, based on the HarvestPlus adoption study and the DIIVA study
Notes: *** p<0.01, ** p<0.05, * p<0.1. ha = hectare; HH = household; km2 = square kilometers; ME = marginal effects; pop = population; std. err. = robust standard errors

has a small positive influence on the adoption of two or more improved climbing bean varieties. This result is consistent with Marenya and Barrett (2007), who found that livestock ownership has a positive effect on the likelihood of adopting improved natural resource management practices. Teklewold, Kassie, and Shiferaw (2013) also found that livestock ownership increases adoption of sustainable agricultural practices in Ethiopia, which the authors linked to the positive influence of wealth on adoption of new agricultural technology.

In terms of market factors, only the distance between the household dwelling and the nearest city is significant in explaining adoption. Living 10 minutes farther from an economic center of 20,000 inhabitants or more reduces the likelihood of cultivating two or more improved climbing bean varieties by 0.5 percentage points. This finding is consistent with Minten, Koru, and Stifel (2013), who found that high transaction and transportation costs reduce improved seed use among farmers living the northwestern Ethiopia.

Few of the household socioeconomic demographics are significant determinants of adoption of improved climbing bean varieties. Households whose head reported farming as the main occupation are 7.9 percentage points more likely to cultivate two or more improved climbing bean varieties, and 2.3 and 5.6 percentage points less likely to be adopters of only one improved climbing bean variety or none, respectively. This may suggest that greater involvement of the household head in farming activities facilitates access to bean varietal technology.

Adoption of Improved Bush Bean Varieties in Rwanda

Agro-climatic factors are key regressors in explaining the adoption of improved bush varieties (Table 4). An increase in elevation and rainfall is associated with a lower probability of adopting improved bush bean varieties. While climbing bean cultivation is most common in regions characterized by high elevation and heavy rainfall, when bush beans are grown under these conditions, local varieties are more likely to be chosen. Soil texture also explains the adoption of improved bush bean varieties. Belonging to a farmers association reduces the probability of being a non-adopter of improved bush bean varieties by 7.7 percentage points, while increasing the likelihood of adopting one improved variety by 4.0 percentage points.

Factors reflecting household resource endowments suggest the presence of constraints to adoption of improved bush bean varieties. A 1-hectare increase in land planted to bush beans reduces the likelihood of being a non-adopter by 8.0 percentage points, while increasing the probability of adopting one and two or more improved varieties by 4.9 and 3.2 percentage points, respectively. The number of adult members, a proxy for labor availability, has a positive influence of the adoption of improved bush bean varieties. This finding is in line with those of Feder, Just, and Zilberman (1985), Feleke and Zegeye (2006), and Marenya and Barrett (2007), who argue that agricultural technology adoption is positively associated with family agricultural labor supply. This positive outcome is explained by the importance of family labor in agricultural activities and limited ability to hire labor. It also may reflect the greater labor requirements of improved over local varieties.

Market factors are also significant determinants of the level of adoption of improved bush bean varieties. Distance to the nearest city and adoption of improved bush bean varieties are positively associated. The likelihood of adopting improved bush bean varieties also increases with the share of the travel distance outside main road networks. These findings could be an indication that uptake of improved varieties among bush bean growers is more common where fewer alternative economic opportunities exist, leading to greater involvement in farming. Among household socioeconomic characteristics, only the occupation of the household head is significant—at the 10 percent level—in explaining adoption decisions of improved bush bean varieties.

Comparison Between Adoption of Improved Climbing and Bush Bean Varieties in Rwanda

To draw strong conclusions about factors constraining and stimulating the adoption of improved bean varieties, we compare findings between bush and climbing bean technologies. Agro-climatic factors are the strongest determinants in explaining the adoption of both kinds of improved beans. This finding is consistent with studies examining adoption of Green Revolution varieties—environmental conditions are the main determinants of adoption rates over time (Feder and Umali 1993). In addition, the literature shows that widespread adoption in Africa has been slowed by heterogeneous environmental conditions within countries. This means that the extent of adoption of the new improved varieties, such as HIB, will depend in the long run on their suitability to broad and specific agro-climatic conditions.

