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Income and Malaria

Evidence from an agricultural intervention in Uganda

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Abstract: We exploit a spatial discontinuity in the coverage of an agricultural extension program in Uganda to causally identify its effects on malaria. We find that eligibility for the program reduced the incidence of malaria by 8.8 percentage points, with children and pregnant women experiencing most of these improvements. An examination of the underlying mechanisms indicates that an increase in income and the resulting increase in the ownership and usage of bednets is the most likely candidate driving these effects. Taken together, these results signify the importance of liquidity constraints in investments for malaria prevention and the potential role that agricultural development can play in easing it.

Keywords: malaria, agricultural extension, regression discontinuity, Uganda
JEL classification: I15, O12, Q16

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Figures and tables at the end of the paper.

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1 Introduction

Income and malaria share a complex two-way relationship. On the one hand, low income can limit households' capacity to buy bednets, nutritional intake and access to health care, leading to high malaria rates (Berthélemy et al., 2013). On the other hand, malaria related morbidity reduces earnings through decreased labor productivity and worker absenteeism (Fink and Masiye, 2015; World Bank, 2008). Further, coping mechanisms such as the sale of assets for smoothing consumption and paying for health care, and taking time off to take care of sick household members can have adverse implications for the productivity and well-being of households (Audibert et al., 2003; Chima et al., 2003). This two-way relationship may result in a poverty trap characterized by low incomes and high malaria rates. In this paper, we examine whether agricultural interventions that aim to increase incomes and combat poverty can help in malaria reduction and potentially break this vicious circle.

While the possibility that an increase in the income generating capacity of agriculture can reduce malaria rates has been discussed widely in the literature (Asxenso-Okyere et al., 2011; World Bank, 2008; van der Hoek, 2004; Ijumba and Lindsay, 2001), causal identification has been challenging due to concerns related to omitted variable bias and reverse causality. We contribute towards filling this gap with evidence from a large-scale agricultural extension program operated by BRAC, one of the largest NGOs, in Uganda. We exploit an arbitrary distance-to-branch threshold for village program eligibility to causally identify the effects on malaria and explore possible channels. This program provides agricultural training and easier access and affordability of high yield variety seeds with the ultimate objective of improving food security and helping households climb out of poverty. In a companion paper, Pan et al. (2015) find that this program significantly improved household consumption, savings and food security.

Using a regression discontinuity framework, we find that the agricultural extension program lead to a reduction in the incidence of malaria in Uganda. For households residing in eligible villages, malaria intensity (proportion of household members affected) reduced by 8.8 percentage points. Further, we observe considerable heterogeneity by age-groups. The largest reductions in the incidence of malaria are for children under 5, the most vulnerable group in the population. While there are no gender differences, pregnant women experience substantial reduction in malaria as well. These findings are robust to a number of checks standard in the literature. As exposure to health shocks in early life can have considerable economic losses over time, our finding that the program reduced malaria incidence among pregnant women and children under 5 indicates that the extension services program is associated with substantial and potentially lifelong benefits that are not accounted for in standard cost-benefit analyses.

This paper makes three important contributions. First, this study contributes to the evidence on the impact of income on health. A variety of papers exploit exogenous variations in household income to identify effects on health. For example, Duflo (2003) finds that an expansion in the coverage of the pension program in South Africa improved health outcomes for girls. Conversely, negative income shocks due to economic crises (Paxson and Schady, 2005), weather shocks (Jensen, 2000) or declines in output prices are found to adversely affect health (see Strauss and Thomas, 2007 for an overview). To the best of our knowledge, this is the first study to identify the causal impact of an income generating program on the incidence of malaria. Given that Sub-Saharan Africa accounts for 90% of malaria deaths globally (WHO, 2013) and that agriculture is the dominant source of income, studying a program that aims to boost agricultural production assumes tremendous policy relevance.

We also contribute to the literature on the adoption of preventive health technologies by exploring the channels through which the intervention has an impact on malaria. In the context of malaria prevention, sleeping under an insecticide treated bednet (ITN) is considered to be highly effective. Despite the substantial long term individual benefits of bednets, usage remains low as poor households often do not have sufficient funds to purchase bednets. Several empirical studies trace the low uptake of ITNs to financial constraints faced by low income households (Guyatt et al., 2002; Dupas, 2009; Tarozzi et al., 2014). For example, in an experimental setting in Uganda, Hoffmann et al. (2009) estimate that the income elasticity of the willingness to pay for an ITN is high (0.25) and find that it is the lack of cash, rather than a low willingness to pay the market price, that explains the low demand for bednets.[1] In line with these findings, our results indicate that access to an agricultural extension program translated into reduction in malaria incidence through improved economic status and an increase in the number of bednets owned per capita.

Finally, this research is also linked to the literature on the intra-household allocation of health resources (see Strauss et al., 2000 and Mwabu, 2007 for recent overviews). Particularly, the distribution of bednets within households with few bednets is of considerable importance as households might have to decide between protecting those that are economically important (working-age adults) and those that biologically require more protection due to naturally lower immunity (children and pregnant women). Previous evidence from Uganda suggests that adults may receive priority over children in households with few bednets (Lam et al., 2014 and Hoffmann, 2009). This paper sheds further light on this as our results indicate that exposure to the agricultural extension program (and the resulting easing of the income constraint) leads to greater allocation of bednets to children.

The rest of the paper is organized as follows. Section 2 provides a background on malaria in Uganda and BRAC's agricultural extension program. Section 3 describes the data and outlines the estimation strategy. The main regression results on malaria are provided in Section 4. Section 5 explores the underlying mechanisms and Section 6 concludes.

[1] Similarly, Cohen and Dupas (2010) find the demand for bednets to be highly price elastic. Overall, liquidity is found to be an important factor constraining household investment in preventive health products (Devoto et al. 2012 and Meredith et al. 2013). See Dupas (2011) for a review of the literature.

2 Background

2.1 Malaria in Uganda

Plasmodium falciparum, the most deadly of the five human malaria parasites, is endemic in Uganda. Malaria spreads to people through the bites of infected female mosquitoes with the most common malaria transmitting vectors in Uganda being *Anopheles Gambiae*. Malaria is endemic in Uganda with 90% of the population experiencing high transmission rates (WHO, 2013). The endemicity of malaria is quite stable - there are very few areas of unstable transmission and epidemics are uncommon. There is some amount of cyclicity as malaria incidence peaks during the two rainy seasons (March to May and September to December). In Uganda, Hoffmann et al. (2009) estimate the economic costs of a malaria episode - medical cost and the value of labor income lost - to be $17.85 (or 7.2% of the average annual per capita non-health consumption expenditure). Further, the burden of malaria is disproportionately borne by poor households, largely due to the fact that they are unable to invest in malaria prevention methods such as bednets (UBOS and ICF, 2012; Uganda Ministry of Health, 2008).

