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Agricultural Extension and Technology Adoption for Food Security: Evidence from Uganda

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Stephen C. Smith
George Washington University

Yao Pan
Aalto University

Munshi Sulaiman
BRAC International

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Institute for International Economic Policy
1957 E St. NW, Suite 502
Voice: (202) 994-5320
Fax: (202) 994-5477
Email: **iiep@gwu.edu**
Web: **www.gwu.edu/~iiep**

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Abstract: We evaluate causal impacts of a large-scale agricultural extension program for smallholder women farmers on technology adoption and food security in Uganda through a regression discontinuity design that exploits an arbitrary distance-to-branch threshold for village program eligibility. We find eligible farmers used better basic cultivation methods, achieved improved food security. Given minimal changes in adoption of relatively expensive inputs, we attribute these gains to improved cultivation methods that require low upfront monetary investment. Farmers also modified their shock-coping methods. These results highlight the role of information and training in boosting agricultural productivity among poor farmers and, indirectly, improving food security.

Keywords: Agriculture; Agricultural Technology Adoption; Extension; Food Security; Information; Regression Discontinuity; Training; Uganda

JEL Classification: O13; Q12; I30

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*Yao Pan, Department of Economics, Aalto University, yao.pan@aalto.fi; Stephen C. Smith, Department of Economics, George Washington University, ssmith@gwu.edu; Munshi Sulaiman, Save the Children, munshi.slmn@gmail.com. We would like to thank Michael Carter, Ram Fishman, Craig Macintosh, Saurabh Singhal, and participants at BASIS Annual Technical Committee Meeting workshops, Centre for the Study of African Economies (CSAE) Annual Conference on Economic Development in Africa, 2014, and seminars at Aalto University and GWU for helpful comments on an early draft of this paper. We would like to thank Andrea Lopez for research assistance. Special thanks to Proloy Barua, M. Mozammel Huq, and Hannan Ali of BRAC Uganda for their assistance with field visits, data and many helpful discussions about the program. Financial support from USAID through BASIS Assets & Market Access Collaborative Research Support Program AID-OAA-L-12-00001, award No.201121454-07, is gratefully acknowledged. All errors are our own.

The recent development economics and agricultural extension literature has focused on the need to address fundamental constraints to improving performance of low-productivity smallholder agriculture while enhancing food security. Many proven technologies and improved farming practices hold great promise for boosting agricultural production and reducing poverty in developing countries, but the adoption of such technologies by smallholder farmers, in particular in Sub Saharan Africa, has been slow, at best (Udry 2010; Duflo, Kremer & Robinson 2011). The low adoption rates have resulted in persistent low agricultural productivity in Sub Saharan Africa (World Bank 2008). Important identified culprits in low adoption include lack of knowledge, lack of access to markets, credit constraints, uninsured risks, and problems of coordination with neighbors (World Bank 2008; Udry 2010; Barrett, Carter & Timmer 2010; Jack 2013). Most research along this line focuses on the adoption of relatively expensive agricultural inputs, such as high yield variety (HYV) seeds and chemical fertilizers; in contrast, there is limited empirical evidence on either initial adoption or the impacts of improved basic cultivation methods. However, promotion of these basic methods such as crop rotation and use of green manure are likely to be extremely important for the poor, such as marginalized smallholder women farmers, who are less likely to adopt improved cultivation techniques on their own. In addition, few studies have assessed extension achievements causally beyond input adoption and production (Anderson & Feder 2007).

This article contributes to filling these research gaps by causally evaluating the impacts of a large-scale agricultural extension program for smallholder women farmers in Uganda on their technology adoption, including both advanced inputs and improved basic farming methods, and food security. The program, designed by the non-governmental organization (NGO) BRAC, features two main components to promote improved technology use: training; and easier and less costly access to and

HYV seeds. According to the program design, eligibility for this program is limited to villages within 6 km to the nearest BRAC branch office, allowing us to analyze the intention-to-treat effects under a regression discontinuity design framework.[1] Using survey data from over 3000 agricultural households near the distance threshold, we estimate the effect of program eligibility at village level on multiple indicators of individual households' food security, which includes possible within-village spillover effects. In addition, detailed inputs usage and farming practices information are reported, providing us the potential to separate the effect of improvement in farming methods from input changes in promoting food security.

Estimated impacts on food security are substantial. For farmers residing in BRAC coverage area ("eligible") villages, the likelihood of having sufficient food for family needs increased by 5.4 percentage points over the previous year compared with farmers residing in ineligible villages. Moreover, a closer examination of food sufficiency each month in the year prior to the survey shows impacts are largest just before the harvest, when food security is generally most precarious. In addition to self-reported food sufficiency (a binary outcome), per capita household food consumption increased by about 11.6% in the week prior to the survey.

As food security is an unobserved variable that is complex and multidimensional, it is crucial to evaluate multiple indicators jointly to better assess food security from various angles. In the month leading up to the survey, households eligible for the program were 6.2 percentage points less likely to limit consumption varieties and were 9.5 percentage points less likely to skip meals. The program had no impact on households' likelihood to worry about insufficient food and to consume limited portions of food. To the best of our knowledge, this article is the first to examine an extension program's impact on all essential aspects of food security noted by Campbell (1991).[2]

If the agricultural program indeed improves farmers' food security, they would be better able to cope with shocks. Among the 54% of households who experienced at least one village shock - drought, flood, pest attack, livestock epidemic, fire, or poor quality seeds - in the 6 months prior to the survey, we find that households eligible for the program were 8.3 percentage points more likely to reduce consumption and 4.9 percentage points less likely to sell assets in the face of covariate shocks, compared with ineligible households. The ability to preserve assets during shocks has potential longer-term benefits. These findings provide additional evidence on improved food security for farmers residing in eligible villages.

In terms of mechanisms, we find the agricultural extension services significantly increase the usage of improved cultivation methods that require low upfront monetary investment. Farmers residing in eligible villages are 9.2 percentage points more likely to use manure (organic fertilizer) and 3 percentage points more likely to irrigate their land compared with those residing in ineligible villages. Being eligible for the program also increases farmers' adoption rate of intercropping and crop rotation by 6 and 8 percentage points, respectively. All these practices have been documented to mitigate soil erosion and increase yields (Liniger et al. 2011). In addition, we find that eligible farmers are more likely to grow coffee, a cash crop that is mainly for sale in the market.

In contrast, the adoption rate of improved seeds remains statistically unchanged regardless of advocacy in training sessions, improved access, and supply side subsidy. Seed purchases from BRAC increases by 4.3 percentage points; and BRAC seeds could be of higher quality than that of existing market seeds, which would represent a potential positive program impact.[3] Moreover, the extension program does not change the adoption rate of other costly agricultural inputs, such as chemical fertilizer and pesticides. Given negligible identified changes in usage of advanced inputs, the findings of improved food security are most likely to be driven by changes in basic farming methods, which are achieved via training and learning.[4]

We find the program to be effective in training and demonstration in the first three years of the program implementation. As noted by Herdt (2010), separating different factors in integrated agricultural production has been a difficult challenge for understanding the contribution of each factor. In our study, the extension program has negligible if any impacts on advanced inputs usages. While the effect of a change in each specific farming practice is hard to identify individually, our evidence offers clear support that the overall changes in basic farming methods are the most likely contributors to the positive impact on food security. The improvement in these farming practices requires low upfront monetary investment and has fewer adoption constraints compared to more expensive advanced inputs.

The rest of this article is structured as follows: we first provide background on agriculture extension in Africa, place our contributions in the context of recent research on impacts of agricultural extension, introduce the project design, and describe the main data source used in this study. We then present our identification strategy and regression discontinuity results on technology adoption. Finally, we examine the program's impact on food security and consider underlying mechanisms. The last section concludes.

Context and Data

In this section, we first review related studies on agricultural extensions. We then outline the program background and describe our data.

Literature review

Agricultural productivity in many low-income countries, and particularly in Africa, remains far below that of developed countries and many middle-income countries; deficient extension services is one explanation (Evenson 2001). Anderson & Feder (2007) decomposed the gap in agricultural productivity between average and best practice yields into the technology gap (referring to potential gains from use of better equipment and inputs), and the management gap (referring to in potential increases in productivity through improved practices). Generally, agricultural extension seeks to close these gaps, narrowing the differential between potential and actual yields.