Membership in a farmers association has a positive influence on the adoption of improved bush and climbing beans. This confirms the role of this type of social network in providing information about the existence

Table 4: Marginal Effects on the Probability of Not Adopting, Adopting 1, or Adopting 2 or More Improved Bush Bean Varieties, Rwanda, 2011

Probability Variables	Non-Adopters		Adopters of 1 Variety		Adopters 2or More Varieties	
	ME	Std. err.	ME	Std. err.	ME	Std. err.
HH head gender (1 = male)	-0.0074	0.0273	0.0045	0.0166	0.0029	0.0106
HH head age	0.0006	0.0010	-0.0004	0.0006	-0.0002	0.0004
HH head education (base = none)						
Primary	-0.0031	0.0302	0.0019	0.0186	0.0012	0.0116
Secondary	-0.0616	0.0492	0.0352	0.0272	0.0264	0.0222
HH head main occupation is farming (1 = yes)	-0.0647*	0.0374	0.0414*	0.0250	0.0233*	0.0125
Membership in farmers association (1 = yes)	-0.0771***	0.0278	0.0444***	0.0152	0.0327**	0.0129
Population density (100 pop/0.8 km2)	0.0028*	0.0015	-0.0017*	0.0009	-0.0011*	0.0006
Elevation (100 meters)	0.0182***	0.0063	-0.0110***	0.0038	-0.0072***	0.0026
Average yearly rainfall 2004–2010	0.0008***	0.0001	-0.0005***	0.0001	-0.0003***	0.0001
Average drought severity index 2005–2010	0.0884	0.0840	-0.0536	0.0509	-0.0349	0.0332
Soil texture (1= fine)	-0.0553**	0.0266	0.0339**	0.0166	0.0214**	0.0101
Distance to city with ≥ 20,000 people (min)	-0.0003***	0.0001	0.0002***	0.0001	0.0001***	0.0000
Ratio of distance to city NOT on road	-0.0054*	0.0031	0.0033*	0.0019	0.0021*	0.0013
Tropical Livestock Unit	0.0123	0.0141	-0.0074	0.0085	-0.0049	0.0056
Land planted to bush beans (ha)	-0.0804***	0.0087	0.0487***	0.0056	0.0317***	0.0039
Number of adults	-0.0156*	0.0087	0.0095*	0.0053	0.0061*	0.0035
Season (1 = Season B)	-0.0119	0.0281	0.0072	0.0171	0.0047	0.0110

Source: Authors, based on the HarvestPlus adoption study and the DIIVA study Notes: *** p<0.01, ** p<0.05, * p<0.1. ha = hectare; HH = household; km2 = square kilometers; ME = marginal effects; pop = population; std. err.= robust standard errors.

of improved varieties, their benefits, and management practices, and thus facilitating adoption of improved varieties. Belonging to a farmers association may also increase one's ability to learn from others.

Variables representing household resource constraints affect the adoption of improved bush and climbing varieties in different ways. The relationship between adoption of improved varieties and land planted to beans is positive for both bean types, but divergences are found for livestock ownership and family labor availability. Assuming that land planted to beans is positively correlated with farm size, various factors can explain the positive relationship between land planted to beans and adoption. Fixed transactions costs, such as the costs of acquiring information, locating, and learning about the new technology, are proportionally greater for small landholders, which may discourage and slow adoption (Feder, Just, and Zilberman 1985). Moreover, various authors have argued that the size of landholding is linked to several factors potentially affecting adoption decisions, such as household ability to bear risk, access to credit and other agricultural inputs, and wealth. Under such conditions, small farmers are at a disadvantage when it comes to technology adoption. While small farmers may eventually catch up with larger farmers in adoption of a given improved variety, inequity may continue as new technologies are constantly introduced. If small farmers lag behind in terms of adoption, they will reap smaller benefits compared with early adopters.

While the availability of family labor has a positive impact on adopting improved bush bean varieties, this relationship is insignificant for improved climbing beans. In the case of improved climbing beans in Rwanda, it may be that labor requirements are similar between the local and improved varieties (unlikely if improved varieties give higher yield), or that controlling for other factors, family labor availability is not a binding constraint. Labor requirements are generally greater for climbing than bush beans, and once the decision to cultivate climbing beans has been made, any additional labor requirements between local and improved varieties may be trivial. Katungi et al. (2015) found that while climbing bean cultivation is more labor intensive than bush beans, climbing bean-producing households are less likely to hire labor than bush bean growers. This provides an indication that family labor is not a limiting factor in the adoption of improved climbing varieties in Rwanda.