The strategies to combat malaria are coordinated by the Uganda National Malaria Control Program (NMCP) and largely center around increasing the availability and usage of ITNs through a mix of commercial sale (full and subsidized prices) and free distribution to vulnerable groups (such as pregnant women through antenatal clinics). According to the Uganda Malaria Indicator Survey in 2009, the most common way of obtaining a bednet was through the open market, shops and pharmacies (UBOS and ICF Macro, 2010). While households' access to bednets has increased rapidly over the last decade, the proportion of population sleeping under a bednet is still low. The Uganda DHS, 2011 estimated that 74% of households reported owning at least one bednet but only 45% of the population had slept under a bednet the night preceding the survey.

Another strategy for vector control is to spray insecticide on the interior walls of a dwelling.

According to the Uganda DHS in 2011, 7.2% of the households reported having had their houses sprayed in 2010-2011 (UBOS and ICF, 2012). While the overall use of indoor residual spraying (IRS) is low due to cost considerations, the government has from time to time funded regional mass spraying. An early experimentation with mass IRS took place in the southwestern district of Kigezi in 1959-61, but these efforts were not scaled up (Uganda Ministry of Health, 2008). More recently, a similar IRS program has been supported by the President's Malaria Initiative (PMI) and the Government of Uganda in 10 districts in the Northern Region of Uganda from October 2009 onwards (PMI, 2013). The survey data used in this study do not overlap with any of these districts.[2]

2.2 BRAC's Agricultural Extension Program

Agricultural extension seeks to improve agricultural productivity by promoting the adoption of modern agricultural technologies via training and demonstrations. Given the potential to improve yields, decrease production cost, increase incomes and reduce poverty, agricultural extension programs have become a popular form of agricultural intervention in developing countries (Godtland et al., 2004; Kassie et al., 2010; Dercon et al., 2009; World Bank, 2008).

BRAC's agricultural extension program in Uganda was launched in 2008 and operated through 60 branches in 41 districts. The program aims to increase the productivity of small, low-income women farmers by encouraging the adoption of modern cultivation techniques. This was done through two complementary arms - one provided agricultural training and the other improved access to inputs. In the first component, "model farmers" were selected, trained in modern cultivation techniques and then required to pass on that training to other peer farmers in the village. In the second component, community agriculture promoters (CAP) were selected from the same villages and provided subsidized HYV seeds to

[2]The 10 districts covered are Kitgum, Agago, Lamwo, Pader, Amuru, Nwoya, Gulu, Oyam, Kole, and Apac. Household coverage is reported to be about 90% in these districts (PMI, 2013).

sell in their villages. There was no cap on the selling price and the objective was to increase the availability of HYV seeds in the village and at the same time help improve the entrepreneurial skills of the CAP. Between 2008 and June 2011, the program had engaged 1200 “model farmers” and reached almost 64,000 general farmers (for further details see Pan et al., 2015).

The agricultural extension program was limited to villages lying within a radius of 6 km from each BRAC branch office. In a companion paper, Pan et al. (2015) exploiting the spatial regression design, find that BRAC’s agricultural extension program was effective in increasing the adoption of modern cultivation techniques and inputs that require minimal upfront investment such as inter-cropping, crop rotation and the use of manure and irrigation. This further translated into significant increase in the value of output, household savings and per capita food consumption by 20.9%, 36.4% and 17.1%, respectively.

Finally, note that BRAC concurrently operated a primary health care program in which it trained local health promoters to provide basic curative services (especially to children under age 5) and pre-natal and post-natal care to pregnant women (see Björkman-Nykvist et al., 2014 for an evaluation). Importantly, this does not invalidate our estimation strategy (discussed below) as there was no institutionally mandated discontinuity in the implementation of the health care program. Further, formal checks in the next section show that there was no discontinuity in the actual implementation of the program at the cutoff of 6 km.

3 Data and Estimation Strategy

3.1 Data

The data used in this paper come from BRAC’s agriculture survey conducted in 2011, 3 years after the launch of the extension program. The household survey collected information on all the usual members of the household including whether the member had suffered from malaria in the preceding six months.[3] Other characteristics used in the analysis are the age and literacy of the household head and a dummy variable indicating whether any member of the household is a member of a village level (or higher) committee. Coverage under BRAC's health program is captured by a dummy variable that takes the value of 1 if at least one household in the village reports having received the services of a BRAC health promoter. Finally, we also have the GPS coordinates of households which allows us to calculate the distance of the household from the nearest BRAC branch.

The survey used a two-stage cluster sampling process. First, in the counties that received the program, 17 villages were picked from the complete list of villages. Next, in each of the selected villages, 25 households were randomly chosen for the survey. Figure A1 in the Appendix depicts the survey areas. For the purpose of this analysis we restrict our sample to villages lying within 10 km of a BRAC branch. This gives us a sample of 7207 households residing in 417 villages. Table 1 shows the summary statistics for the sample. The household head is on average 43.7 years old and 73.2% are literate. At the household level we measure malaria intensity by the proportion of household members who reported experiencing malaria in the six months preceding the survey. While the average malaria intensity is 28.7%, there is considerable heterogeneity across age groups with the incidence of malaria being highest for children aged 5 or below (50%). While malaria incidence is fairly similar across genders, 40% of pregnant women reported experiencing malaria in the six months preceding the survey.

[3]Admittedly, self-reported incidence of malaria suffers from measurement error. Self-reported malaria incidence may be both under-reported or over-reported. There is however, no reason to believe that misreporting varies systematically with treatment status. Self-reported incidence of malaria is also used in other studies such as Tarozzi et al. (2014), Fink and Masiye (2015), and Hoffmann (2009).