Agricultural extension programs have had mixed records of success (see e.g. Van den Berg & Jiggins 2007; Aker 2011; Davis et al. 2012). Research has examined their effects on input use (notably seed varieties, fertilizer and pesticide use), and on productivity (variously measured by crop yield per hectare, crop value, and net profits from agriculture); results are mixed. For example, the literature includes evidence that Training and Visit (T&V) programs have raised yields in Kenya and Burkina Faso (Bindlish & Evenson 1997), and in India (Feder & Slade 1986), and increased the value of production per hectare in Zimbabwe (Owens, Hoddinott & Kinsey 2003). But Hussain, Byerlee & Heisey (1994) found that T&V in Pakistan had at best limited effects. Field schools in some studies were found to significantly increase pesticide knowledge and use (e.g. Godtland et al. 2004; Tripp, Wijeratne & Piyadasa 2005; Van den Berg & Jiggins 2007); but other studies found small impacts - particularly in relation to their relatively high per-farmer costs (e.g. Feder, Murgai & Quizon 2004). Davis et al. (2012) studied essentially identically designed field school programs in Kenya, Tanzania and Uganda, and found generally positive but very widely varying impacts on productivity and incomes. In addition to face-to-face services, Van Campenhout (2017) found agricultural information and extension services provided by mobile phone, an information and communication technology (ICT) based intervention, changed households' crop choices, but did not increase productivity.

Most research on agricultural extension focuses on adoption of advanced inputs and production; few rigorous studies have assessed other extension achievements, including adoption of basic farming techniques, and food security. In addition, the literature has been plagued by identification problems: first, there is potential positive selection of higher-ability farmers by trainers, as well as positive self-selection by farmers; second, there could be endogeneity in the choice of program villages or regions.

The positive relationship between extension activities and adoption of basic farming techniques has been documented in Herath & Takeya (2003) and Thangata & Alavalapati (2003). However, those studies do not address the issue of self-selection into extension programs; and their estimates cannot be interpreted as causal. To the best of our knowledge, Kondylis, Mueller & Zhu (2017) is the only rigorous study addressing the impact of an extension activity on adoption of basic farming methods; they find that adding extra "contact" (model) farmer training to that of their existing extension program training had no impact on adoption choices of other farmers. Their study lacks a pure control group without the pre-existing program intervention; thus their findings of no *additional* impact of the centralized training of contact farmers on adoption are not comparable to the overall program impacts of extension studied in our article. Moreover, their sample includes a large fraction of male farmers; the extension program that we study is exclusively oriented to female smallholders.[5]

There has been very little rigorous research on the impact of extension on food security. Matchaya & Chilonda (2012) found that the number of extension worker visits to the household is one of the determinants of food insecurity (at the 10% significance level) when measured both by a dietary diversity index and reported food security. The point value for the impact on food security is large at 49 percentage points. However, their study is limited in sample size (about 200 people) and in geography (one area in Malawi, Central Kasungu). More importantly, they do not address causality; extension access is correlated with household wealth and other factors; and selection seems likely, depending on which households that extension program designers or agents expect to be more responsive to their advice or other factors. Similarly, Yahya & Xiaohui (2014) confirm the positive correlation between extension and food security, but also do not address causality.

One study explicitly addressing the non-random program placement issue is Bonan & Pagani (2016), who use difference-in-differences and matching to examine spillover effects from a school program and found positive effects on household knowledge and a food consumption score. Nonetheless, their estimates of spillover effects are not comparable to direct impacts of extension on farming methods and food security estimated in our article.[6]

The study most related to our work is Larsen & Lilleør (2014); they estimate impacts on food security of farmer field schools in Tanzania that have similar features to the program we study. They report impacts on ten hunger indicators (including a "household hunger scale"); four or five of these are statistically significant at 5% depending on the method used (at 10%, 1 to 3 additional indicators become significant). They do not consider shock coping, as we do in this article. Their estimates using differencing across intervention status and matching do not approach good-as-random identification properties of regression discontinuity; but their study offers useful benchmarks. The BRAC Uganda program examined in this article was implemented in a way that provides a natural experiment in comparing treatment and non-treatment villages; we show that this provides a convincing regression discontinuity identification of causal impacts that has been missing in most of the literature to date.

Program background

Agriculture plays an important role in the Ugandan Economy, accounting for 73% of employment, 50% of household income, and 21% of GDP (UBOS 2006, 2007, 2010). Despite the importance of agriculture in Uganda, its growth has been slow and subsistence farming is still prevalent in Uganda. Subsistence farmers account for 71% of the total farmers in the country. The adoption rates of advanced agricultural inputs and cultivation methods remain relatively low (UBOS 2006, 2007).

Launched in August 2008, BRAC's large-scale agriculture program in Uganda seeks to improve food security of smallholders by promoting improved basic cultivation methods and the usage of HYV seeds, primarily maize, and other inputs.[7] Adoption of these technologies is expected to improve productivity of smallholder women farmers for greater food security. This program provides extension services and supports a network of Model Farmers and Community Agriculture Promoters (CAP). The program operated 60 branches in 41 districts in Uganda (Poghosyan 2011), engaged 1200 Model Farmers and reached 63,936 general farmers by the time of the survey in 2011.

Model Farmers were selected by BRAC from among poor, smallholder women. They were similar to their neighbors in terms of farm size and input use, though slightly more progressive in their use of improved practices and were chosen from those with some education. They received six days of training in crop production techniques, adoption of new crop varieties and pest control, as well as follow-up refresher courses. Then, they were made responsible for setting up a demonstration plot using learned techniques and providing a three-day training activity for fifty other ("general") farmers in their villages. All training sessions recommended the usage of improved farming methods and HYV seeds. Model Farmers received a small compensation, in the form of 10 kg HYV seeds, for each season in service, which were to be used for demonstration purposes on their farms.[8]

Community Agriculture Promoters (CAPs) were also selected from the same populations; their role is to make available and sell advanced agricultural inputs in the villages, mainly HYV seeds (Barua 2011). They received HYV maize seeds at a modestly subsidized price of 2600 Ugandan Shillings (USh) per kg, which is approximately 10% lower than the market price of 2800-3000 USh, then set their own price to resell to the general public. Compared to direct purchase subsidy, this program component aims to improve entrepreneurial skills of the CAPs, and to help build up the local supply chain so it reaches the village level. The transfer of subsidized price to general farmers is not guaranteed, and in fact could be counterproductive to the goal of establishing local village supply sustainably.

Both types of agriculture extension workers are selected from villages within an arbitrary radius of 6 km from BRAC branch offices according to the program design, which allows us to study the impact of BRAC's agricultural program in a regression discontinuity design framework. The 6 km radius boundary was first introduced during the program's pilot phase, before the expansion into the study branches. The country level management team made the decision of 6 km when the pilot was launched considering two factors - whether there would be enough farmers to reach programmatic targets and keeping transport costs low for program assistants. The specific features were special to the organization of the initial local NGO branch and the geography of that county. After "inventing" the 6 km radius, this limit continued in official BRAC program documents and in the training of program assistants in all other branches irrespective of the geography and population density in the new branches studied in our article. These facts underline the relatively arbitrary nature of the program's geographic boundaries.

Dataset

The data used in this article come from BRAC's agriculture survey, conducted in 2011, when the program had been running continuously for three years. There are two cropping seasons each year. The survey covers demographic information and detailed agricultural practices records for the previous two cropping seasons between July 2010 and June 2011. Figure 1 shows the surveyed counties in Uganda. The survey villages are identified within the counties receiving the program. 17 villages were randomly selected from a complete village list in each county. Then, 25 households were randomly selected from the selected villages (Barua 2011). According to summary statistics for the main estimation sample presented in table 1, modern techniques adoption rates are low in general, especially for manure (8.6%), irrigation (2%), and fertilizer (7.2%). Food security is far from being achieved: only 20.2% of households reported that they had sufficient food in the year prior to the survey.

Empirical Strategy

As described in the previous section, households' eligibility for the program depends on their villages' distance to the nearest BRAC branch offices. This feature allows us to analyze the impacts of the program using regression discontinuity design, which requires relatively mild assumptions compared to those for other non-experimental approaches (Lee & Lemieuxa 2010). This method has been widely adopted in the economics literature to evaluate the impact of development programs and policy reforms, such as the effect of secondary schooling in Kenya (Ozier 2016), the impact of development projects on addressing voilent conflict in the Philippine (Crost, Felter & Johnston 2014), and the impact of removing migration selectivity on education in China (Pan 2016).

First, we present evidence of program coverage discontinuity at the predetermined cutoff distance. The extension activities were reported in the six months preceding the survey, and we compile this limited information to show discontinuity in the participation in the first three years of the agricultural program. We construct a village activities indicator that equals one if any surveyed households in a given village received training from a Model Farmer or purchased seeds from a CAP *in the last six months*, and equals zero otherwise. We show the relationship between the proportion of households who live in villages with any program activity and their village distances to the nearest BRAC branch office in figure 2. In particular, we subtract out branch fixed effects from the proportion of households eligible for the program, and plot the residuals on the y-axis against distances. The visual evidence shows a clear decrease in the incidence of program activities in villages at the cutoff value of 6 km. Note that the training component of the program was implemented more intensively in the beginning of the three-year program period because Model Farmers were only responsible to train up to fifty general farmers in their villages. Therefore, program activities in the six months preceding the survey provides a somewhat noisy measure - if anything a conservative estimate - of program participation during the whole program period. Despite this, figure 2 provides clear evidence of a discontinuity in the actual coverage at the program's predetermined cutoff distance.