Livestock ownership has a positive and significant influence on the adoption of improved climbing bean varieties, but is insignificant in explaining the uptake of improved bush bean varieties. This is likely because of the complementarity between livestock production and climbing bean cultivation. Climbing beans produce significant quantities of biomass, which can then serve as livestock feed (Katungi et al. 2015). The complementarity between technology adoption and other farm practices has been previously discussed in the adoption literature (Feder, Just, and Zilberman 1985; Marenya and Barrett 2007; Traxler and Byerlee 1993).

Adoption of the Most Popular Improved Bean Varieties in Rwanda and their Attributes

After having analyzed the determinants of adoption of improved bean varieties, we narrow our focus to the three most popular improved varieties. The aim is to determine whether common patterns of adoption exist for the most popular varieties. This information can serve to inform the design of future dissemination strategies. Since the likelihood of adopting an improved variety is likely influenced by the adoption of other varieties, multivariate probit models [8] were estimated. This specification assumes that error terms between equations are correlated. This hypothesis is supported by the data for popular improved climbing and bush beans.

Climbing Beans

The estimates of rho—indicating correlation among equations' error terms—are jointly significant (p-value of zero), indicating that the decision to adopt one of the three most popular improved climbing bean varieties is correlated with the decision to grow the other two popular improved climbing bean varieties. More precisely, the decision to adopt Kaki is negatively correlated with the cultivation of Decelaya and Vuninkingi, while the decisions to grow Decelaya and Vuninkingi are not significantly interrelated. As shown in the Figure 3, Decelaya is most popular in the Northern Province, while cultivation of Vuninkingi is most common in the Southern Province.

Despite restricting the analysis to the most popular improved climbing bean varieties, agro-ecological factors are still dominant in explaining varietal choice among bean producers in Rwanda (Table 5). Elevation reduces the likelihood of adopting any of the three most popular improved varieties. The probability of cultivating Decelaya and Kaki is significantly and negatively associated with average yearly rainfall between 2004 and 2010. An increase in the drought severity index, which means wetter-than-normal conditions, reduces the likelihood of adopting Kaki. The opposite effect is found for Vuninkingi. Households that experienced wetter-than-normal

8 Model was estimated in Stata 13 using the user-written command "cmp" (Roodman 2009).

Table 5: Marginal Effects on the Probability of Selecting One of the Top-Three Improved Climbing Bean Varieties, Rwanda, 2011

	Decelaya		Kaki		Vuninkingi	
Probability variables	ME	Std. err.	ME	Std. err.	ME	Std. err.
HH head gender (1=male)	-0.0042	0.0254	-0.0223	0.0228	0.0007	0.0254
HH head age	0.0008	0.0009	0.0012	0.0008	0.0005	0.0009
HH head education (base = none)						
Primary	0.0505*	0.0259	0.0316	0.0236	0.0261	0.0259
Secondary	0.0745*	0.0434	0.0655*	0.0391	0.0148	0.0444
HH head main occupation is farming (1 = yes)	0.0463	0.0346	0.0003	0.0331	0.0210	0.0353
Membership in farmers association (1 = yes)	0.0530*	0.0273	-0.0612***	0.0231	0.0802***	0.0272
Population density (100 pop/0.8 km2)	0.0029**	0.0015	0.0002	0.0011	-0.0031*	0.0016
Elevation (100 meters)	-0.0264***	0.0048	-0.0270***	0.0046	-0.0122***	0.0045
Avg. yearly rainfall 2004–2010	-0.0003**	0.0001	-0.0005***	0.0001	-0.0002	0.0001
Avg. drought severity index 2005–2010	0.0113	0.0657	-0.4033***	0.0667	0.1568**	0.0693
Soil texture (1 = fine)	-0.0885***	0.0233	0.1413***	0.0188	0.0889***	0.0218
Distance to city with ≥ 20,000 people (min)	-0.0000	0.0001	-0.0001	0.0001	-0.0000	0.0001
Ratio of distance to city NOT on road	-0.0007	0.0019	-0.0092***	0.0030	-0.0050**	0.0021
Tropical Livestock Unit	0.0480***	0.0158	-0.0054	0.0126	-0.0141	0.0138
Land planted to climbing beans (ha)	-0.0305**	0.0144	0.0132	0.0117	0.0235*	0.0124
Number of adults	-0.0183**	0.0077	0.0008	0.0070	0.0003	0.0077
Season (1 = Season B)	-0.2271***	0.0224	-0.1000***	0.0210	0.0153	0.0237

Source: Authors, based on the HarvestPlus adoption study and the DIIVA study
Notes: *** $p<0.01$, ** $p<0.05$, * $p<0.1$. ha = hectare; HH = household; km2 = square kilometers; ME = marginal effects; pop = population; std. err.= robust standard errors.

