Impacts of Improved Bean Varieties on Food Security in Rwanda

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Introduction

Common bean (*Phaseolus vulgaris*) is an important subsistence crop for smallholding farmers in Rwanda. It is often referred to as the meat of the poor because of its high protein content and affordability. Beans are also vital sources of micronutrients such as iron, reducing iron deficiency caused by the lack of diversity in the starch-based diets of the poor. Rwanda has one of the highest per capita bean consumption in the world (Kalyebara and Buruchara, 2008), confirming that bean is a key crop for food security. Beans provide 32 and 65 percent of calories and protein intake in the Rwandan diet, whereas protein sourced from animal provides only 4 percent of the protein intake (Asare-Marfo, et al., 2011, CIAT, 2004).

Previous studies have found that nearly all rural households in Rwanda cultivate beans (Asare-Marfo, et al., 2011, Larochelle, et al., 2013). Beans are grown twice a year in many farming systems. They are intercropped with banana, cassava, maize, peas, and others, and grown in different agro-ecological conditions. To accommodate this environmental diversity, two 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 to bush beans. This vertical growth property confers climbing beans a yield advantage over bush beans and makes them less likely to be intercropped.

Rwanda's ability to move from a position off net importer, to self-sufficiency, and exporters of dry beans is due to the spread of high yielding varieties combined with a shift from bush to climbing bean cultivation. Important research efforts have been devoted to select, breed, and disseminate new bean varieties that enhance the productivity and quality of food crops, alleviating poverty and food insecurity. In Rwanda, bean is the crop that receives the most research attention, followed by sweet potato and banana (Karangwa, 2007). The bean research program at Rwanda Agriculture Bureau (RAB), formally Institut des Sciences Agronomiques du Rwanda (ISAR), in collaboration with international partners such as International Center for Tropical Agriculture (CIAT) and HarvetPlus, has released nearly 100 bean varieties over the last four decades (PABRA, 2012, RAB, 2012)

Adoption and benefits from improved beans varieties in Rwanda is documented in Johnson, et al. (2003). According to that source, 15 percent of bean area was planted to CIAT-related varieties. The yield gain of these varieties over local ones is estimated to be at 900 kg/ha. This high productivity gain is partially attributed to a shift from bush to climbing beans in northern Rwanda. This yield gain contributes to an annual incremental production of 28,888 tons of a gross annual value of US$8.7 million (Johnson, et al., 2003).

Since adoption and impacts of improved varieties released prior to 1998 are documented in Johnson, et al. (2003), we focus on bean varieties released from 1998 until 2010[1]. According to Pan-Africa Bean Research Alliance (PABRA) database, 46 improved bean varieties were released in Rwanda between 1998 and 2010. This represents multiple millions of dollars invested in bean research, but very little is known about their impacts--whether these improved varieties are widely adopted and their

[1] Data collection took place in 2011 and no varieties were released in 2011 in both Rwanda and Uganda, making 2010 the obvious upper bound.

distributional impacts on the poor. Policy makers and donors need information on these impacts to allocate resources to fruitful lines of research and to strengthen the role of agricultural research in fighting poverty, hunger, and malnutrition. This study assesses the impact of improved bean varieties[2] on food security among rural households in Rwanda and Uganda

International organizations and governments expect improved varieties to alleviate malnutrition and hunger, but, to date, impact assessment studies have mainly focused on productivity and aggregate welfare measures. Fewer studies document the impact of technology adoption on household food security (Kabunga, et al., 2014, Rusike, et al., 2010, Shiferaw, et al., 2014). Various reasons explain the limited number of studies on food security. Nutrition is one of the last outcomes to be affected along the long adoption impact pathway (Chung, 2012). Because of the important lag between adoption and improvement in nutritional status, one might fail to detect impact. Moreover, measuring food security, due to its multidimensionality, is challenging and consensus on the methodology to use is lacking (Barrett, 2010, Coates, 2013). Traditional approaches to measuring food security such as caloric intake and anthropometric indicators require extensive and costly data collection. Significant efforts have recently been devoted to the development and validation of new measures of food security (e.g. at IFPRI and Tufts University) As a result, a growing numbers of low-cost indicators of household food security are now available to researchers.

For example, Kabunga, et al. (2014) used the Household Food Insecurity Access Scale (HFIAS) to assess the impact of tissue culture banana technology on food security

[2] This study focuses on bean varieties released since 1998 because adoption and benefits of varieties released prior to 1998 are documented in Johnson, et al. (2003).

in Kenya. This measure of food security is based on household's own perception of access to food and is captured through nine questions reflecting anxiety and uncertainty about food supply, food quality, and food quantity. The authors found that adoption of tissue culture technology significant and positively contribute to household farm income, total income, and food security. Shiferaw, et al. (2014) use food consumption expenditures and household subjectivity of their food security situation to examine the impact of improved wheat varieties on rural household food security in Ethiopia. Household assessment of their food security is based on only one question. The adoption effect for adopters is a 2.7 percentage point increase in food consumption expenditures. If non-adopters were to adopt improved wheat varieties, their food consumption expenditures would raise on average by 4.5 percentage points.