3.2 Estimation Strategy

The nature of the implementation of BRAC's agricultural extension program provides us an opportunity to assess its effect on the incidence of malaria using a regression discontinuity (RD) design. As per BRAC's rules, coverage under the program was limited to villages within the radius of 6 km of each BRAC branch office, making access to the agricultural extension program a discontinuous function of a continuous variable (distance to the nearest BRAC branch office). For every village, we computed each household's distance from the nearest BRAC branch using GPS coordinates and then used the median household's distance as a proxy for the distance of the village from the nearest BRAC branch. The running variable, z_j, is then defined as the distance of the village in kilometers from the cutoff point of 6 km:

$$z_j = d_j - 6 \tag{1}$$

where d_j is the distance of the village j from the BRAC branch. A village should have received the extension program if $z_j \leq 0$. As we restrict the data to villages lying within 10 km of each BRAC branch for the analysis, the running variable lies in the range [-6, 4]. Our RD model can be written as:

$$Y_{ij} = \alpha(T_{ij}) + f\left(z_j\right) + \epsilon_{ij} \tag{2}$$

where, Y is the outcome of interest for household i in village j. As discussed above, the running variable z_j is the distance of the village from the cutoff point. T_{ij} is a dummy variable that equals one if the household resides in a village below the cutoff point ($z_j \leq 0$) and zero otherwise. We also include a flexible control function of the running variable $f\left(z_j\right)$, that is allowed to differ on either side of the cutoff. The coefficient of interest, α captures the effect of being eligible for the agriculture extension program on the outcome - the "intent-to-treat" (ITT) effect. The analysis includes any spillovers within the village.

Correctly modelling the control function is one of the main issues in RD design. Our primary approach is the non-parametric one suggested by Hahn, Todd and Van der Klaauw (2001) and Porter (2003). We use local linear regressions to estimate the left and right limits of the discontinuity at the cutoff of 6 km, and the difference between the two limits indicates the effect of being eligible for the agricultural extension program on the outcome. The choice of the bandwidth can also play an important role in non-parametric estimations. The method suggested by Imbens and Kalyanaraman (2012) gives us an optimal bandwidth of 2.01 km for the primary outcome of interest (malaria intensity), whereas the alternative method suggested by Calonico, Cattaneo and Titiunik (2014) gives a similar optimal bandwidth of 1.99 km. Further, the optimal bandwidth may vary with the outcome variable and the sample size. As this may lead to unnecessary confusion, we fix our bandwidth to 2 km and then check the sensitivity of our results for the alternative bandwidths of 1.5 km and 3 km. We use a triangular kernel in order to give higher weights to points nearer to the threshold and compute standard errors using the delta method (Imbens and Lemieux, 2008; Lee and Lemieux, 2010).

While our primary estimates are based on non-parametric estimations, we also check the sensitivity of our results by modelling the control function as global second-order polynomials.[4] More specifically, we run the following reduced form regressions that allow quadratic trends to differ on either side of the threshold:

$$Y_{ij} = \beta + \alpha T_{ij} + \lambda_1 z_j + \lambda_2 z_j^2 + \lambda_3 T_{ij} z_j + \lambda_4 T_{ij} z_j^2 + \epsilon_{ij} \tag{3}$$

[4]Both the bin regressions method and the Akaike information criteria suggested by Lee and Lemieux (2010) indicate that the optimal order of the polynomial is two. Recent research also recommends limiting RD analysis to quadratic polynomials (Gelman and Imbens, 2014).

where, once again α captures the effect of eligibility for the program. We do not consider the local average treatment effects of the program as we have limited information on actual program participation. While the program was launched in 2008, from our survey we can only identify if a household received BRAC's extension services in the six months preceding the survey in 2011 - and not the whole program period. The program was implemented more intensively at the start and therefore, program activities in the six months proceeding the survey would only provide a noisy (and an underestimated) measure of actual program participation.

Before proceeding to the analysis, we assess the validity of the RD design in the following ways. First, we check for manipulation of the running variable at the point of discontinuity. Figure 1 shows the number of households in each 0.6 km bin plotted against the distance of the village to the cutoff. If the households selectively moved in order to be eligible for the extension services program then it would lead to bunching just below the threshold. Figure 1 indicates the absence of such manipulation. Further, using the McCrary (2008) density test we are unable to reject the null hypothesis of no discontinuity in the density of households at the cutoff.

Second, to assess whether households on either side of the program discontinuity are similar, we check if other covariates such as the age and literacy of the household head, the presence of a committee member in the household and the coverage under BRAC's health program vary smoothly around the cutoff. In Figure 2 we plot the mean of these covariates in each 0.6 km bin against the distance to the cutoff. Also plotted is the local polynomial fit on each side of the discontinuity separately. A visual inspection does not indicate any substantial discontinuity at the cutoff point. A standard way to formally test for smoothness at the cutoff is to perform 'placebo' tests by estimating the reduced form using the covariates as the outcome variables. As the results presented in Table A1 in the Appendix show, we did not observe any discontinuity in these covariates. Throughout the paper we also check if the inclusion of these covariates changes the estimated effect. These results are presented along with the primary results in the following sections.

We are particularly interested in the effects of the agricultural intervention on the incidence of malaria for young children and pregnant women, the most vulnerable group. But it is possible that access to the agricultural extension program could have lead to an endogenous change in the fertility decisions of households. However, we do not think this is a concern as we do not find a discontinuity in either the probability that a household has had a child since the start of the intervention (i.e., household has a child aged 3 or below) or the probability that at least one member of the household is pregnant. Another assumption for identification is the absence of selective attrition due to death. In our data we find that less than 3% of households reported a death in the six months preceding the survey. Moreover, there is no discontinuity at the cutoff in the proportion of households reporting a death and all the results that follow continue to hold if we exclude households that reported a death.[5]

4 Results

We begin with providing evidence of the discontinuity in actual participation in BRAC's agricultural extension program. We then go on to present the primary results on the incidence of malaria at the household level before exploring heterogeneity in the treatment effects by different age groups and gender.

4.1 Discontinuity in Actual Program Participation

First we address the question whether the probability of coverage under BRAC's agricultural extension program is indeed discontinuous at the 6 km cutoff. For this purpose we define a program activity indicator takes the value of 1 if at least one household in the village reports

[5] These results are available from the authors.

receiving BRAC's agricultural extension program (either training from a model farmer or purchased seeds from a CAP), and 0 otherwise. Program activity is defined at the village level for two reasons: (i) "model farmers" and "CAP" provided extension services to peer farmers residing in their villages; and (ii), as discussed earlier, from our survey we can only identify if a household received BRAC's extension services in the six months preceding the survey, i.e, we do not know if a household was *ever* treated.