Table 6: Marginal Effects of Variety Attribute Performance on the Predicted Probability of Cultivating Popular Improved Climbing Bean Varieties, Rwanda, 2011

	Decelaya		Kaki		Vuninkingi	
Variety attribute performance as stated by farmers	ME	Std. err.	ME	Std. err.	ME	Std. err.
Yield	0.0164	0.0123	0.0392**	0.0175	-0.0037	0.0072
Maturity	0.0368**	0.0154	0.0148	0.0199	0.0143**	0.0071
Grain size	-0.0573***	0.0128	-0.0329**	0.0150	0.0098	0.0076
Grain color	-0.0112	0.0137	0.0170	0.0154	-0.0090	0.0094
Storage	0.0188*	0.0104	0.0705***	0.0152	0.0169*	0.0090
Cooking time	0.0114	0.0147	-0.0390**	0.0192	0.0067	0.0088
Taste	0.0543***	0.0170	0.0166	0.0181	0.0171*	0.0088
Drought Tolerance	0.0056	0.0118	0.0010	0.0110	0.0007	0.0051

Source: Authors, based on the HarvestPlus adoption study and the DIIVA study Notes: *** p<0.01, ** p<0.05, * p<0.1. ME = marginal effects; std. err. = robust standard errors.

conditions over the last five years are more likely to be adopters of Vuninkingi, compared with other improved varieties. Soil texture is also a significant determinant in explaining the adoption of the three most popular improved climbing bean varieties.

Factors positively influencing the adoption of Decelaya, the most popular improved climbing bean variety, are the education of the household head, membership in a farmers association, population density, and TLU (Table 5). Kaki is the second most popular improved variety and was released in Rwanda in 2010. Surprisingly, belonging to a farmers association is negatively associated with the adoption of this variety. [9]Households that have to travel greater distance outside the main road networks to reach the nearby town are less likely to be cultivating Kaki. The probability of growing Vuninkingi, the third most popular improved climbing bean variety, compared with other improved varieties, is greater among households belonging to a farmers association and decreases with distance to the main road.

Given the importance of agro-climatic factors in explaining adoption patterns, predicted probabilities of adoption should be a good indicator of where a given variety is more or less suitable, given household agro-ecological conditions. Low probabilities of adoption should be associated with less than ideal agro-environmental conditions for the variety in question, while high probabilities should indicate that the variety would perform well, given household agro-ecological conditions. Based on this argument, the predicted probabilities of adoption—for the three most popular improved varieties—are regressed on variety attributes' performance as assessed by the adopting farmers.

The attributes considered in the regressions are yield, early maturity, grain size and color, storability, cooking time, taste, and drought tolerance.[10] As predicted

9 As a general rule, membership in a farmers association increases adoption of improved bean varieties (see Tables 3, 4, 5, and 7). Kaki is an exception, and the reason for this is uncertain. It could be that being recently released, Kaki has not been promoted yet among farmers associations. Farmers who cultivate Kaki could be those who do not belong to farmers associations and who obtain new planting material informally.

10 The marketability attribute is excluded from the analysis, since not all farmers participate in the market and, thus, may have difficulty assessing this attribute. The hypothesis is supported by the data: various farmers did not provide a score for this attribute, leading to several missing values for marketability.

Table 7: Marginal Effects on the Probability of Selecting One of the Top Three Popular Improved Bush bean Varieties, Rwanda, 2011