This study adds to the thin literature on food security impacts of technology adoption by rigorously documenting the linkages between adoption of improved bean varieties and household dietary diversity. Dietary diversity has been widely used in the literature as indicators of nutritional adequacy; to our knowledge, this is the first study using such an indicator within an impact assessment study framework.

Data and descriptive analysis

Data collection and sampling design

This study is based on a major effort[3] to document bean varietal adoption and its technological impacts. A nationally representative rural farm household survey was

[3] This study was conducted under the Diffusion and Impact of Improved Varieties in Africa (DIIVA) project and targeted crops in Rwanda are beans, potatoes, and sweet potatoes. Collaborators in this study include CIAT, CIP, RAB, and Virginia Tech.

carried in 2011. Data gathered cover the cropping season that ran from March to July/August 2011, which is locally referred as cropping season B[4]. An extensive household questionnaire collected information on household and housing characteristics; household production and consumer assets; social networks; farmer knowledge and adoption of improved bean varieties; production activities including land areas, inputs used and yields; market access and participation; food security; and access to agricultural input supplies.

Due to the length of the questionnaire, respondents were interviewed twice over the cropping season. This methodology also helped reduce potential recall bias. Covering the same season, the first round of data was collected following planting activities while the second round began after the completion of harvest and marketing. The first visit prepared respondents for the subsequent one and encouraged the careful keeping of plot-specific records. In the second round, in addition to complementing the household survey, a consumption and community questionnaire were administrated. About half of the households were interviewed about their consumption expenditures. The respondents – usually the person preparing and cooking the food – were asked to recall household food consumption over a 7-day period. This includes food purchased, home-produced or received as a gift or in-kind payment by any household member. The consumption questionnaire also included questions on food consumed away from home, non-food expenditure over the last 30 days, and rent, and land expenditure.

The community questionnaire, administered through focus group interviews, gathered information on village characteristics, market access, crop prices, and

[4] In Rwanda, Season B corresponds to the second harvest of a given year.

agriculture practices. It also included questions around issues such as access to extension specialists, input distributors, the presence of seed distribution programs, seed availability, cultivar changes, and agro-climatic shocks. One purpose of the community questionnaire was to collect information that could explain varietal adoption patterns without affecting our outcomes of interest.

A random stratified sampling procedure combined to probability proportionate to population method was used to identify the respondents. The first stage consisted of stratifying the sample based on the country ten major agro-ecological zones. Then, probability weights were computed for each zone based on total village population. Eighty villages were randomly sampled based on these population weighted probabilities. Selected villages are distributed across 27 out of the country 30 districts. The final step was to randomly select 18 households to be interviewed in each village, giving a total sample size of 1,440 households[5].

In order to determine which households to interview for the consumption questionnaire[6], the sample was divided after the first round of data collection into two groups: adopters and non-adopters of improved varieties. Then, in each village, a maximum of five households were randomly selected to represent each group. Focusing only on bean growers interviewed for food consumption expenditures results in a sample size of 654 households.

Identifying adopters

[5] Out of the total sample size, about 1,300 households produce beans.
[6] The full consumption questionnaire took 30–40 minutes to complete, and the choice of only administering the questionnaire to half of the survey was based on time and resource constraints.

In order to identify adopters of improved bean varieties, we worked in collaboration with national (RAB) and international partners (CIAT and HarvestPlus). Several experts reviewed the list of bean varieties reported by farmers and identified official and local names--as given by farmers--for improved varieties. A household is considered to be an adopter if improved varieties were planted for the season under consideration. Since some farmers cultivate a mixture of varieties for reasons such as risk mitigation and preferences, adoption can also be measured as a continuum. The sensitivity and robustness of the results to the definition of adopters is explored in this study by comparing binary to continuous treatment effects of adoption on food security. An alternative measure of adoption could be the share of bean area planted with improved seeds. Due to difficulties in correctly measuring plot size, we consider that the quantity of improved seeds (in kg) planted over the total quantity of bean seeds planted to be a more accurate representation of the intensity of adoption. Since farmers in Rwanda plant bean seeds at similar densities, despite variation in varieties, the share of improved seeds planted should be a good proxy for the share of bean land under improved varieties.