As the extension activities were not reported before six months prior to the survey, it is not possible to construct either an indicator of having ever received training for each household or an indicator of program coverage such as the fraction of farmers having ever received training in the sample village.[9] Our strategy then is to focus on the impact of the planned program eligibility at village level on farming technology adoption and food security of households residing in these villages. Although the distance from village centers to the nearest BRAC branch was not directly reported, using GPS coordinates for each household and each branch, we compute the household's distance to the closest BRAC branch and use the median household distance in a village as a proxy to village distance.[10]

Our preferred estimates use the nonparametric approach proposed by Hahn, Todd & Van der Klaauw (2001) and Porter (2003) to estimate the treatment effects, which relaxes functional form assumptions in parametric regressions. This method estimates the left and right limits of an outcome variable and a treatment variable using local linear regression and then takes the difference of these two limits. As concluded by Hahn, Todd & Van der Klaauw (2001), this method only requires a weak functional form restriction, i.e. a local continuity restriction on potential outcomes; the choice of local linear regression also overcomes the boundary problem of kernel regression.

While BRAC program eligibility depends on a single-dimensional threshold (i.e. distance) as in traditional regression discontinuity applications, the resulting service boundary forms a two-dimensional discontinuity in longitude-latitude space (i.e. distance from a BRAC office in any direction). Therefore, we further include geographic controls to ensure we are comparing treatment and control households along the same boundary segment. In particular, we estimate the following regression discontinuity model:

$$y_{ij} = \alpha + \beta T_j + \gamma(z_j - c) + \delta T_j(z_j - c) + spatial\_controls_j + \epsilon_{ij} \tag{1}$$

where y_{ij} is an outcome variable of household i in village j, z_j is the distance between the household's residing village and the nearest BRAC branch, c is the program eligibility cutoff distance ($c = 6km$ in the context of this study), and T_j is a dummy variable that equals one if the household resides in a village within the cutoff distance ($z_j \leq 6$) and zero otherwise. For spatial controls, we make use of our GPS data to include longitudinal and latitudinal distances between the village j and the corresponding BRAC branch office following Basten & Betz (2013), as well as a full set of branch fixed effects. Standard errors are calculated using the Delta Method following Hahn, Todd & Van der Klaauw (2001) and Porter (2003).

We report our main results using a triangular kernel with a bandwidth of 2.16 km. We follow Imbens & Kalyanaraman (2012) to calculate this optimal bandwidth and also report results for bandwidths ranging from 1.5 km to 3.5 km. Since the treatments are defined as the planned agricultural extension coverage in the village, the estimates can be interpreted as intention-to-treat (ITT) effects. These effects incorporate diffusion and spillover from treated households to other households in the village.[11] As robustness checks, we also report results for the main outcomes using traditional single-dimensional regression discontinuity without geographical controls, and using parametric regressions, in which standard errors are clustered at the village level.

When interpreting the results, it should be kept in mind that the actual coverage can differ from the plan. Some eligible villages may be excluded while ineligible ones may participate due to imperfect compliance. If this is the case, the change in the program participation rate is less than one at the cutoff distance. Our main results therefore are smaller in magnitude than the average treatment effect on the treated obtained using eligibility as an instrument for participation.

One concern that could be raised about our approach is that ineligible households might move to program villages in order to participate in the program (Lee 2008). In our sample, the migration rate is very low. Less than 1% of households in our estimation sample ever moved since the launch of the agricultural extension program (in the last three years). Moreover, if households excluded from the program purposely moved closer to the branch in order to be eligible for the extension services, we would expect a spike in the households density right below the cutoff distance of 6 km. Figure A2 in the Appendix plots the number of households in each 0.6 km bin against households' distance to the nearest BRAC branch. Visual evidence shows no noticeable jump in the density around the cutoff distance. In addition, the density smoothness test proposed by McCrary (2008) fails to reject the smoothness of households' density at the cutoff. This and other evidence confirms that endogenous movement of households is not a concern for this study.

Valid spatial regression discontinuity design requires that households are relatively similar at all points on the boundary (Keele & Titiunik 2015). As BRAC did not conduct an initial baseline survey before the intervention, we use data from the Uganda National Household Survey 2005-06 (UNHS) to show households are similar over the 6 km cutoff before the implementation of the BRAC agricultural program.[12] This timeline is summarized in Appendix figure A1. We combine households' GPS coordinates collected by UNHS and those of BRAC branches to calculate households' distance to the nearest BRAC branch, and estimate the same model with geographical controls as outlined in equation 1. In total, 708 households resided within 2.16 km from the 6 km distance-to-branch threshold. As shown in table 2, we find that households do not differ in terms of adoption of various agricultural technologies, self-reported land quality, log of agricultural income, food consumption per capita, likelihood of having a household member working for wage employment, or whether the household engaged in non-agricultural business. Although the sample size here is smaller than our survey sample for the main analysis and we do not have enough statistical power to fully rule out the possibility of discontinuity in some potential outcomes, signs of the estimated pre-intervention differences are not consistent across indicators and do not show eligible households were systematically better in terms of adopting modern cultivation techniques and food security. For instance, while eligible households had a slightly higher value of food consumption per capita, they were less likely to adopt manure and intercropping, both of which were highly promoted by BRAC. This evidence supports the argument that households on either side of the cutoff were similar before the implementation of the program.

Impact on Agricultural Practices

In this section, we first present the estimated impact of BRAC's agricultural program on technology adoption. We then examine changes in households' crop choices.

Adoption of basic techniques vs. advanced inputs

We divide the examined technologies into two categories according to the upfront costs incurred during adoption. The cultivation methods that require low upfront monetary investments include manure usage,[13] intercropping, crop rotation, irrigation,[14] and weeding. The advanced farming inputs are relatively more expensive, including HYV seeds, chemical fertilizer, and pesticides. All these farming methods and the usage of improved seeds were strongly recommended by the Model Farmer in their trainings to general farmers, except that the program cautiously promoted chemical fertilizer due to environmental concerns; and for pesticides, the recommendation is to be aware about diseases and use Model Farmers' service for pesticide use if necessary.

We begin with analysis of the impact of the program on the adoption of improved cultivation methods promoted by BRAC. Regression results reported in table 3 column 1 - 4 show that compared with households residing in villages just above the 6 km distance cutoff, residing in villages within the threshold increases the adoption rates of manure by 9.2 percentage points, intercropping by 6 percentage points, crop rotation by 8 percentage points, and irrigation by 3 percentage points. Observational evidence from the field shows no new construction of dams or other large scale capital intensive irrigation systems. Thus, the increased irrigation is mainly through the often observed labor intensive effort of low cost basic irrigation. All these results provide evidence that Model Farmers have been effective in this program in promoting their neighbors' adoption of improved basic farming methods that require minimal monetary investments.

While weeding is also recommended in the agricultural training sessions, the increased practices of intercropping and crop rotation has the potential to reduce weeding requirements. In the agronomy literature, both intercropping and crop rotation have been documented to reduce weed population density and are important components of weed management strategies (Liebman & Dyck 1993; Cléments, Weise & Swanton 1994). On net, the extension program increases the likelihood of weeding by 6.3 percentage points, though this effect is not statistically significant.

The training provided by Model Farmers not only promotes the adoption of improved cultivation methods, but also the usage of HYV seeds. Interestingly, the estimated impact of the program on the adoption rate of improved seed is minimal (table 3 column 8), regardless of improved access for general farmers and subsidy to local sellers (CAPs), which may or may not transfer to other farmers. The household survey did not collect information on prices that the CAPs sell BRAC seeds; but a special BRAC survey conducted one year later collected such price data. The average per kg prices CAPs charged for maize and bean seeds in the first season of 2012 were 2888 USh and 2817 USh, respectively, which lie in the range of market prices, 2800-3000 USh. Thus, the modest subsidy to CAPs transferred little if at all to general farmers and apparently had minimal impact on the overall adoption rate of HYV seeds three years into the program.

On the other hand, from table 3 column 9 the extension program increases the seed purchase rate *from BRAC sources* by 4.3 percentage points, possibly due to exposure to BRAC seeds in the training sessions. Together, the increased seed purchases from BRAC and unchanged overall HYV adoption suggest substitution of BRAC-sourced seeds for existing market seeds. Thus the main benefit to general farmers of buying seeds from CAPs could be to save time and costs of travel to purchase seeds at market centers. The other main potential benefit is that BRAC seeds may have higher average quality than standard market sources in which a significant fraction of seeds are of low quality (Bold et al. 2017); however, we lack comparative data to address this possibility.