	Mutiki		Shyushya		Kiryumukwe	
Probability variables	ME	Std. err.	ME	Std. err.	ME	Std. err.
HH head gender (1 = male)	0.0033	0.0327	-0.0383	0.0278	-0.0304	0.0305
HH head age	-0.0003	0.0013	-0.0023**	0.0010	0.0000	0.0011
HH head education (base = none)						
Primary	0.0551	0.0366	-0.0384	0.0311	0.0785**	0.0323
Secondary	0.1397**	0.0596	-0.0298	0.0483	0.0227	0.0465
HH head main occupation is farming (1 = yes)	-0.0399	0.0481	0.0517	0.0392	0.0186	0.0397
Membership in farmers association (1 = yes)	-0.0358	0.0344	0.0927***	0.0308	0.0300	0.0305
Population density (100 pop/0.8 km2)	-0.0031**	0.0015	0.0012	0.0015	-0.0014	0.0015
Elevation (100 meters)	-0.0337***	0.0091	0.0085	0.0075	0.0226***	0.0062
Average yearly rainfall 2004–2010	0.0019***	0.0002	-0.0008***	0.0001	-0.0005***	0.0001
Average drought severity index 2005–2010	0.3253***	0.1097	-0.7382***	0.1003	-0.3043***	0.0905
Soil texture (1 = fine)	-0.0374	0.0344	-0.0950***	0.0262	0.1510***	0.0250
Distance in minute to city with ≥ 20,000 people	-0.0002	0.0002	-0.0001	0.0001	-0.0002*	0.0001
Ratio of distance to city NOT on road	-0.0016	0.0028	0.0192***	0.0042	0.0026	0.0026
Tropical Livestock Unit	-0.0572***	0.0168	-0.0155	0.0170	0.0552***	0.0197
Land planted to bush beans (ha)	0.0136	0.0100	0.0199**	0.0078	0.0002	0.0077
Number of adults	0.0053	0.0100	0.0003	0.0088	-0.0080	0.0091
Season (1 = Season B)	-0.1950***	0.0385	0.0515*	0.0292	-0.1384***	0.0318

Source: Authors, based on 2011 HarvestPlus adoption study and DIIVA study

Notes: *** $p<0.01$, ** $p<0.05$, * $p<0.1$. ha = hectare; HH = household; km2 = square kilometers; ME = marginal effects; pop = population; std. err.= robust standard errors.

Table 8: Marginal Effects of Variety Attribute Performance on the Predicted Probability of Cultivating Popular Improved Bush Bean Varieties, Rwanda, 2011

	Mutiki		Shyushya		Kiryumukwe	
Variety attributes	**Coef.**	**Std. err.**	**Coef.**	**Std. err.**	**Coef.**	**Std. err.**
Yield	0.0772***	0.0201	-0.0555*	0.0298	0.0161	0.0243
Maturity	0.0259	0.0175	0.0321	0.0316	0.0321	0.0204
Grain size	-0.0013	0.0177	0.0472**	0.0232	-0.0172	0.0246
Grain color	0.0428*	0.0225	0.0331	0.0263	-0.0179	0.0253
Storage	0.0155	0.0178	-0.0196	0.0203	0.0308	0.0266
Cooking time	-0.0605***	0.0193	0.0613*	0.0363	0.0163	0.0299
Taste	0.0471*	0.0268	-0.0008	0.0310	0.0348	0.0287
Drought tolerance	-0.0323***	0.0117	-0.0047	0.0162	-0.0270*	0.0139

Source: Authors, based on 2011 HarvestPlus adoption study and DIIVA study

Notes: *** p<0.01, ** p<0.05, * p<0.1. Coef. = coefficient; std. err.= robust standard errors.

probabilities theoretically range between 0 and 1, models were estimated considering these values as lower and upper truncation points. Results indicate that when grown under the most suitable agro-climatic conditions, Decelaya is adopted for its early maturity, storage properties, and good taste (Table 6). High yield and good storability properties are associated with high probability of adopting Kaki. Varietal attributes explaining high probabilities of adoption for Vuninkingi are early maturity, and good storability and taste.

Our results also suggest that large seed size is not a preferred attribute among all households. Farmers with high probabilities of adopting Decelaya and Kaki, which are considered large seed varieties, rank these varieties lower in terms of grain size (Table 6). These results are consistent with the descriptive statistics on varietal attributes (Table 2). Vuninkingi ranks higher for grain size than Decelaya and Kaki, but the difference is statistically significant only between Vuninkingi and Decelaya.

Bush Beans

The estimates for rho—the coefficients for the correlation of error terms between equations—are jointly significant at p-value near zero. When individually tested, rho is significant and negative for Mutiki and Shyushya, and Mutiki and Kiryumukwe. This means that the probability of adopting Mutiki is negatively correlated with the likelihood of cultivating Shyushya or Kiryumukwe. However, the decision to adopt Shyushya is not significantly linked to the probability of cultivating Kiryumukwe. These results are consistent with the geographical patterns of adoption of these varieties (Figure 3). Mutiki is most adopted in the Eastern Province, where Shyushya is not grown and adoption of Kiryumukwe is minimal.