Descriptive analyses

About 26 percent of bean-producing households in Rwanda are adopters of improved bean varieties. Among those, 15 percent are considered partial-adopters and 11 percent full-adopters. The density of the share of improved seeds planted for partial adopters is provided in Figure 1. Fewer households are located at the extremities of the distribution and the distribution peaks where the share of improved seeds planted ranges between 50 and 60 percent.

Descriptive statistics on household and farm characteristics disaggregated by adoption status are presented in table 1. None of the variables reflecting household characteristics is statistically different between adopters and non-adopters. The majority of households (74 percent) are male-headed and the average age for the household head is 46 years. Twenty-seven percent of household heads have no formal education while 68 and 5 percent, respectively, have achieved some primary and secondary education. The average household size is 5.17 members and has 0.92 dependents per working-age adult member. A wealth index [7] reveals that household socio-economic status is similar between adopters and non-adopters.

When it comes to farm characteristics, some differences are observed between adopters and non-adopters of improved bean varieties. In terms of farmland owned per household member, there is no statistically difference between the two groups. However, the amount of land cropped for adopting households (1.34 ha) is greater than for households that do not cultivate improved bean varieties (0.9 ha). Similarly, land cropped per household member is also greater among adopters compared to non-adopters (0.31 vs. 0.20 ha). Livestock ownership in Tropical Livestock Unit (TLU[8]), is 0.95 for adopters compared to 0.78 for non-adopters; this gap is statistically different at the 10 percent level. The descriptive statistics suggest that adopters of improved bean varieties might be more involved in farming activities than non-adopters. However, the count of agricultural equipment owned per household does not differ significantly by adoption status.

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[7] The wealth index is estimated using Polychoric PCA and include the following: household ownership of durable goods, housing characteristics, and access to sanitation. (Larochelle et al., 2014)

[8] Tropical livestock unit (TLU) is a measure of livestock equivalent. Conversion factors are based of the FAO definition of TLU where the base is the camel, i.e. the camel=1. The 250 kg live weight relevant conversion factors for this analysis are cattle=0.7, pig=0.2, sheep=goat=0.1 and poultry=0.01.

Measuring food security

Household food security is assessed based on household diet diversity. More diverse diets are positively correlated with greater energy intakes, better macro and micronutrient adequacies, and more favorable anthropometric measures in adults and children (Arimond, et al., 2010, Hoddinott and Yohannes, 2002, Kennedy, et al., 2011, Kennedy, et al., 2007, Ruel, 2003, Smith and Subandoro, 2007, Steyn, et al., 2006, Swindale and Bilinsky, 2006). Diet diversity is usually measured as the count of the number of food items or food groups consumed over a predetermined period of time (Ruel, 2003). Measures of dietary diversity based on the number of food *groups* consumed, rather than food *items*, are likely to more accurately reflect the diversity of macro and micronutrient intakes. Diets consisting of a limited number of food items, especially starchy staples, can lack the macro and micronutrient adequacy despite meeting calorie requirements (Kennedy, et al., 2011).

This study uses the Household Dietary Diversity Score (HDDS). HDDS is a simple and easily administered method and classifies each food item consumed by the household into twelve different food groups[9]. A food group is counted only once, regardless of the number of times it was consumed over the last seven days, our reference period. This means that the HDDS ranges for a minimum of one and to a maximum of 12. A high HDDS reflects a diverse diet and suggests food security while a low HDDS is indicative of food insecurity.

We hypothesize that the adoption of improved beans can lead to greater diet diversity and improved food security through various channels. First, adoption is

[9] The 12 food groups are: 1.Cereals, 2.Roots and tubers, 3.Vegetables, 4.Fruits, 5.Meat and poultry, 6.Eggs, 7.Fish and seafood, 8.Pulses, legumes and nuts, 9.Milk and milk products, 10.Oil and fats, 11.Sugar and honey, and 12.Spices, condiments, and beverages.

expected to have a direct and position impact on farm income. As a result of this income growth, we expect a shift away from staples and greater consumption of meat, dairy products, fresh fruits and vegetables. In low-income countries such as Rwanda, a large share of income is spent on food and food consumption is highly responsive to changes in income. Thus, food consumption patterns should adjust quickly to income growth by moving from a staples-based diet and more towards a diverse diet. Moreover, income increases can enable precautionary savings and allow the household to take steps to insure itself against food-related shocks (Alwang, et al., 2001). Second, adoption of improved varieties, through higher yield, can indirectly affect food consumption patterns and food security through changes in production patterns. This pathway is complex and depends on factors such as household structure and market orientation. For a household involved in the bean market as seller, adoption of improved varieties might result in more land being allocated towards bean production, augmenting the income effect of adoption on food security. Because of greater bean production due to adoption of improved varieties, a household might move land away from bean towards a more diverse production system. This substitution effect is expected to improved food security as greater agricultural production diversity should lead to greater diet diversity (Jones, et al., 2014). The direction of changes in production patterns following adoption is unclear, but the expected effects (either income or substitution) should lead to improved diet and food security among rural households.