Finally, the effects of the extension program on the adoption rate of chemical fertilizer and pesticides are small and statistically insignificant. Again, these practices were not emphasized by the program. Our estimated impacts on technology adoption are consistent with the visual evidence shown in figure A3 of the Appendix. In addition, these results are qualitatively the same and quantitatively similar in robustness checks with different bandwidths, with household-level controls,[15] using traditional single-dimensional regression discontinuity specification, and using parametric regressions, as reported in tables A1, A2, A3, and A4 of the Appendix, respectively.

Crop choices

The agricultural extension program provides comprehensive training to participating farmers, including but not limited to the inputs and methods examined above. For instance, farmers may learn from the training about local soil quality and switch to crops that (they believe) are more profitable on their farm land. As shown in table 4, farmers eligible for the extension program are 4.2 percentage points more likely to grow coffee, a popular cash crop that is mainly for sale in the market, albeit only at the 10% level. There is a reduction of 5.1 percentage points in the share of these farmers who are growing beans, although the effect is not statistically significant. The program does not affect the likelihood of growing other major crops, defined as those grown by more than 5% of the surveyed households.

Food Security

In this section, we first show the impact of the agricultural program on food consumption. We then go on to examine changes in farmers' shock-coping methods. We discuss channels that could potentially explain these substantial welfare improvements at the end of the section.

Food consumption and sufficiency indicators

Given its positive impact on the adoption of productivity-enhancing cultivation methods, BRAC's agricultural extension program has large potential for improving farmers' food security. As shown in table 5 column 1, overall food sufficiency (measured as whether households had sufficient food to meet family needs over the previous year) increases by 5.4 percentage points for households residing in villages eligible for (in the coverage areas of) BRAC's agricultural program. In addition to overall food sufficiency, households also reported whether they had enough food for each of the 12 months prior to the survey. We run the same local linear regression for each month to test for the heterogeneous impact on food sufficiency over the agricultural cycle.

Figure 3 plots the estimated change in the food sufficiency indicator for each month with 95% confidence intervals.[16] Overall, the agricultural program had a strong impact in June and July, 2011 on the proportion of households with sufficient food; in contrast, the program had a minimal (no statistically significant) effect during the other months in 2011. This finding corresponds with the Uganda Food Security Outlook, which reports that, while abundant rain led to above-average harvest in the second cropping season in 2010, the delayed rain in the first cropping season in 2011 subsequently delayed the harvest to July-August and put stress on food security for at least some regions in Uganda (FEWS NET 2010, 2011). In other words, the impacts of the extension program are largest right before the harvest, during which time the food security is generally worst (as is the case in most developing countries).

Moreover, our data contain detailed information on household consumption during the seven days prior to the survey conducted in July 2011, a period of heightened food insecurity. Using this information, we find the extension program increases per capita household food consumption expenditure by about 11.6%, as shown in table 5 column 2.

As widely noted, food availability is only one of the indicators needed to assess food security (Campbell 1991; Maxwell 1996*a*). As argued by Barrett (2002), different indicators often categorize different households as food secure and yield different measures of the incidence and intensity of food security in an area. Therefore, it is crucial to evaluate multiple indicators jointly to better assess food security from various angles. However, the availability of such data is often limited by data collection costs and policymakers' interest (Babu & Pinstrup-Andersen 1994).

Fortunately, the survey includes detailed self-reported data, which we use to examine impacts on food security measured in several dimensions. In the month prior to the survey, households were far from food secure. According to summary statistics reported in table 1, 79.1% households worried about food, 82.2% ate limited food varieties, 73.5% had limited meal portions, and 64.1% skipped meals. The correlation between these indicators and overall food insufficiency during the past year (defined as 1 minus the overall food sufficiency) is as low as 0.39 (table 6), showing the usefulness of examining food security along each of these dimensions, consistent with the argument of Barrett (2002). In our regression sample, only 5.7% of hourseholds were food insecure in none of these measures. The share of households that experienced food insecurity in 1, 2, 3, or 4 dimensions were 12.4%, 8.1%, 13.7%, and 54.8%, respectively. 5.4% of the households were food insecure in all measures. While food insecure households tended to suffer from multiple dimensions simultaneously, there were significant cross-household variations in the particular food issue faced by each household.

As shown in table 5, households eligible for the agricultural extension programs were 6.2 percentage points less likely to limit consumption varieties and 9.5 percentage points less likely to skip meals, compared with control group households . However, the program had no detectable impact on the likelihood of worry over insufficient food or the likelihood of consuming limited portions of food at each meal. Taken together, these results confirm the positive impact of eligibility for the extension program on improving food security among participating villages, and show the impact is realized mainly via increased food variety and meal frequency.

Results may be compared with those of Larsen & Lilleør (2014), mentioned earlier in the article, who found substantial program impact magnitudes, generally between 6 to 25 percentage points, but with very high impacts on worst-month hunger scale, estimated as a more than 70 percentage points improvement. In particular, they show a 17.2 percentage points reduction in the likelihood of households suffering from hunger during the past year. Their intent-to-treat (ITT) estimates, that are the most similarly constructed to ours, do not differ much from those of their other approaches.

The impact on food security lies within the potential range obtained by agronomic field experiments. In particular, all the improved cultivation methods that we examined earlier have been documented in the agronomy literature to significantly increase yield. For instance, intercropping cowpea and millet can increase the yield of millet by up to 103% (Hulet & Gosseye 2007); application of carbonized and dried chicken manure boosts maize yield by up to 43% and soybean yield by approximately 30% (Tagoe, Horiuchi & Matsui 2008). Moreover, Florentín (2010) finds that maize production increased by more than 30% after rotation with white lupine. In addition, Robins & Domingo (1953) find that 6 to 8 days of water stress during pollination reduced maize yield by 50% in a field study in the U.S., which indicates a 100% yield increase using irrigation during drought (>50% surveyed households in our sample reported that they experienced drought). These findings are also correspond with those of Pandey, Maranville & Admou (2000), from an experiment conducted in an Africa context, in which they found that lack of irrigation during vegetative and reproductive periods reduces maize yields by up to 52%. Unfortunately, yield information was not collected by BRAC. To show some evidence on the production-enhancing effect of these cultivation methods in our studied sample, we regress household self-reported net agricultural income from several major crops on the adoption of each of these methods using OLS.[17] As shown in Appendix table A5, the adoption of each of the basic cultivation methods is associated with higher agricultural income, and therefore has the potential to improve food security.

Coping with shocks

As pointed out by Chambers (1989) and Watts & Bohle (1993), households without access to "noninjurious shock-coping mechanisms" are the most food insecure. Because people employ a graduated sequence of responses to shocks, the methods households use to cope with these shocks can serve as another measure of food security. An examination of coping strategies enables us to capture an important aspect of food insecurity that traditional measures miss. Moreover, in addition to locating (or identifying) the presence of food insecurity, observation of coping behaviors provides a powerful indicator of the intensity of food insecurities (Barrett

2002).[18]

Corresponding to the insufficient rain in the first cropping season of 2011, more than 40% of households reported that they experienced drought conditions. Overall, about 54% of households experienced at least one covariant shock, including drought, flood, pest attack, livestock epidemic, fire, or poor quality seeds in the village in the 6 months prior to the survey, providing us an opportunity to study their shock-coping behaviors.[19]

Restricting the analysis to these households, table 7 shows the impact of program eligibility on the usage of the seven most reported shock-coping methods. As shown in column 3, households in villages covered by the extension program are 4.9 percentage points less likely to sell assets in the face of covariate shocks. Asset smoothing is considered one of the least favorable methods to cope with shocks as it may limit production capability and often comes at a cost of impaired future food security. Selling assets implies generally higher transaction costs than adjustment through savings (or credit); farmers may also face unfavorable terms as contemporaneous distress sales of assets by neighbors cause downward pressure on prices. A reduction in asset-selling behavior in response to shocks suggests that households are more food secure.

While severe hunger is detrimental, modest current reduction in food consumption may be less injurious over the long term. As pointed out by Maxwell (1996*b*) and Barrett (2002), most households are quite prepared to sacrifice food intake to a certain degree in order to preserve productive assets to secure future food security. Besides food, households may also cut consumption on other goods and services, such as temptation goods and entertainment activities; doing so is often less harmful than selling assets. Therefore, reducing overall current consumption is not as unfavorable as asset smoothing. Correspondingly, we anticipate that the agricultural program may shift some farmers away from asset smoothing and toward consumption smoothing. Moreover, as the program also increases household food consumption (as documented earlier in this section), this leaves more room for consumption reduction while maintaining minimum nutritional levels. Consistently, farmers exposed to the program are 8.3 percentage points more likely to reduce consumption during shocks, significant at the 5% level. In addition, we also find households in program villages are slightly more likely to resort to borrowing, a preferred coping strategy, although the effect is not statistically significant at conventional levels. In sum, the documented changes in shock-coping behavior indicate improved food security in program villages.