The discontinuity in program activities in the six months preceding the survey is graphically shown in Figure 3 where we plot the proportion of households that receive treatment in each 0.6 km bin against the distance of the village from the cutoff. The figure indicates a clear discontinuity in the coverage of the program - a jump in probability of approximately 40 percentage points at the threshold - indicating the appropriateness of the RD design.[6]

4.2 Effect on Malaria

We begin with a discussion of the results on the intensity of malaria at the household level. Figure 4 illustrates the impact of residing within the radius of 6 km from a BRAC branch on the intensity of malaria. We measure the intensity of malaria at the household level as the proportion of members who reported being infected by malaria in the previous six months. This is depicted on the y-axis, while the x-axis measures the distance of the village from the cutoff. The figure shows a clear jump at the cutoff, indicating that households residing in villages just below the cutoff distance (eligible for the extension program) have a lower proportion of members infected by malaria in the last six months.[7]

Table 2 presents results from the formal evaluation of the agricultural extension program on malaria around the cutoff. Column 1 reports the results from estimating the reduced form relationship between being eligible for the program and the incidence of malaria without

[6] Formal tests for discontinuity in the availability of the program using local linear regressions are provided in Table A2 in the Appendix.

[7] Alternatively, one could measure the incidence of malaria at the household level with a dummy variable that takes the value of 1 if at least one member of the household reports being infected by malaria and 0 otherwise. Our primary results are robust to this measure as well. Results are available from the authors.

controlling for any other covariates. The coefficient in column 1 indicates that, under the preferred bandwidth of 2 km, in households in villages just below the cutoff distance the proportion of members infected by malaria is 8.8 percentage points lower than that for households just above the cutoff.

We perform a variety of tests to check the robustness of these results. First, we check if the baseline results are sensitive to the inclusion of other controls. In addition to the covariates discussed in Section 3.1 (the age and literacy of the household head, the presence of a committee member in the household and coverage under BRAC's health program), we also include the household distance to BRAC branch office (as a proxy for market access) and find that this does not alter the magnitude or significance of the ITT estimates. This check is presented in column 2 of Table 2. Second, we show that the result is robust to using alternative bandwidths of 1.5 km and 3 km (columns 3-6 of Table 2). In a finer check of the sensitivity of our result to the choice of bandwidth, we estimate the ITT effects for bandwidths at every increment of 0.2 km from 1 km to 4 km. In Figure 5 we present the estimated effect of the extension services program on malaria incidence and the 95 percent confidence intervals for these bandwidths. As one would expect, the precision of the estimate increases with bandwidth. Overall, the figure clearly indicates that our primary finding is not sensitive to the choice of bandwidth.

As stated earlier in Section 3.2, parametric regressions may be viewed as a further robustness check to the non-parametric results presented here. We estimate the reduced form using a quadratic polynomial specification where the coefficients of the polynomials are allowed to differ on either side of the cutoff (equation 3 above) and the error terms are clustered at the village level. The results are presented in column 1 of Table A3 in the Appendix and are similar to those obtained for the non-parametric method.

4.3 Heterogeneity

We now undertake an individual level analysis to investigate the heterogeneity in the effects across different age groups. We particularly care about the effects on children and working age adults because of the implications for current and future labor productivity. A substantial amount of literature finds that exposure to health shocks during pregnancy and early life can adversely affect long-term health and economic wellbeing (Almond and Currie, 2011). In the case of malaria, exposure to anemia - the typical manifestation - when child is in-utero and early-life, reduces the availability of oxygen and nutrients, thereby hampering the development of organs and cognitive capacity. Further, childhood morbidity due to malaria can, in turn increase vulnerability to other diseases. Barreca (2010) estimates that a standard deviation increase in exposure to *in utero* and postnatal malaria reduced educational attainment by 0.23 years. Similarly, a number of studies use exogenous variation in the introduction of malaria eradication programs to identify adverse effects of early life exposure to malaria on future educational attainment and earning capacity (Cutler et al., 2010; Bleakley, 2010; Lucas, 2010). In particular, Bleakley (2010) estimates that malaria incidence during childhood reduces future income by around 50%. The implications of childhood exposure to malaria are graver still, if one takes into account that these effects extend into old age, as recent literature finds that such individuals are more susceptible to cardiovascular diseases and are less likely to work when old (Hong, 2013).

We first focus on children aged 5 or less, who are considered to be the most vulnerable group in terms of exposure to the disease (older cohorts acquire immunity from repeated exposure). As the summary statistics reported in Table 1 show, we find that about 50% of children aged 5 or below are reported to have experienced malaria in the previous six months, which is higher than the infection rates for other age groups. The other age groups we consider are children aged 6-19 and the working-age adults in the age group of 20-60.

The first row in Panel A of Table 3 reports the effects on children aged 5 or less. We find that children residing in villages eligible for the agricultural extension program are 11.2 percentage points less likely to report having experienced malaria in the preceding six months (column 1, Table 3). The other rows of Panel A of Table 3 show the effects on other age groups. Reductions, although smaller, are also found for individuals in the age groups of 6-19 and 20-60.

On analyzing the data for males and females separately, we find significant reductions in malaria for both groups. The magnitude is similar, indicating that there are no differential effects by gender. These results are presented in Panel B of Table 3. Finally, we also examine the impact of the agricultural extension program on the malaria rates for pregnant women. While the sample size is smaller, the results presented in Panel C of Table 3 show large, significant reductions in the incidence of malaria for pregnant women. These results are robust to the inclusion of controls (columns 3-4 in Table 3); varying the bandwidth (Table A4 in the Appendix); and parametric estimation (columns 2-7 of Table A3 in the Appendix). In light of the decline in mortality and morbidity associated with reduction *in utero* and postnatal exposure to malaria discussed earlier, our results imply that the agricultural extension services program could translate into significant benefits in terms of saving lives and boosting health and incomes in the long-run.

5 Mechanisms

5.1 Income

As discussed in Section 1, a number of papers have pointed to the possibility that improvements in the income generating capacity of agriculture can reduce malaria. Assuming household income to be the sum of the net revenue from agricultural and livestock production, household enterprises and wage employment and using the same RD design, we find that eligibility for the agricultural extension program increased income by 29.5% (columns

1-2 of Table 4). Improved economic status of the household could have reduced the incidence of malaria in two important ways - (i) by increasing the capacity to buy bednets and; (ii) by improving nutritional status and immunity. We explore these channels in turn now.