Identifying food secure households

In order to distinguish between different levels of food security, the following cut-off values are set for the HDDS. Households consuming less than 6 food groups are considered to be food insecure; those consuming 6 to 9 food groups are moderately food secure; and those consuming more than 9 food groups are food secure[10].

The mean HDDS in rural Rwanda is 7.36 food groups, with a minimum and maximum of 3 and 12 food groups. Based on the HDDS benchmarks discussed above, 13 percent of bean-producing households are considered food insecure, 75 percent moderately food secure, and 12 percent food secure (table 2). Regardless of the adoption measure considered, HDDS is always significantly greater for adopters compared to non-adopters. Households that do not cultivate improved bean varieties have a HDDS of 7.24 food groups compared to 7.71 for those adopting improved bean varieties. As a result, food insecurity is significantly more prevalent among non-adopters (14.67 percent) than adopters (9.41 percent). Distinguishing between full- and partial-adopters reveals that full-adopters have greater HDDS than partial-adopters (7.79 vs. 7.64), and both scores are statistically higher than the average score of non-adopters. There is also a clear relationship, depicted in Figure 2, between the percent of improved seeds planted, our continuous measure of adoption, and measured diet diversity. As the share of improved seeds planted raises, HDDS increases.

Econometric framework and estimation strategies

The main challenge in assessing the impact of technological adoption using observational data is selectivity bias. Selectivity is likely to arise when the technology is not introduced at random because observable and unobservable factors affecting the

[10] There are no set benchmarks for the HDDS. Despite the existence of cut-off values suggested for the Food Consumption Score (World Food Program), caution is appropriate regarding their universal use. The cut-off values must be set in light of the country- specific context, food consumption patterns, and the reference period. Using the cut-off values specified above results in food insecurity statistics similar as those reported by the World Food Program, bringing confidence in our measure of food insecurity(WFP, 2009).

adoption decision are likely to be correlated with the outcomes of interest. The magnitude of the bias depends on the importance of the unobservable factors and their correlations across decisions and outcomes (de Janvry, et al., 2011). Bias complicates identification of the treatment effect—the causal impact of adoption on the outcome.

In order to correctly identify the casual impacts of improved varieties on household food security, the endogenous nature of the adoption decision must be carefully addressed. Econometric techniques to achieve this include instrumental variables (IV) and propensity score matching (PSM) methods. PSM controls for observable factors that simultaneously affect both the adoption decision and outcome of interest. However, if unobservable variables are also believed to influence the adoption decision and outcomes of interest, PSM will fail to establish a valid counterfactual (i.e. the outcome of interest if adopters had not adopted) based on the population of non-adopters (de Janvry, et al., 2011). Consequently, we use an IV approach, which controls for observables and unobservables influencing adoption and outcome.

Since food security is measured by the HDDS, a Poisson model is the most appropriate econometric specification to capture the count nature of the dependent variable. In order to address the endogeneity of adoption, we resort to a Generalized Method of Moments (GMM) estimation technique. The basic moment conditions of the Poisson model, as specified in equation (1.a), do not hold in the presence of endogeneity, leading to (1.b). If there exist instrumental variables z, such that the basic moment conditions can be augmented, as in equation (1.c), minimizing these moment conditions will provide consistent and efficient estimators of the β's, including the treatment effect of adopting improved varieties on HDDS (Cameron and Trivedi, 2009).

$$E\{y - \exp(x'\beta) \mid x\} = 0 \tag{1.a}$$

$$E\{y - \exp(x'\beta) \mid x\} \neq 0 \tag{1.b}$$

$$E[z_i\{y \ - \exp(x'\beta) \mid x\}] = 0 \tag{1.c}$$

Coefficient estimates of the (endogenous) decision to adopt improved beans are used to compute the counterfactual HDDS for adopting households. Food insecurity incidences, based on the benchmarks specified above, are calculated for the observed and counterfactual HDDS. Differences in the food insecurity incidences between the two measures reflect the food security impacts associated with technology adoption.