Discussion of Mechanisms

This research has identified a substantial increase in food security for farmers eligible for BRAC's agricultural program. Our interpretation of the findings is straightforward: that improved crop yields of women smallholder farmers occurs through adoption of basic practices not requiring significant cash outlays; increased own consumption or agricultural income leads to an improvement in family food security. While most of the basic practices adopted require some labor time, the opportunity cost of unskilled labor is low in rural Uganda.

An alternative mechanism may be proposed that the program's impact is realized via female empowerment and reallocation of resources within a household, rather than through information and training. In many African countries, husbands and wives farm separate plots; and plots controlled by women tend to receive less labor and fertilizer inputs and are less productive than farmed controlled by men (Udry 1996; Duflo & Udry 2004). As a result, households could generate higher income by reallocating recourses across the household' various farm plots (Udry 1996). Since BRAC's agricultural extension program targeted only female farmers, the improved food security could result also from improved female intra-household bargaining power. We cannot completely rule out this explanation without detailed data on intra-household resource allocation. However, we test this possibility by using the share of household consumption expenditure spent on alcohol and tobacco as a proxy of female bargaining power, and check if the program increases the bargaining power of women. Using the same local linear specification, we do not find that eligibility for the extension program changes the share of households' expenditure on these items, a finding inconsistent with a female empowerment mechanism.

In sum, the evidence of this study show that the enhanced food security is likely attributed to increased adoption of improved cultivation methods as a result of information provision via training. Note that these improved practices are not limited to the specific ones for which we have household data (and thus examined in this article). In particular, while the rate of advanced inputs usage remains the same, the agricultural training may lead to improved use of these inputs. Previous evidence suggests that farmers do not necessarily use the inputs they purchase correctly to make these inputs profit-enhancing (e.g. Duflo, Kremer & Robinson 2008). Correct timing and dosage of fertilizer application are both possible results of the extension program. In addition to topics covered in the household survey, the agricultural training also provides practical information about other productivity-enhancing activities such as plant spacing, pest and disease management, green fertilizer timing, and labor saving harvest methods. These other efficiency-enhancing activities promoted by the training likely contribute to the production gains as well; and these activities are also likely to require little if any cash outlays.

Nonetheless, the improved food security may perhaps be understood as the *com-*

bined impact of these several channels of practices promoted by the program. Based on previous agronomic research, such effects are certainly plausible; what is particularly remarkable is that an agricultural extension program could bring about a sufficient package of such changes simultaneously so as to realize such a significant impact on food security primarily through such low-cost activities.

Concluding Remarks

This article examines the impact of a well-known NGO-designed and operated agriculture extension program for smallholder women farmers in Uganda. In sum, we find the program leads to improved farmers' food security and better shock-coping methods. To the best of our knowledge, this article is the first to examine the impact of an extension program on all essential aspects of food security, including sufficiency, consumption, diversity, meal frequency, and food anxiety; and we find positive and significant impacts across all of these dimensions except food anxiety. Results suggest that these effects are most likely driven by adoption of improved cultivation methods that are relatively costless in monetary terms.

Note that our impact estimates are applicable specifically for smallholder farmers living around the 6 km boundary from BRAC branches, which generally are located at or near at county centers; thus, although these are rural agricultural households, they have better market access than those even more distant from county centers; we cannot be confident about the external validity of the results for more remote farmers. However, although the program was not fully nationally representative, because it did not operate in the semi-arid northern districts (a region differing from the rest of Uganda in that it has mostly one cropping season per year, is more sparsely populated, and was recovering from conflict); otherwise the program had a wide geographic coverage, distinguishing it from most studies, which cover small geographic areas.

Regardless of these limitations, the case of the BRAC Uganda extension program provides important insights into how agricultural extension services in sub-Saharan Africa can have a substantial positive effect on food security. A large literature indicates that the potential benefits of using advanced inputs are large. However, many constraints impede farmers from adopting these expensive inputs. In contrast, this article has shown that improved basic cultivation methods, which require minimal upfront monetary investment, can significantly increase production. These methods are especially important for the poor, such as smallholder female farmers studied in this article, who (unlike wealthier farmers) are often marginalized and less likely to adopt these basic cultivation techniques on their own. Moreover, this research found a strong associated improvement in household food security. This effect is far from guaranteed, adding another reason to study similar programs, perhaps in direct comparison with more traditional programs, for which the estimated link between agricultural production and food security has been much weaker.

It may be that impacts on outcomes such as use of advanced inputs become apparent only after time to consolidate the more foundational improvements such as those identified in this study. In this sense, in countries such as Uganda, food security may need to be achieved in stages, with sequential support from extension services. The resulting policy question concerning whether extension and development assistance could be more cost-effective if different components are implemented in a sequence must be left for future research.

Notes

[1]The Intention to Treat effect is defined as the effect of being offered, but not necessarily receiving, treatment (Angrist & Pischke 2008).

[2]These aspects are quantitative availability, qualitative aspects concerning types and diversity of food, psychological dimensions relating to feelings of deprivation or anxiety related to food availability, and social consumption patterns such as meal frequency.

[3]We do not have data on the relative quality of BRAC seeds and other HYV seeds available on the general market. However, recent evidence indicates high incidence of counterfeit seeds and substandard fertilizer sold at input markets accessible to smallholders in Uganda, with low correlation between quality and price (Bold et al. 2017). This could be a reinforcing explanation for why other advanced inputs were not adopted. On the other hand, the negative coefficient on all HYV seeds is insignificant, but has a negative sign that is about three-quarters that of the coefficient on BRAC seeds; so it is possible that BRAC seeds have "crowded out" other market seeds without a significant improvement of quality, at least within the first three years of the program, and in the zone studied. Note that adoption of improved seeds may eventually increase after the program has been in place for a longer period.

[4]The agriculture training also promotes other productive farming methods and knowledge beyond the ones examined here, such as timing and dosage of fertilizer use and pest diagnostics. However, we do not have data on these additional practices as they are not covered by the survey.

[5]The Kondylis et al mixed male and female sample (of a mixed extension program) is a fundamental difference from our study. Differences between male and female farmers in the Kondylis et al dataset are not reported, but, in virtually all locations where this has been studied in Africa, male farmers are wealthier, have higher chances of having been visited by extension agents in the past, and may be more likely to adopt improved basic cultivation methods on their own. In contrast, our study consists only of marginalized female farmers, who typically lack access to training on improved basic farming techniques, as women were often excluded in past extension activities, which otherwise tended to address the situation of male farmers. Finally, the Kondylis et al study does not address food security or shocks.

[6]Specifically, Bonan & Pagani (2016) found the program was associated with an increase in house-

hold as well as students' agricultural knowledge, and improved household food security as measured by a food consumption score, though not by either a Household Dietary Diversity Score or the number of food types consumed weekly; effects on consumption of individual foods are mixed. The authors also used difference-in-differences and PSM methods to try to address the nonrandom placement of treatment schools, which were chosen on the basis of having previously received programs. DIDM methods do not provide reliable causal estimation to the extent possible with regression discontinuity methods. Their sample size was 211.

[7]Bean and vegetable seeds were also made available for purchase, though only about 10-20% of total value of seeds distributed were non-maize items.

[8]The cost of this program is not the focus of our article.

[9]We estimate the fraction of households trained in eligible villages as approximately 41%. This estimate is calculated using administrative data reported in BRAC's internal memo. We divide the overall program outreach (total number of farmers involved) by the total number of households residing in program areas.

[10]This method may introduce fuzziness around the cutoff if households are not uniformly distributed in the village.

[11]The estimation does not take into account possible spillover effect across villages. While BRAC's agriculture workers are restricted to work in certain areas, there may be information spillover effects through communication between farmers in nearby villages. Thus, the results reported in this article may underestimate the overall program effects.

[12]The UNHS sample is nationally representative. The characteristics of the UHNS estimation sample are quite similar to the BRAC sample, with an average age of household head of 43.2 and household head literacy rate of 69.9%.

[13]We categorize manure as an inexpensive farming method instead of an advanced agriculture input because it is readily available and mostly free.

[14]We categorize irrigation as an inexpensive cultivation method in monetary terms as its changes are mainly in the form of low cost basic irrigation (i.e., farmers lifting water to the farm) in studied areas. No new construction of dams, channels or other large-scale irrigation systems were observed in the field during the intervention period.

[15]Controls include household heads' age, literacy, whether any household member holds positions in the village or higher-level committees, and the coverage of BRAC's microfinance program. The microfinance program has the potential to lift credit constraints, which has been documented in the literature as one of the main obstacles in technology adoption. However, this program is operated by separate teams and does not have any distance-to-branch restriction.

[16]The Y-axis is the estimated change in the food sufficiency indicator.

[17]These crops include common staple varieties, maize, beans, millet, groundnut, along with the leading cash crop, coffee.

[18]Shock coping mechanisms therefore have clear implications for household food security. They also play an important role in poverty trap analysis (see, e.g., Zimmerman & Carter 2003; Carter & Lybbert 2012; Janzen & Carter 2013); while this is a potentially important topic for future research on effects of agricultural extension in Uganda and elsewhere, our article focuses on shock coping solely as an indicator of food security.