First, the incidence of malaria could decrease if the increased income resulting from the intervention was invested in malaria prevention technologies such as bednets. Previous surveys suggest that household income plays a role in constraining access to bednets. As discussed earlier in Section 2.1, while the NMCP does support the distribution of some free and subsidized bednets, the most common way of obtaining a bednet is through the open market. The negative association between income and bednet ownership is borne out in several surveys. For example, the Uganda DHS, 2011 finds that while 67.2% of households in the lowest wealth quintile owned at least one bednet, 84.2% did so in the highest wealth quintile (UBOS and ICF, 2012). Our survey collected information on the ownership of bednets at the household level and whether each usual member of the household had slept under a bednet the night previous to the survey.[8] Note that while we have information regarding ownership at the household level, we only have information on usage at the individual level. Using this information and the same estimation strategy described in Section 3.1, we investigate the plausibility of this channel.

The ITT estimates are shown in columns 3-4 of Table 4 for the preferred bandwidth of 2 km. At the household level we find that bednets owned per capita are higher by 0.08 in households residing in villages eligible for the extension program. This strongly indicates that low income is a barrier to investment in preventive health technologies.[9]

Turning to the use of bednets at individual level, we find that children and adolescents (age groups 0-5 and 6-19) in villages eligible for the extension program are more likely to sleep

[8]Bednets can be broadly classified into three types: untreated bednet, insecticide-treated bednets (ITNs) and Long-lasting insecticidal bednets (LLINs). Our data do not distinguish the type of bednet used.

[9]Congruently, this result also indicates that with an increase in the opportunity cost of falling sick (due to the income effect of the agricultural intervention), households are more willing to buy bednets in order to avoid being sick.

under bednets by 14.4 and 9.7 percentage points, respectively (Panel A of Table 5). This is in line with the sharp reduction in the incidence of malaria found for these age groups in Section 4.3. The positive effect on the use of bednets is smaller and not statistically significant for adults in the age group of 20-60. Further, the increase in the use of bednets is not gender specific as shown in Panel B of Table 5. Both males and females experience a similar increase in the use of bednets (7 and 5.8 percentage points, respectively). Finally, we do not find any significant effects on the use of bednets by pregnant women (Panel C). Columns 3-4 of Table 5 show that these results are robust to the inclusion of controls discussed in Section 3.1.

These results are also important as they underscore the intra-household allocation of health resources when households are faced with financial constraints. Previous evidence from Uganda suggests that in households with limited income, children - the more biologically vulnerable group - may not receive priority in the allocation of bednets (Lam et al., 2014 and Hoffmann, 2009). Our results are consistent with this finding as they indicate that an easing of the income constraint leads to greater usage of bednets, and a corresponding decline in malaria, among children.

Second, improved nutritional status of household members could reduce the incidence of malaria through a reduction of infections and faster recovery. Studies such as Caulfield et al. (2004) find that malnutrition is associated with higher morbidity and mortality rates from malaria. The likely pathways are deficiencies in micro-nutrients such as zinc and vitamin A that reduce the ability of the immune system (Shankar, 2000). While we do not have information on nutritional intake, Pan et al. (2015) find that coverage under the program not only increased per capita consumption but also reduced scarcity of food especially in the pre-harvest periods.

While an increase in the use of bednets could explain the decline in malaria incidence for those under the age of 20, it does not explain the decline noted for pregnant women. Our hypothesis is that the decreased malaria rate for pregnant women could be via other channels, such as increased food security documented in Pan et al. (2015) or consumption of antimalarial drugs such as sulfadoxine-pyrimethamine (SP/Fansider). We do not have individual level data on food or anti-malarial drugs required to further examine this channel.[10] It is also possible that pregnant women in villages below the threshold benefited from positive intra-village spillover effects from the use of bednets (Hawley et al., 2003).

Finally, it is possible that an increase in household income resulted in the use of other preventive technologies such as indoor residual spraying (IRS). While we are unable to observe the use of IRS, as discussed in Section 2.1, only around 7% of the households in the Uganda DHS reported using IRS in 2011. Further, bednets continue to be the dominant technology promoted by the Government of Uganda, NGOs and other international organizations. Similarly, we are also unable to observe modifications made to the dwelling - closing openings in ceilings, doors, windows and eaves with screens or other methods - in order to reduce the indoor density of mosquitoes.

5.2 Other possible channels

Beside income, we explored three additional channels that could potentially explain the noted decline in malaria. First, it is possible that the use of agricultural inputs such as irrigation, particularly in the case of rice production, may be conducive for malaria vectors (Ghebreyesus et al., 1999).[11] We looked for changes in patterns of irrigation in the area under study. Majority of cultivation in Uganda is rain-fed, with only 2.51% of farmers reporting using irrigation in our sample. Nonetheless, an increase in irrigation can result

[10] The NMCP supports the use of intermittent preventive treatment during pregnancy (IPTp) in order to reduce the incidence of malaria. This consists of taking at least two doses of sulfadoxine-pyrimethamine (SP/Fansidar) during pregnancy. These are available through antenatal clinics (ANC) or the private sector. According to the Uganda DHS in 2011, 27% of women reported using IPTp during their last pregnancy (UBOS and ICF, 2012). We do not find a discontinuity in the likelihood of visiting an ANC during pregnancy for women pregnant during the survey or those who gave birth in the year preceding the survey.

[11] However, recent medical literature from Africa suggests that even though irrigation increases the density of malaria vectors, this may not necessarily translate into a higher incidence of malaria - resulting in what is termed as the "paddies paradox." A possible explanation is that the mosquito *An. arabiensis* Patton, with lesser malaria carrying capacity, multiplies faster in rice fields and may displace *An. Gambiae* Giles, the most effective malaria vector (Ijumba and Lindsay, 2001).

in the occurrence of small stagnant water bodies and an increase in the moisture content of soil. Observations from the field do not indicate construction of new dams or other major irrigation systems. Moreover, Pan et al. (2015) find that the agricultural extension program *increased* the probability that a household used irrigation, leading us to believe that this channel is not driving our results.[12]

Second, investment in malaria prevention may be low if there is lack of information regarding its transmission and effects. Recent studies have noted the potential of using farmer field schools as a vehicle to provide information on malaria and influence behavior regarding investments in preventive measures and seeking treatment (Weilgosz et al., 2012). The agricultural extension program studied here did not include any such component. Still, it is possible that by facilitating more social interaction, the agricultural extension program resulted in the exchange of health related information as well. The BRAC questionnaire asked respondents if they were related to or friends with other surveyed respondents in the village, providing partial information on the social network of the household. On restricting our sample to households with at least a friend or a relative covered in the survey, we find that the likelihood of turning to their social network for health related information does not change significantly at the cutoff.[13] Note that this only partially rules out the information channel as playing a role in the reduction of malaria. For example, it is possible that the respondents received information from parts of their social network that were not surveyed or from other external sources.