The instrumental variables considered to address the endogenous adoption decision and identify the treatment effects are localized events that contribute to discontinuity in seed availability, proxies for source and access to information about the new technology, and access to the technology itself. These variables were identified and discussed during the focus groups accompanying the community questionnaire. Variables considered are measured at the village-level (as opposed to household-level) to limit potential endogeneity. Having a wide range of potential instruments, several IV testing procedures were performed to identify the most appropriate instruments[11]. These procedures include testing for overidentication (Hansen J statistic), underidentification, weak instruments, and weak identification robust inference. The tests, performed while adjusting for potential heteroskedasticity, support the following choice of instrumental variables: whether there was a flood in the village over the last 10 years affecting seed

[11] The tests are performed in STATA using the ivreg2 command (Baum, et al., 2010). This required a logarithmic transformation of the dependent variable, resulting in a log-linear model. The transformed data have a distribution similar to a Poisson (Cameron and Trivedi, 2005).

availability, the number of households in the village, and existence of market services for agricultural crops in the village[12]. Discontinuity in seed availability following a natural disaster such as droughts or floods might result in households receiving seed aid (where the seeds distributed under the seed aid program are commonly improved varieties) or being forced to buy new seeds (instead of the custom of recycling seeds[13]), favoring adoption of new seed varieties. There should be no correlation between previous nature disasters and current food security situation. Living in a highly populated village facilitates the acquisition of information about agricultural technology and increases the opportunities to learn from others. Adoption is expected to be facilitated with greater information about technology. Living in a village where agricultural crops are bought and sold should facilitate the diffusion of improved seeds. Shiferaw, et al. (2008) found that availability of seeds positively influences adoption and the intensity of adoption. However, low transactions costs of acquiring improved seeds should not have a direct impact on food security other than through their influence on adoption of improved seeds.

Estimation strategies

The Poisson model is employed to estimate the impact of improved varieties on food security. This means that the dependent variable y_i, the HDDS, is assumed to have a Poisson distribution with the probability mass function:

$$\Pr(Y = y) = \frac{e^{-\mu}\mu^{y}}{y!}, \qquad y=0, 1, 2, \ldots \tag{2}$$

[12] The p-value for the Hansen J Statistic is 0.6057 while the other tests have p-values inferior to 0.05.
[13] Bean seeds do not lose their potency as a result of being recycling, meaning there is no time limit to number of seasons seeds can be recycled. Bean seeds are self-pollinated and do not commonly cross-pollinate.

Where μ corresponds to the first two moments of the distribution[14]. For estimation purposes, the HDDS is re-scaled such that the minimum value is equal to zero[15]. The rescaling does not alter the meaning of the food security measure, as it is a categorical variable and provides the needed Poisson distribution to perform the GMM estimation. Tests are performed to assess model specification and goodness-of-fit. The results indicate that Poisson model fits well the data[16]. The model is estimated twice, the first time considering adoption as binary, and a second time, where adoption is measured as the share of planted seeds that are improved.

Additional explanatory variables assumed to influence household food security are identified based on the literature. These include household size (expressed in adult equivalents[17]), wealth (wealth index expressed in quintile, and livestock ownership expressed in TLU), agricultural productive capacity (farmland owned in ha, and the number of agricultural tools), and household head characteristics (age, gender, and education). Household size is expected to influence food security, as consumption requirements (quantity and diversity) is increasing with the number of household members. Wealth and agricultural productive capacities are expected to be positively correlated with household food security. Using a wealth index as opposed to consumption expenditures as a measure of household socio-economic status has the advantage of reducing potential endogeneity that could arise from the correlation in measurement

[14] One property of the Poisson distribution is that its expected mean is equal to its expected variance. This is called the equidispersion property (Cameron and Trivedi, 2009).
[15] This is accomplished by subtracting three from all observed HDDS.
[16] The goodness-of-fit chi-squared test is not statistically significant, indicating that the data fit the Poisson model well (http://www.ats.ucla.edu/stat/stata/dae/poissonreg.htm). The correlation coefficient (0.5) between the observed and predicted values also indicates a good fit. Last, the link test for model specification suggests that the dependent and independent variables are well specified. The predictions squared have no explanatory power (p-value = 0.466) (Cameron and Trivedi, 2009).
[17] The composition of adult equivalents is expressed as: 1 + 0.7*(Adult - 1) + 0.5*Children

errors between consumption and food expenditures. Dummy variables representing the 10 agro-ecological zones of Rwanda are included to capture differences in production systems, which are expected to play a role in household food consumption patterns (as consumption is mainly derived from own production), and thus dietary diversity. When relevant, squared terms are added to the model to control for potential non-linear effects.

Results

The results of the GMM Poisson are presented in table 3 for both measures of adoption of improved bean varieties. Results are consistent and robust to alterative measures of adoption and reveal that adoption has a positive and significant impact on food security for rural households in Rwanda. Based on the binary measure of adoption, the HDDS would be about 57 percent (based on a scale from 0-9) lower among adopters in the absence of improved varieties. Using the continuous adoption measure, HDDS (based on a scale from 0-9) would be 56 percent higher if households that planted only improved varieties had not adopted. While estimates for full-adopters are nearly identical between the two estimation strategies, considering adoption as binary would over-estimate the treatment effect for partial-adopters. Consequently, the counterfactual HDDS is slightly lower when computed based on intensity of adoption. The average counterfactual is 6.91 and 7.02 according to the binary and continuous measure of adoption compared to the actual 7.36. This means that the percentage of food insecure household would go up from 13.3 percent to somewhere between 21.1 to 22.9 percent in the absence of improved bean varieties. Moreover, the share of households considered food secure would drop from 11.8 percent to around seven percent (table 2).