[19]There is no discontinuity in the incidence of shocks at the cutoff distance of 6 km.

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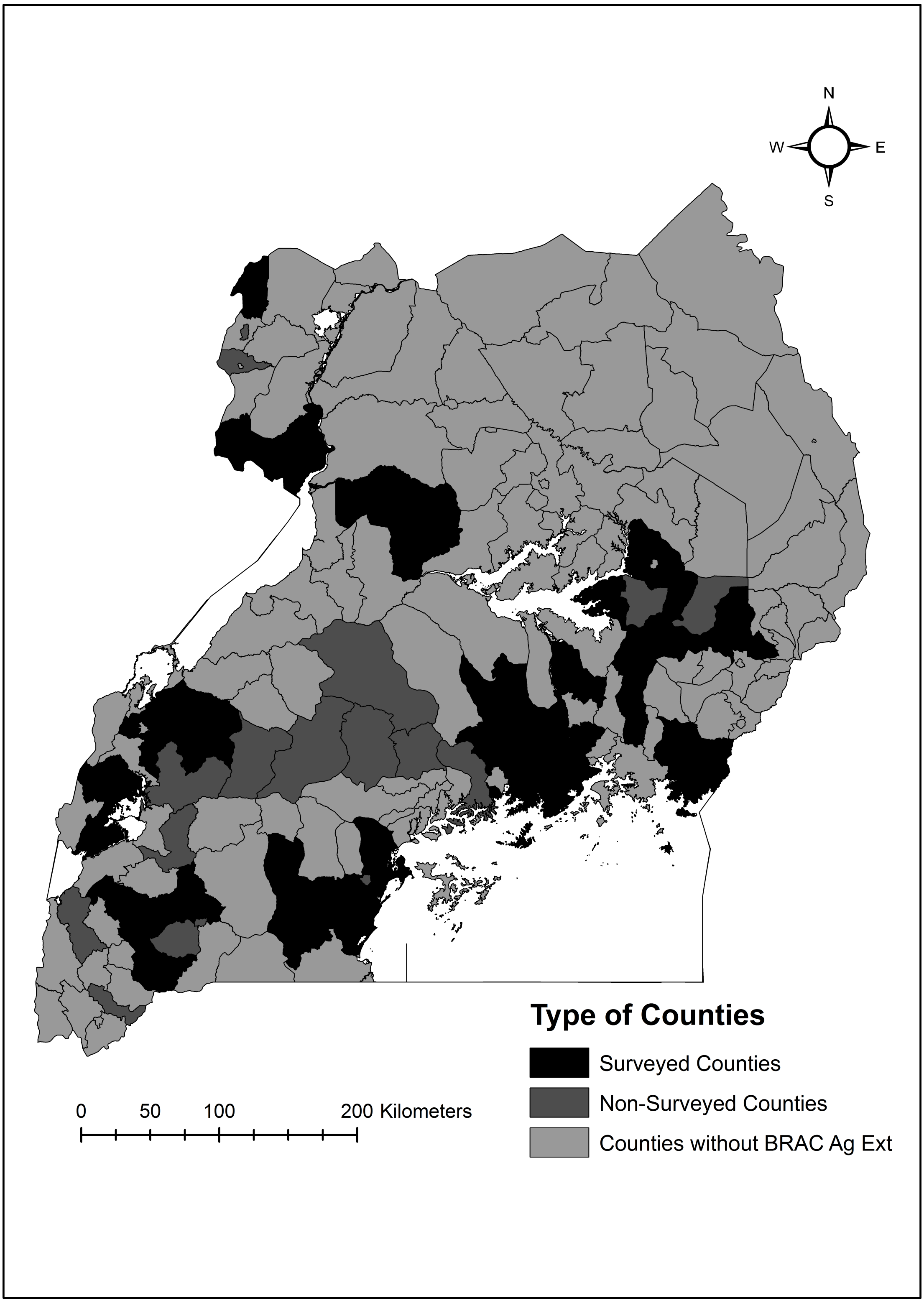

Figure 1: Surveyed counties

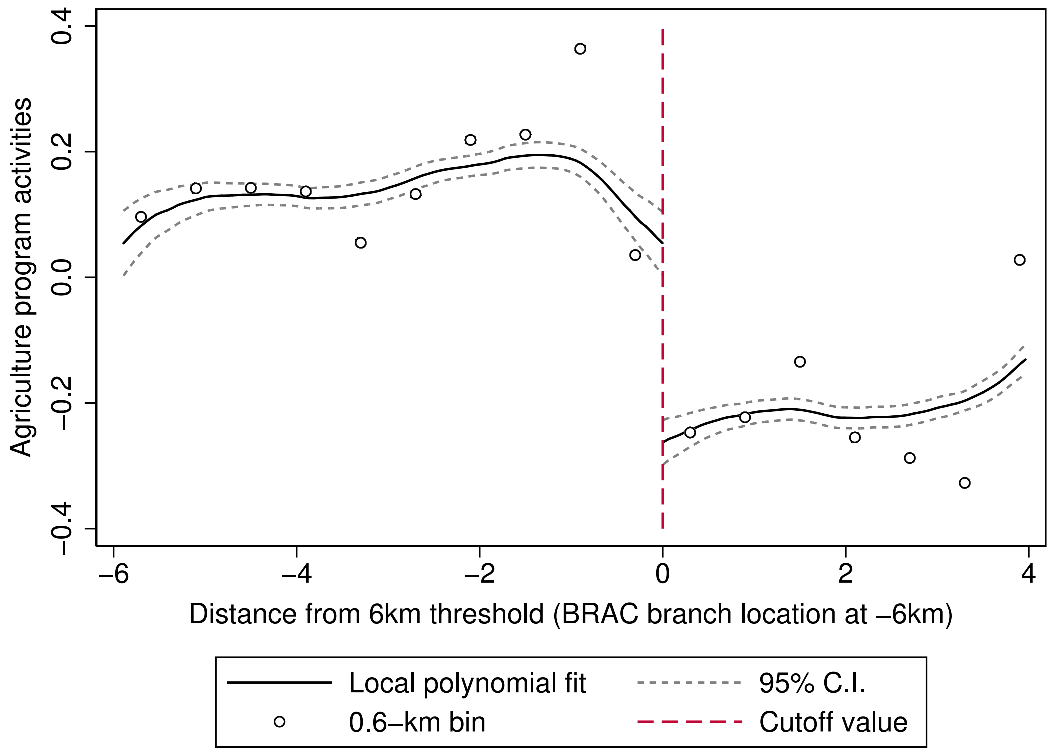

Figure 2: Program activities during the six months prior to the survey (residuals from branch fixed effects)