Finally, it is worth noting that the reduction in malaria is associated with an agricultural extension program that specifically targeted female farmers. Some of the existing literature finds that women are more likely to invest in health than men (see Strauss et al., 2000). Then the increase in the household ownership of bednets may not only be due to an increase in income but also due to a resulting increase in the bargaining power of women. We use the proportion of household consumption expenditure spent on tobacco and alcohol as a

[12]Unfortunately, we do not observe the method of irrigation in the data.
[13]Results are available from the authors.

proxy for the bargaining power of women (Hoddinott and Haddad, 1995) to check if the program increased the bargaining power of women. Using the same RD design we do not find a reduction in the share of household expenditure on these items at the cutoff point (results available from the authors). Nonetheless, while this result indicates that an increase in the bargaining power of women may not be primary force driving the reduction in malaria, we do not rule out the possibility that it might have played a role in it.

6 Conclusion

Malaria is endemic in Uganda. In this paper, we find that access to an agricultural intervention program in Uganda led to substantial reductions in the incidence of malaria. The effects are largely concentrated in the most vulnerable groups - children under the age of 5 and pregnant women. As exposure to health shocks in early life can translate into considerable economic losses over time, our results imply that the agricultural extension services program could have substantial long-term benefits that are not accounted for in standard cost-benefit analyses.

The explanation most consistent with our data seems to be that the reduction in malaria is driven by an increase in incomes. Overall, we estimate that agricultural extension program increased household income by 29.5% while it reduced malaria intensity by 8.8 percentage points, thereby highlighting the role of financial constraints in limiting investments in malaria control. Moreover, the finding that an easing of the income constraint leads to greater bednet use and reduction in malaria among children indicates that the interplay between the lack of income and preferences for intra-household allocation of health resources may have severe implications for the most vulnerable household members. Further research into the preferences for intra-household allocation of health resources other than bednets, such as nutritional intake and preventive medicine consumption could inform policies that seek to promote health status of the most vulnerable members.

While the results are specific to the ecology of the area under study, they do indicate that higher incomes associated with increased agricultural productivity can perhaps improve health outcomes in other similar contexts as well. While the relationship between agriculture and malaria is complex, continued assessment of the health impacts of agricultural interventions can further our understanding. To that end, we also recommend including questions regarding health and preventive health investments in agricultural survey instruments.

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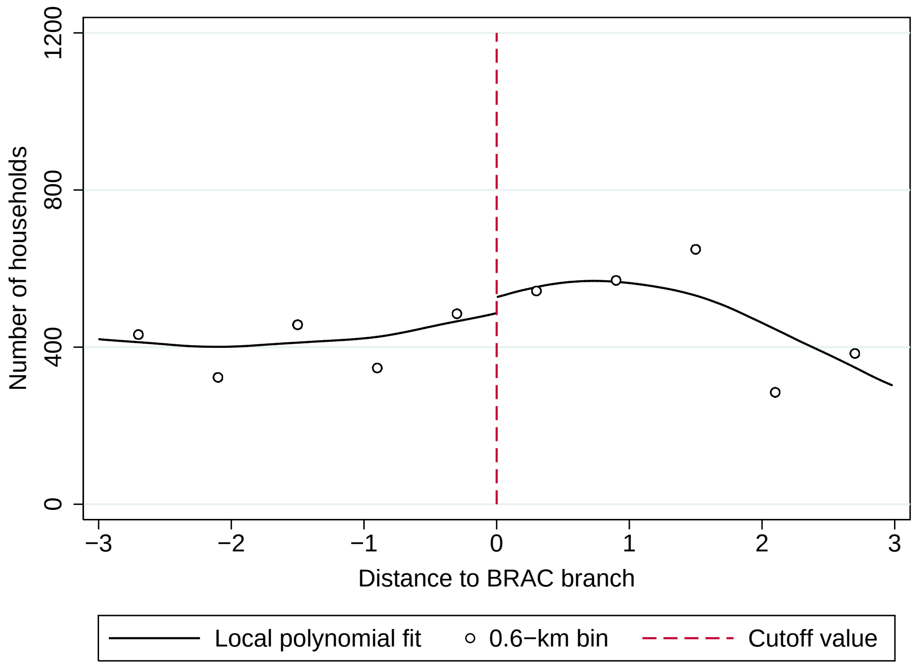
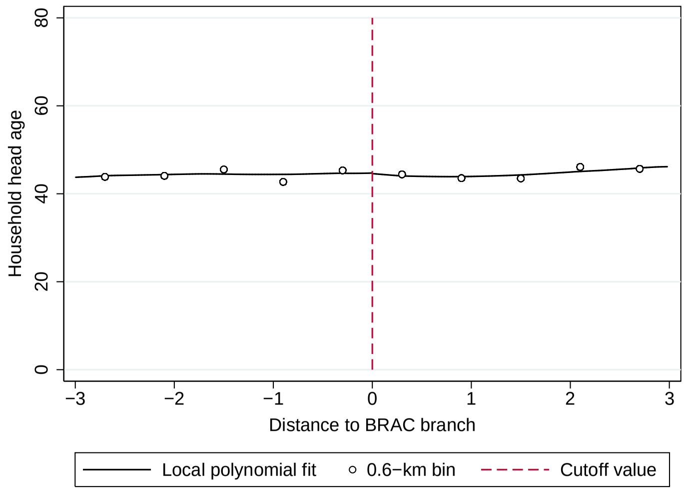
Figures and Tables

Figure 1: Household Density

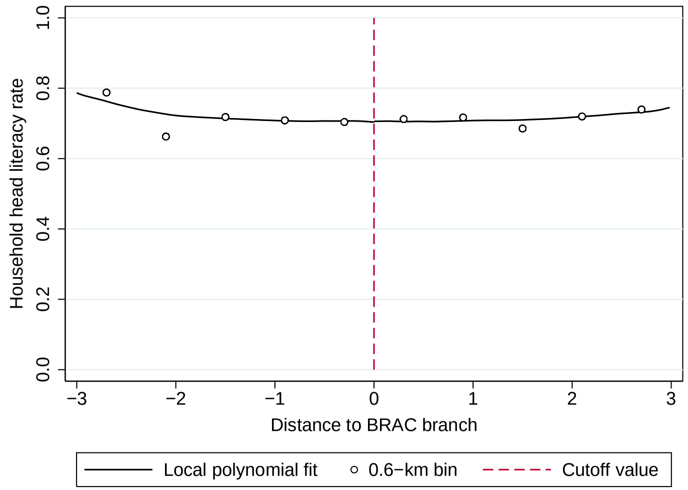


Source: Authors' illustration based on the survey data.