In addition to adoption of improved bean varieties, key variables explaining variation in HDDS are household size, household head characteristics, and household socio-economic status[18]. The number of adult equivalent within a household has a positive and but decreasing impact of HDDS. This result might reflect the greater diet diversity needs of larger households. The age of the household head has a negative impact on dietary diversity. An increase of 10 years in the age of the household head reduces HDDS by about forth percent. The influence of the household head education on HDDS is relatively large; the HDDS is about 9 and 25 percent higher for households whose head attended primary and secondary school, respectively, compared to households whose head has no formal education. This effect is after controlling for other factors, indicating that education can improve household nutritional status through channels other than income. Last, wealth is a strong predictor of HDDS and thus household food security situation. Households belonging to the third, fourth, and fifth wealth quintiles have HDDS that are on average 15, 18, and 25 percent higher compared to households that are at the bottom 20 percent of the distribution. These results of consistent with the notion that food consumption patterns are responsive to changes in income and that as income raises, households move away from starchy diets and consume more diverse food groups.

Conclusion

This study makes significant contributions to the literature by documenting the impact of improved bean varieties on food security among rural households in Rwanda. Massive investments have been devoted to crop research and bean production in Rwanda

[18] Discussion regarding alternative variables is based on the results of the continuous treatment effect model, which are presented in table 3, column 3.

is a great example. Collaboration between national and international research institutions resulted in the released of 46 improved bean varieties between 1998 and 2010. Despite this impressive research effort, little is known about adoption rates and welfare impacts of these varieties. This research narrows this gap down by reporting adoption level and estimating the causal impact of adoption on food security. While agricultural technology and nutrition outcomes are closely connected, limited number of studies have previously analyzed food security outcomes within an impact assessment framework. This can be partially explained by difficulties in measuring food security, lack of consensus regarding which indicators to use, and costly data collection approaches. Our contribution consists of using the HDDS, a well-established indicator of individual and household nutritional status, to evaluate the impact of improved bean varieties on household food security in Rwanda. Despite that this measure does not encompass all dimensionalities of food security, such as social acceptability and uncertainty, our research provides evidence that it is a useful tool to assess food security and deserves consideration in further impact evaluation studies.

A GMM Poisson model was used to control for the endogeneity of the adoption decision and identify the treatment effects. Two treatment effects were considered; first where adoption is measured as in dichotomous way and second, where adoption represents the share of improved seeds planted. The model performs well and indicates that the HDDS of adopters would be 1.3 food groups lower, i.e. 6.4 as opposed to 7.7, if they had not adopted improved bean varieties (continuous treatment effect). Based on an adoption rate of 26 percent, where 15 percent of households are partial-adopters and 11 percent, full-adopters, the sample counterfactual HDDS is 7.02 compared to the observed

7.36 food groups. Consequently, about 22 percent of households would be food insecure in the absence of improved beans compared to the current 13 percent.

The impacts on food security are likely be more pronounced than those on bean farm income. This is because adoption of improved varieties influences food consumption through channels in addition to the farm profitability channel. For example, some of the new improved varieties have shorter production cycles, which can free up labor, and allow household members to be engaged in additional income-generating activities. Higher productivity can also allow households to reallocate resources to other crops, increasing agricultural production diversity and thus food consumption diversity, as household food consumption is mainly derived from home production. Contrarily, higher productivity can lead to an increase in land planted to beans. Gender is another channel that can influence the impact pathway from adoption to food security. In the case of Rwanda, bean is mainly a woman's crop. This might contribute to additional food security impacts as woman might have better control over the income gains from adoption, and thus, be in a stronger position to influence household nutrition outcomes. Further research should consider investigating the importance and size of different channels of influence on household food security.