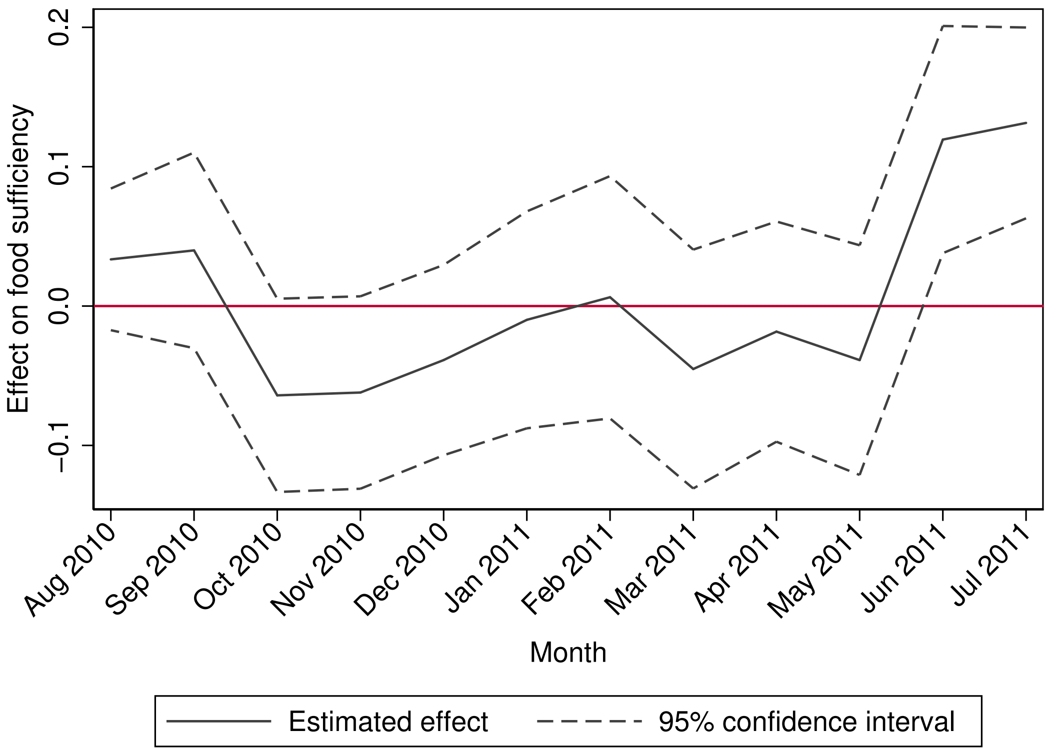

Figure 3: Program effect on food sufficiency across months

Table 1: Summary Statistics

	Mean	S.D.	N
Household characteristics			
HH head age	44.4	14.5	3367
HH literacy	0.703	0.457	3359
HH member in council	0.364	0.481	3403
Modern techniques adoption			
Manure	0.086	0.281	3103
Intercropping	0.813	0.390	3103
Crop rotation	0.823	0.381	3103
Irrigation	0.020	0.141	3103
Weeding	0.711	0.453	3103
Fertilizer	0.072	0.259	3103
Pesticides	0.130	0.337	3103
HYV seeds	0.358	0.479	3103
Food security			
Overall food sufficiency (last year)	0.202	0.401	3455
Log food cons. per capita	9.140	0.951	3065
(last 7 days, in Ushs)			
Worry about food (last month)	0.791	0.407	3408
Limited variety (last month)	0.822	0.382	3414
Limited portion (last month)	0.735	0.441	3411
Skip meals (last month)	0.641	0.480	3416

Note: Summary statistics are reported for the sample used in main estimations, including farmers residing in villages that are within 2.16 km on each side of the 6 km cutoff distance to the closest BRAC branch offices.

Table 2: Pre-intervention Smoothness of Key Variables Using UNHS (2005-06)

(a) Technology adoption: estimated discontinuity below 6 km threshold

Manure	Inter-cropping	Chemical fertilizer	Pesticides	HYV seeds
(1)	(2)	(3)	(4)	(5)
-0.018	-0.116	0.003	0.011	-0.016
(0.071)	(0.141)	(0.036)	(0.036)	(0.117)

(b) Welfare indicators: estimated discontinuity below 6 km threshold

Land quality	Agricultural income	Business activity	Wage emp.	Per capita food cons.
(1)	(2)	(3)	(4)	(5)
0.054	0.061	-0.055	-0.078	0.015
(0.106)	(0.404)	(0.153)	(0.152)	(0.205)

Note: The table reports non-parametric reduced form estimates using the bandwidth of 2.16 km. Asterisks *, ** and *** denote significant levels of 10%, 5% and 1% respectively.

Table 3: Technology Adoption: Regression Discontinuity Results

Manure	Inter-cropping	Crop rotation	Irrigation	Weeding	Chemical fertilizer	Pesticides	All HYV seeds	BRAC Seeds
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
0.092***	0.060*	0.080***	0.030***	0.063	-0.019	-0.035	-0.034	0.043***
(0.026)	(0.033)	(0.031)	(0.009)	(0.039)	(0.024)	(0.032)	(0.038)	(0.013)

Note: The table shows intention-to-treat (ITT) impact of BRAC's agricultural program on technology adoption, estimated using local linear regressions with a bandwidth of 2.16 km and a triangular kernel. Regressions include geographic controls and branch fixed effects. Asterisks *, ** and *** denote significant levels of 10%, 5% and 1% respectively.

Table 4: Impact of Agricultural Program on Crops Grown

Millet	Maize	Rice	Groundnut	Bean	Coffee
(1)	(2)	(3)	(4)	(5)	(6)
-0.003	0.003	-0.004	-0.007	-0.051	0.042*
(0.023)	(0.036)	(0.014)	(0.031)	(0.032)	(0.025)

Note: The table shows intention-to-treat (ITT) impact of BRAC's agricultural program on farmers' choice of crops grown, estimated using local linear regressions with a bandwidth of 2.16 km and a triangular kernel. Regressions include geographic controls and branch fixed effects. Asterisks *, ** and *** denote significant levels of 10%, 5% and 1% respectively.

Table 5: Impact of Agricultural Program on Food Security

	Other measures of food security				
Overall food sufficiency	Per capita food cons.	Worry about insuf. food	Limited variety	Limited portion	Skip meals
(1)	(2)	(3)	(4)	(5)	(6)
0.054**	0.116*	0.005	-0.062**	-0.021	-0.095**
(0.027)	(0.066)	(0.029)	(0.030)	(0.032)	(0.037)

Note: The table shows intention-to-treat (ITT) impact of BRAC's agricultural program on food consumption, estimated using local linear regressions with a bandwidth of 2.16 km and a triangular kernel. Regressions include geographic controls and branch fixed effects. As standard practice in the literature, respondents reported on their consumption patterns over the last 7 days. Asterisks *, ** and *** denote significant levels of 10%, 5% and 1% respectively.

Table 6: Correlation Between Food Security Measures

	Food in-sufficiency	Worry about food	Limited variety	Limited portion	Skip meals
Food insufficiency	1	—	—	—	—
Worry about food	0.511	1	—	—	—
Limited variety	0.484	0.757	1	—	—
Limited portion	0.460	0.694	0.705	1	—
Skip meals	0.389	0.580	0.590	0.714	1

Note: The table shows correlations between different food security measures. All indicators were measured in the month prior to the survey, except for food insufficiency, which was measures over the previous year.

Table 7: Impact of Agricultural Program on Shock-coping Methods

Reduce consump.	Use savings	Sell assets	Additional emp.	Begging	Borrowing	Friend transfer
(1)	(2)	(3)	(4)	(5)	(6)	(7)
0.083**	-0.035	-0.049**	0.007	-0.006	0.054	-0.007
(0.042)	(0.047)	(0.021)	(0.015)	(0.026)	(0.035)	(0.018)

Note: The table shows intention-to-treat (ITT) impact of BRAC's agricultural program on major methods used to cope with covariant shocks, estimated using local linear regressions with a bandwidth of 2.16 km and a triangular kernel. Regressions include geographic controls and branch fixed effects. Asterisks *, ** and *** denote significant levels of 10%, 5% and 1% respectively.