Consistent with previous findings, agro-climatic factors are the major determinants of adoption of popular improved bush varieties (Table 7). Education of the household head has a positive influence on the probability of adopting Mutiki and Kiryumukwe.

Population density and adoption of Mitiki are negatively correlated. This finding is consistent with the results in Figure 3, showing that Mutiki is more commonly grown in the Eastern Province, where population density is lower. The likelihood of adopting Shyushya decreases with the age of the household head and increases for households belonging to a farmers association. Last, livestock ownership is positively associated with the probability of cultivating Kiryumukwe.

The predicted probabilities of adopting one of the most popular improved bush bean varieties were regressed against variety attributes' performance using a truncation process. Higher scores for yield, grain color, and taste are associated with higher probabilities of adopting Mutiki (Table 8). Grain size and cooking time are significant and positive attributes explaining the probability of adopting Shyushya—an indication that its consumption properties partly drive its adoption.

5. CONCLUSION

This study documents spatial adoption patterns of both improved and the most popular improved bush and climbing bean varieties in Rwanda, and identifies factors associated with these adoption decisions. Eighty-six percent of climbing bean growers have adopted improved climbing varieties, while 50 percent of bush bean growers cultivate improved bush varieties. Adoption rates of improved climbing bean varieties are the highest in the Northern Province, where climbing beans were first introduced, and in two districts near Kigali. Higher adoption rates for improved bush bean varieties are found in the Southern Province. The most popular improved varieties, in terms of number of farmers, are Decelaya, Kaki, and Vuninkingi for climbing beans, and Mutiki, Suyushya, and Kiryumukwe for bush beans. Geographical adoption clusters exist for of all these varieties (Figure 3).

Ordered probit models were estimated to identify household characteristics reflecting preferences for and constraints to adoption of improved climbing and bush bean varieties. We found similarities as well as differences in adoption patterns between the two bean technologies. These differences highlight the complexity of technological adoption decisions and the highly specific and localized conditions under which adoption decisions take place. Similarities include the role of agro-ecological conditions, land area planted to beans, and membership in a farmers association.

As argued in Gilligan (2012), high adoption and consumption rates are needed for biofortified crops to successfully reduce malnutrition. Our study reveals that working with local farmers associations at the initial phase of the diffusion process can stimulate adoption by informing households about the existence of HIB varieties, their benefits, and management practices. The role of informal channels in gaining information and access to the new varieties should also be considered. Farmers with more land planted to beans are more likely to be adopters of improved varieties. This means that dissemination strategies of HIB should ensure that small landholders are reached. In addition, for adoption to occur, it may require putting in place programs and policies designed to lift the underlying adoption constraints faced by small landholders. Results also indicate that to achieve high levels of adoption of HIB, various varieties must be released and carefully disseminated, such that they are well adapted to different and specific agro-ecological conditions.

Last, regression results of this study indicate that a single variety does not appear to outperform other varieties on more than a few attributes, with preferred attributes varying among the most popular improved varieties. For example, Kaki is preferred for its high yield and storability properties, while Decelaya is adopted for its early maturity and good taste. Attributes most important in explaining probabilities of adoption of popular improved bush and climbing bean varieties are storability, taste, early maturity, yield, and grain size. Therefore, breeding efforts for HIB varieties should be targeted to include some of these preferred attributes. Katungi et al. (2011) reported that bean farmers in Kenya put higher value on production than consumption attributes when allocating land to different improved varieties. If this finding holds for bean producers in Rwanda, HIB varieties should also be bred to have superior production attributes. During dissemination efforts, these superior production attributes should be emphasized to farmers in addition to the high iron content to ensure producers' acceptability of HIB.

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APPENDIX

Table A1: Ranking of Common Top 10 Improved Bean Varieties

Common Improved Varieties	National Rank	
Climbing	**HarvestPlus**	**DIIVA**
Deceleya	1	5
Kaki (RWV 2070)	2	4
Cajamarica	4	9
Vuninkingi (G685)	3	1
Muhondo	5	10
Flor de mayo	6	3
Gisenyi	9	7
Bush	**HarvestPlus**	**DIIVA**
Mutiki	1	3
Kiryumukwe	2	4
Shyushya (RWR 719)	3	1
Koruta	4	5
Rwandarushya (RWR221)	5	2
Rozikoko (A1312)	6	7

Sources: HarvestPlus adoption study (Asare-Marfo et al. 2011) and Dissemination and Impact of Improved Varieties in Africa (DIIVA) study (Larochelle et al. 2015).