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Tables

Table 1: Descriptive statistics for adopters and non-adopters of improved bean varieties, Rwanda

	Sample		Adopters		Non-Adopters	
	mean	sd	mean	sd	mean	sd
Household characteristics						
HH head gender (1=male)	0.75	0.43	0.78	0.41	0.74	0.44
HH head age	45.68	13.56	45.96	13.15	45.58	13.72
HH head education						
None	0.26	0.44	0.24	0.43	0.27	0.44
Primary	0.69	0.46	0.72	0.45	0.68	0.47
Secondary & +	0.05	0.21	0.04	0.19	0.05	0.22
HH size	5.22	2.11	5.39	2.18	5.17	2.09
Dependency ratio (dep/adults)	0.92	0.79	0.92	0.85	0.92	0.77
Wealth index	-0.13	1.08	-0.08	1.12	-0.15	1.06
Farm characteristics						
Land own per capita (ha)	0.27	0.66	0.32	0.55	0.25	0.70
Land crop (ha)***	1.02	1.56	1.34	1.83	0.90	1.44
TLU*	0.82	0.97	0.95	1.19	0.78	0.87
Agricultural tools (number)	8.28	5.64	8.44	5.66	8.23	5.64

Note: *, **, and *** indicate that mean is statistically different at the 10, 5, and 1 percent level between adopters and non-adopters

Table 2: Descriptive statistics of observed and counterfactual HDDS and food security incidence, Rwanda

	Observed HDDS			*Counterfactual HDDS*	
	Non-Adopters	Adopters	Sample	Adopters (0/1)	% improved seeds
HDDS average	7.24	7.71	7.36	6.91	7.02
	%	%	%	%	%
Food insecure	14.67	9.41	13.30	22.94	21.10
Moderate food secure	76.65	70.00	74.92	70.64	71.71
Food secure	8.68	20.59	11.77	6.42	7.19

Table 3: GMM Poisson results for impact of adoption of improved bean varieties on food security, Rwanda

	Adopters (0/1)		*% of improved seeds*	
	(1)	(2)	(3)	(4)
HDDS (0-9)	Coef.	Std. Err.	Coef.	Std. Err.
Adoption	**0.571****	**0.236**	**0.0056*****	**0.002**
Adult equivalent (AE)	0.143**	0.053	0.132**	0.054
AE squared	-0.016**	0.006	-0.014**	0.006
HH head gender (1=male)	-0.046	0.041	-0.049	0.040
HH head age	-0.004**	0.002	-0.004**	0.001
HH head education (Base=none)				
Primary	0.086*	0.045	0.094***	0.042
Secondary & +	0.263**	0.084	0.248***	0.068
Land own per capitat (ha)	0.010	0.031	0.016	0.025
TLU	-0.012	0.017	0.005	0.013
Agricultural tools (number)	0.004	0.003	0.005	0.003
Wealth index (base = poorest quintile)				
Quintile 2	0.051	0.051	0.047	0.047
Quintile 3	0.153**	0.062	0.145**	0.058
Quintile 4	0.190**	0.067	0.177**	0.058
Quintile 5	0.231***	0.056	0.249***	0.050
Agro-Ecological Zone (Base = 1)				
2	-0.064	0.138	-0.087	0.125
3	0.208**	0.087	0.217**	0.087
4	0.141	0.145	0.081	0.119
5	-0.104	0.083	-0.059	0.079
6	0.081	0.140	0.052	0.122
7	-0.058	0.247	-0.083	0.229
8	0.062	0.114	0.041	0.104
9	-0.158	0.149	-0.216*	0.124
10	0.054	0.130	0.030	0.111
Constant	0.962***	0.227	1.020***	0.197

Note: * p<0.05; ** p<0.01; *** p<0.001. Standard errors are made heteroskedasticity robust and clustered at the village-level