APPENDIX

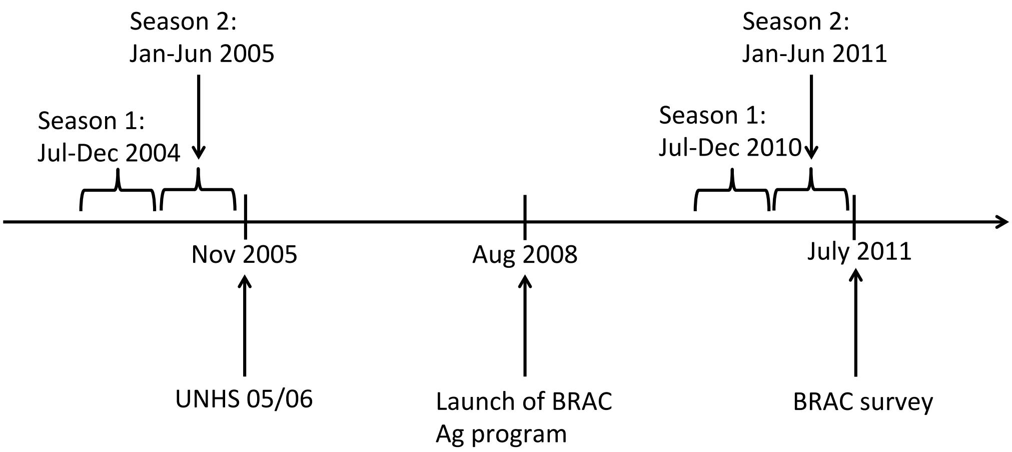

Figure A1: Timeline for the Program and UNHS and BRAC Surveys

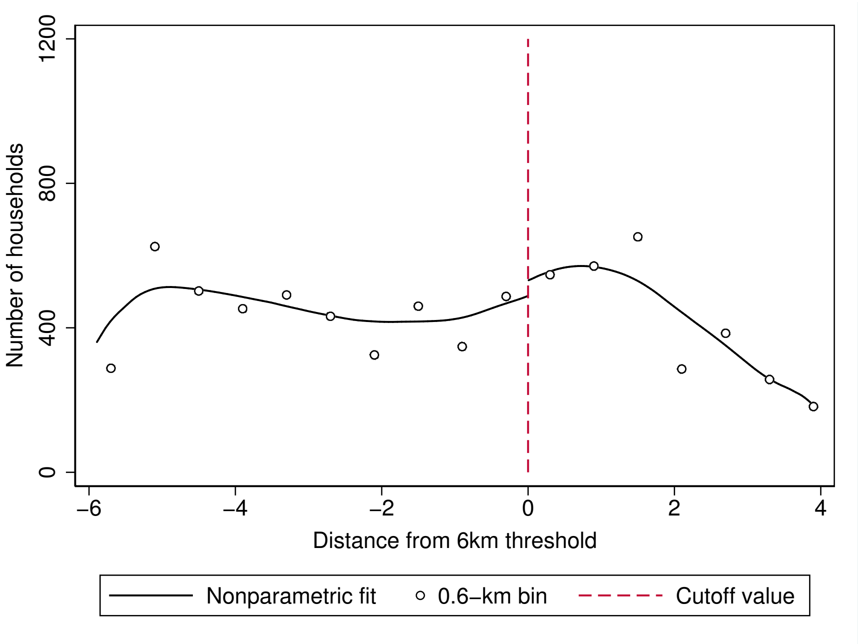

Figure A2: Household density against distance from 6km threshold

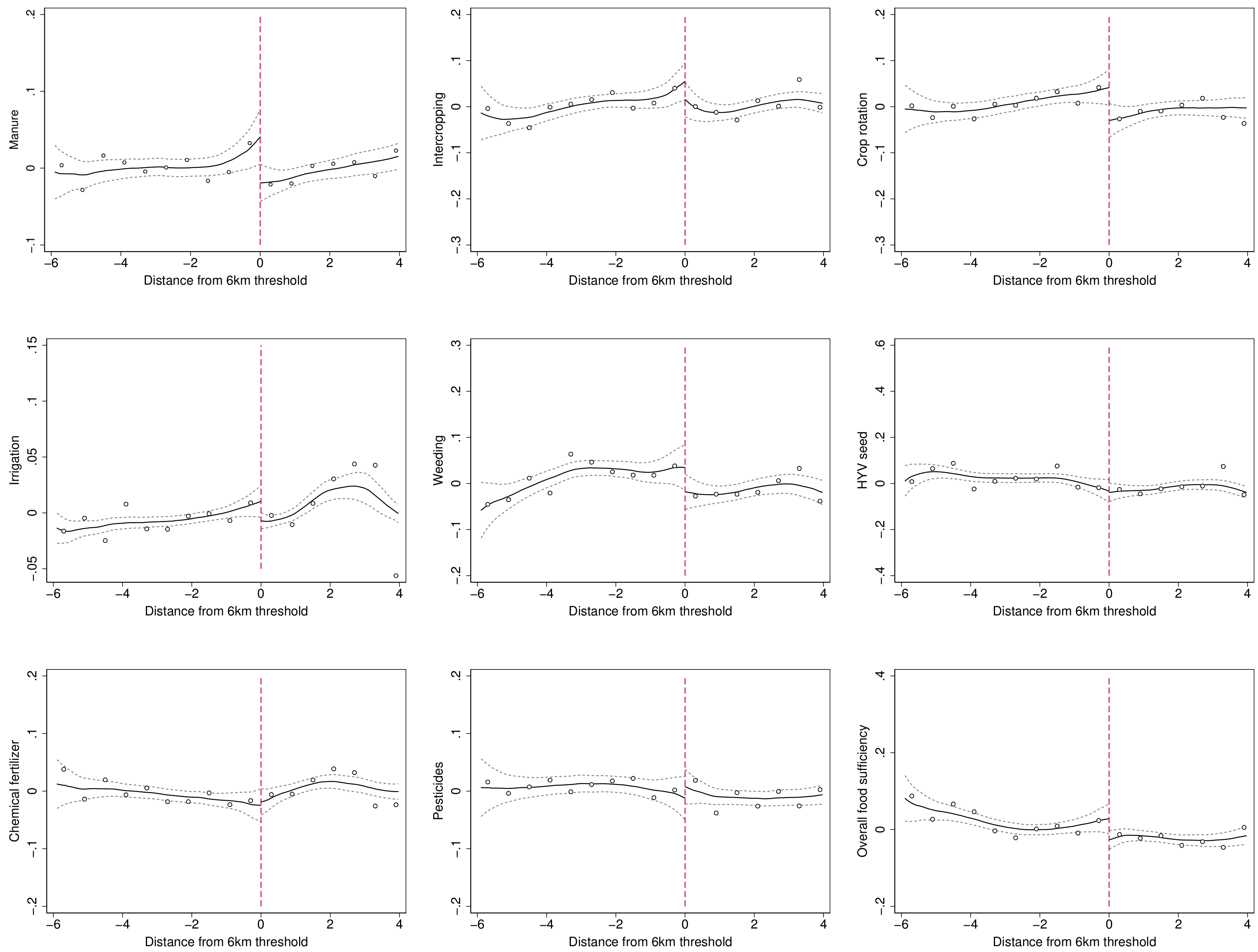

Figure A3: Discontinuity in key outcomes ((residuals from branch fixed effects))

Table A1: Robustness to Bandwidth Choices

	Manure	Inter-cropping	Crop rotation	Irrigation	Weeding	Chemical fertilizer	Pesticides	Improved seeds	Overall food sufficiency
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Bandwidths									
1.5 km	0.104^{***}	0.068^{*}	0.072^{*}	0.035^{***}	0.072	-0.021	-0.045	-0.039	0.066^{**}
	(0.032)	(0.042)	(0.039)	(0.012)	(0.048)	(0.031)	(0.040)	(0.046)	(0.034)
2.5 km	0.083^{***}	0.058^{*}	0.083^{***}	0.027^{***}	0.064^{*}	-0.022	-0.034	-0.026	0.054^{**}
	(0.025)	(0.031)	(0.029)	(0.009)	(0.036)	(0.022)	(0.029)	(0.035)	(0.025)
3.5 km	0.058^{***}	0.068^{***}	0.075^{***}	0.028^{***}	0.057^{*}	-0.026	-0.028	-0.002	0.041^{**}
	(0.020)	(0.025)	(0.024)	(0.007)	(0.029)	(0.017)	(0.023)	(0.028)	(0.020)

Note: The table shows intention-to-treat (ITT) impact of BRAC's agricultural program on technology adoption and overall food sufficiency, using different bandwidth choices. Asterisks *, ** and *** denote significant levels of 10%, 5% and 1% respectively.

Table A2: Robustness to Inclusion of Household Controls

Manure	Inter-cropping	Crop rotation	Irrigation	Weeding	Chemical fertilizer	Pesticides	All HYV Seeds	Overall food sufficiency
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
0.088**	0.059*	0.065**	0.026***	0.054	-0.031	-0.055*	-0.046	0.045*
(0.027)	(0.035)	(0.032)	(0.010)	(0.040)	(0.026)	(0.033)	(0.039)	(0.027)

Note: The table shows intention-to-treat (ITT) impact of BRAC's agricultural program on technology adoption and overall food sufficiency. In addition to branch fixed effects and longitudinal and latitudinal distance between the village and the closest BRAC branch office, we also control for household head's age, literacy, whether any household member holds positions in the village or higher-level committees, as well as the coverage of BRAC's microfinance program. Asterisks *, ** and *** denote significant levels of 10%, 5% and 1% respectively.

Table A3: Robustness to One Dimensional Analysis

Manure	Inter-cropping	Crop rotation	Irrigation	Weeding	Chemical fertilizer	Pesticides	Improved seeds	Overall food sufficiency
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
0.045*	0.060**	0.054*	0.028***	-0.101***	0.025	0.024	0.020	0.272***
(0.025)	(0.028)	(0.029)	(0.009)	(0.035)	(0.020)	(0.028)	(0.037)	(0.030)

Note: The table shows intention-to-treat (ITT) impact of BRAC's agricultural program on technology adoption and overall food sufficiency without geographic location controls. Asterisks *, ** and *** denote significant levels of 10%, 5% and 1% respectively.

Table A4: Robustness to Parametric Regression

Manure	Inter-cropping	Crop rotation	Irrigation	Weeding	Chemical fertilizer	Pesticides	All HYV Seeds	Overall food sufficiency
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
0.067**	0.031	0.094***	0.024**	0.031	-0.008	-0.035	–0.001	0.051*
(0.027)	(0.039)	(0.036)	(0.011)	(0.040)	(0.027)	(0.033)	(0.042)	(0.031)

Note: The table shows intention-to-treat (ITT) impact of BRAC's agricultural program on technology adoption and overall food sufficiency using quadratic regressions, allowing coefficients to be different at each side of the cutoff. Errors are clustered at the village level. Asterisks *, ** and *** denote significant levels of 10%, 5% and 1% respectively.

Table A5: Agricultural Practice and Income

Dependent Variable: Agricultural Income		
	Coeff.	S.D.
Manure	0.123*	(0.067)
Intercropping	0.379***	(0.050)
Crop Rotation	0.017	(0.048)
Irrigation	0.977***	(0.128)
Weeding	0.225***	(0.041)
Fertilizer	0.241***	(0.082)
Pesticides	0.372***	(0.060)
All HYV Seeds	0.333***	(0.040)

Note: Table shows the correlation between the adoption of each studied agricultural practice and self-reported household agricultural income over major crops. Asterisks *, ** and *** denote significant levels of 10%, 5% and 1% respectively.