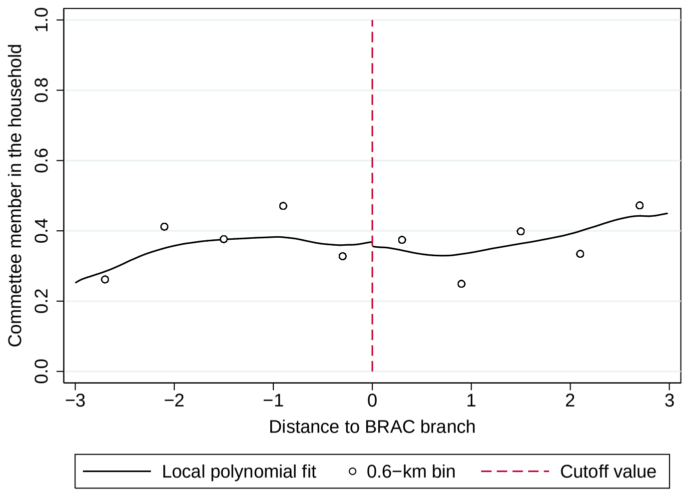
Figure 2: Discontinuity in Covariates



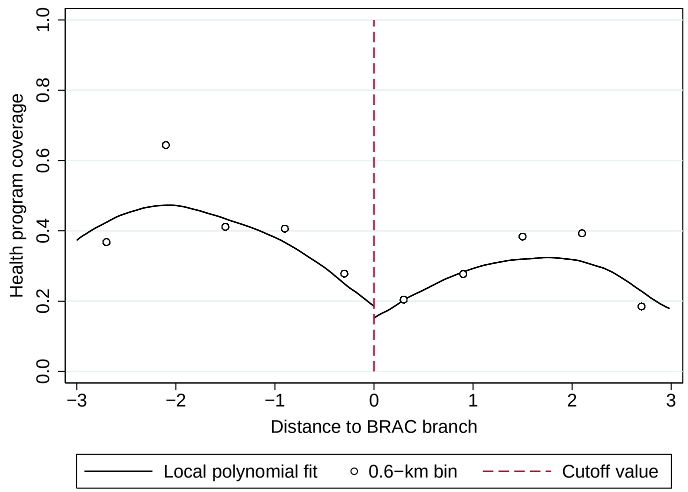
(a) Age



(b) Literacy



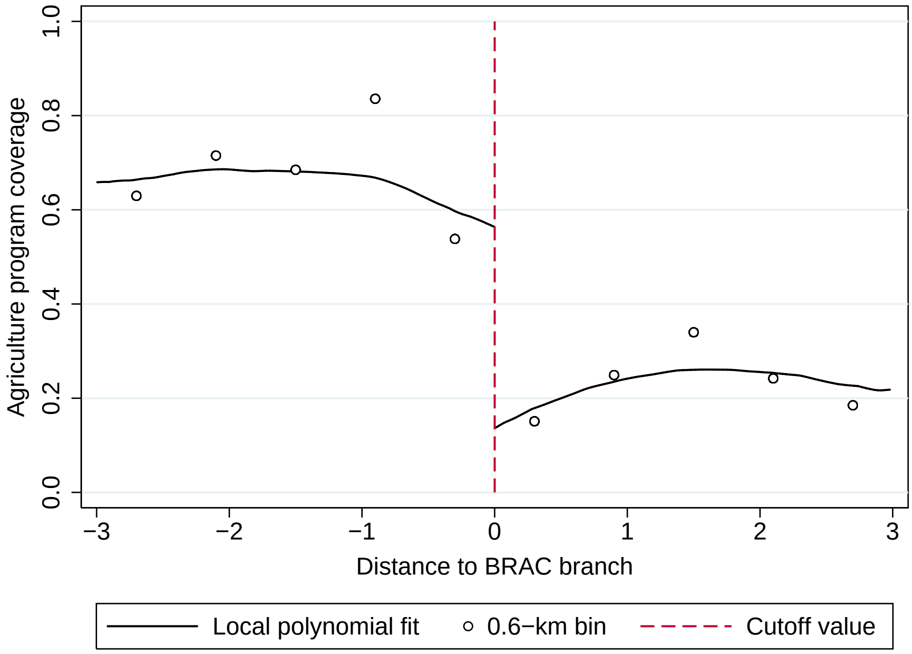
(c) Committee Member



(d) Health Program

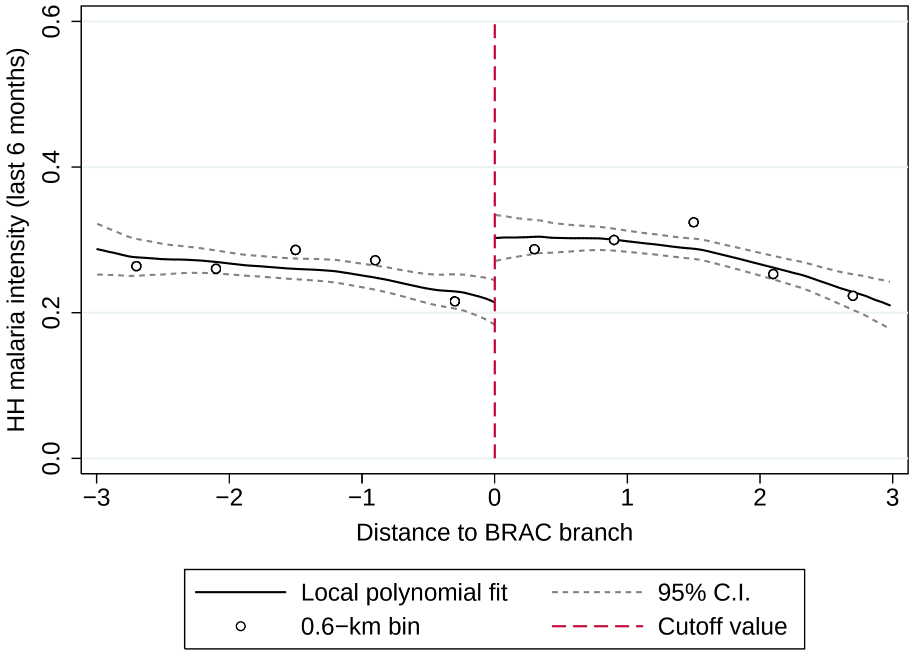
Source: Authors' illustration based on the survey data.