Figures

Figure 1

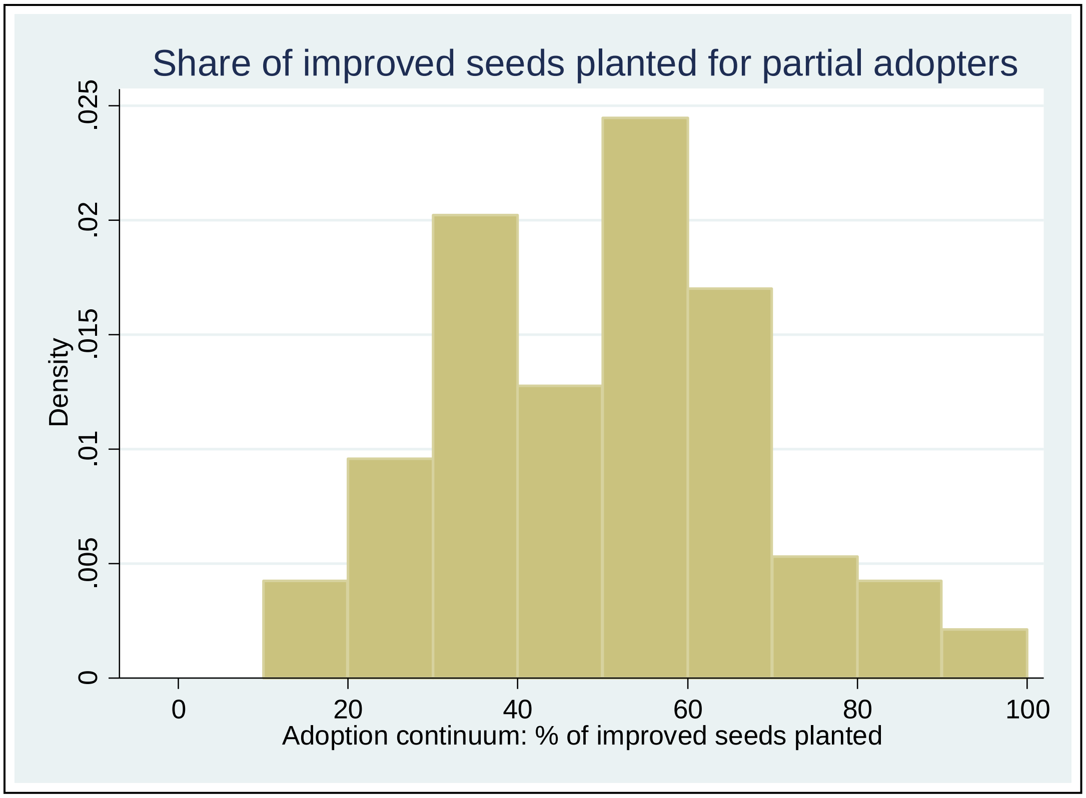
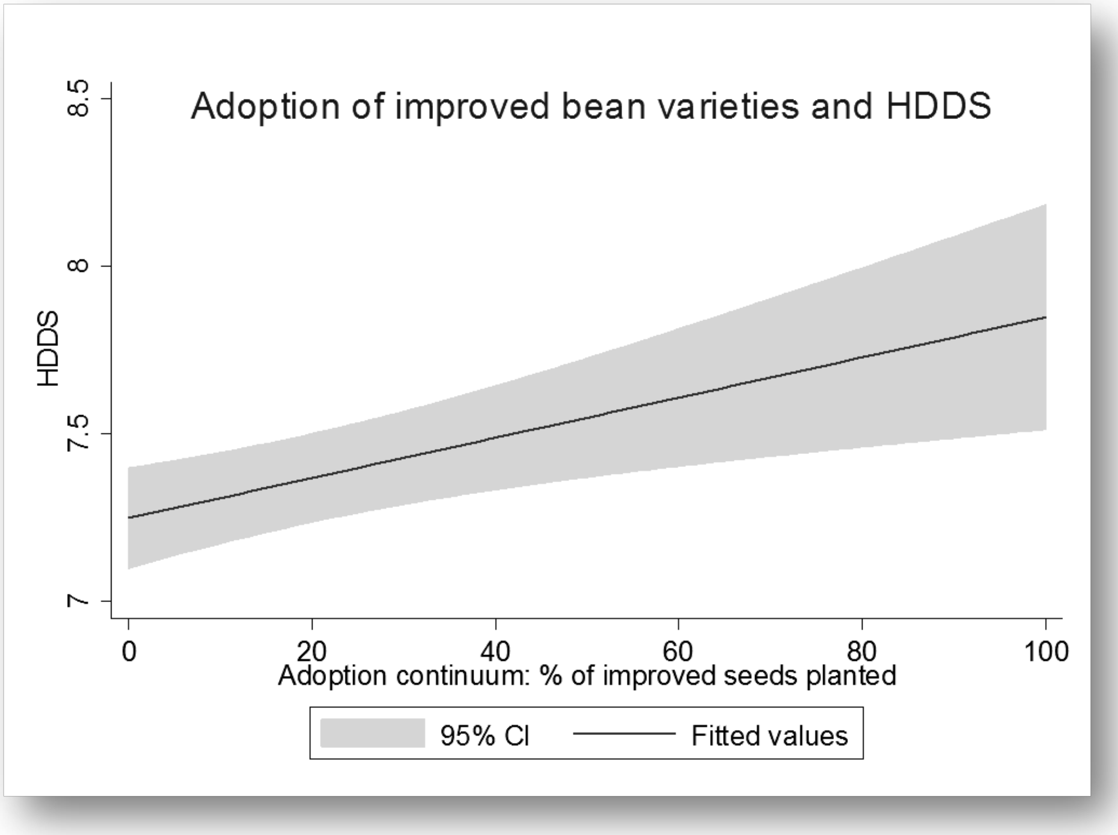


Figure 2


Adoption of improved bean varieties and HDDS
HDDS
8.5
8
7.5
7
0
20
40
60
80
100
Adoption continuum: % of improved seeds planted
95% CI
Fitted values