Figure 3: Discontinuity in Program Activities 6 Months Preceding the Survey



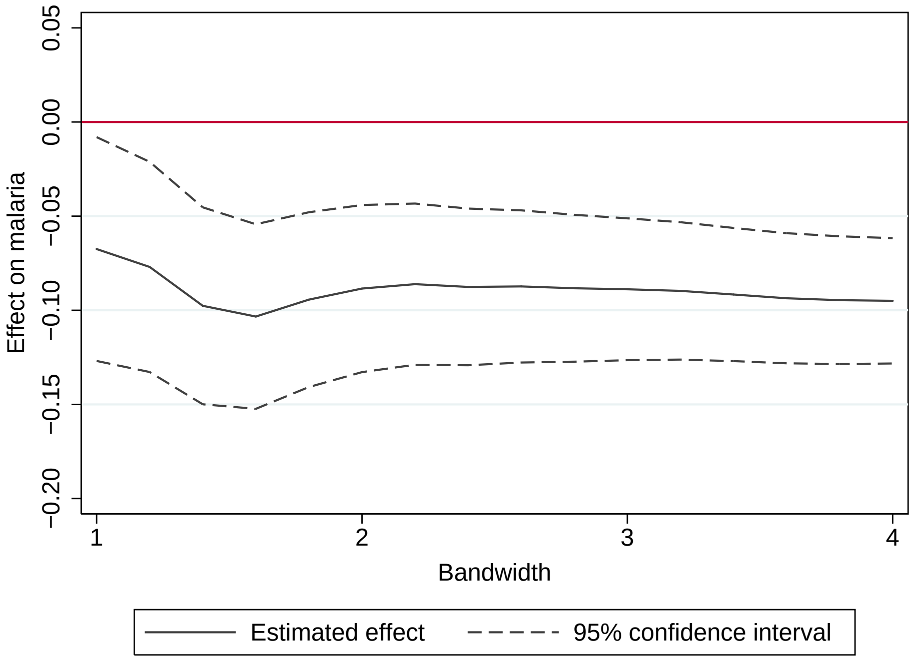
Source: Authors' illustration based on the survey data.

Figure 4: Impact of Program Eligibility on Malaria



Source: Authors' illustration based on the survey data.

Figure 5: Effects on malaria intensity, by varying bandwidths



Source: Authors' illustration based on the survey data.

Table 1: Summary Statistics

Variable	Mean	SD
Household level		
HH head age	43.7	14.1
HH head literacy	0.732	0.443
Committee Member	0.330	0.470
Health Program	0.408	0.491
Malaria intensity	0.287	0.320
Bednets owned per capita	0.400	0.462
Individual level malaria incidence		
Ages 0-5	0.503	0.500
Ages 6-19	0.354	0.478
Ages 20-60	0.295	0.456
Males	0.336	0.472
Females	0.370	0.483
Pregnant	0.399	0.490
Number of observations		
Number of villages	417	
Number of households	7207	
Number of individuals	36522	

Notes: Malaria intensity is measured by the proportion of household members who reported being infected by malaria in the previous 6 months. The sample is restricted to villages within 10 km. of a BRAC branch office. Source: Authors' estimates from survey data.

Table 2: Effect on Malaria Intensity at Household Level

	Malaria Intensity					
	Bandwidth=2		Bandwidth=1.5		Bandwidth=3	
	(1)	(2)	(3)	(4)	(5)	(6)
Eligible	-0.089***	-0.082***	-0.105***	-0.104***	-0.089***	-0.083***
	(0.023)	(0.022)	(0.026)	(0.025)	(0.019)	(0.019)
Controls	No	Yes	No	Yes	No	Yes
Observations	3241	3122	2489	2394	4476	4318

Notes: This table shows the effect of eligibility for the agricultural extension program on malaria intensity using the non-parametric method described in the text. Controls included are age and literacy of the household head, presence of a committee member in the household, coverage under BRAC's health program and household distance. Standard errors calculated using the delta method are reported in parentheses. * significant at 10%,** significant at 5%,*** significant at 1%. Source: Authors' estimates from survey data.

Table 3: Effects on Malaria: Individual level

	Without controls		With controls	
	ITT Estimate	N	ITT Estimate	N
	(1)	(2)	(3)	(4)
Panel A: Age groups				
Ages 0-5	-0.112**	2319	-0.094*	2245
	(0.049)		(0.049)	
Ages 6-19	-0.058**	7093	-0.049**	6872
	(0.024)		(0.024)	
Ages 20-60	-0.062**	6331	-0.056**	6174
	(0.024)		(0.024)	
Panel B: Gender				
Males	-0.084***	7812	-0.076***	7575
	(0.023)		(0.022)	
Females	-0.074***	8279	-0.063***	8044
	(0.023)		(0.022)	
Panel C: Pregnant				
Pregnant	-0.225**	366	-0.206*	359
	(0.106)		(0.107)	

Notes: The table reports non-parametric estimates of the impact of program eligibility using the bandwidth of 2 km. Controls included are age and literacy of the household head, presence of a committee member in the household, coverage under BRAC's health program and household distance. Standard errors calculated using the delta method are reported in parentheses. * significant at 10%,** significant at 5%,*** significant at 1%. Source: Authors' estimates from survey data.

Table 4: Effects on Household Income and Bednet Ownership

	Log Income		Bednet ownership per capita	
	(1)	(2)	(3)	(4)
Eligible	0.295**	0.258**	0.078**	0.068**
	(0.130)	(0.130)	(0.031)	(0.031)
Controls	No	Yes	No	Yes
Observations	2857	2764	3187	3088

Notes: The table reports non-parametric estimates of the impact of program eligibility using the bandwidth of 2 km. Controls included are age and literacy of the household head, presence of a committee member in the household, coverage under BRAC's health program and household distance. Standard errors calculated using the delta method are reported in parentheses. * significant at 10%,** significant at 5%,*** significant at 1%. Source: Authors' estimates from survey data.

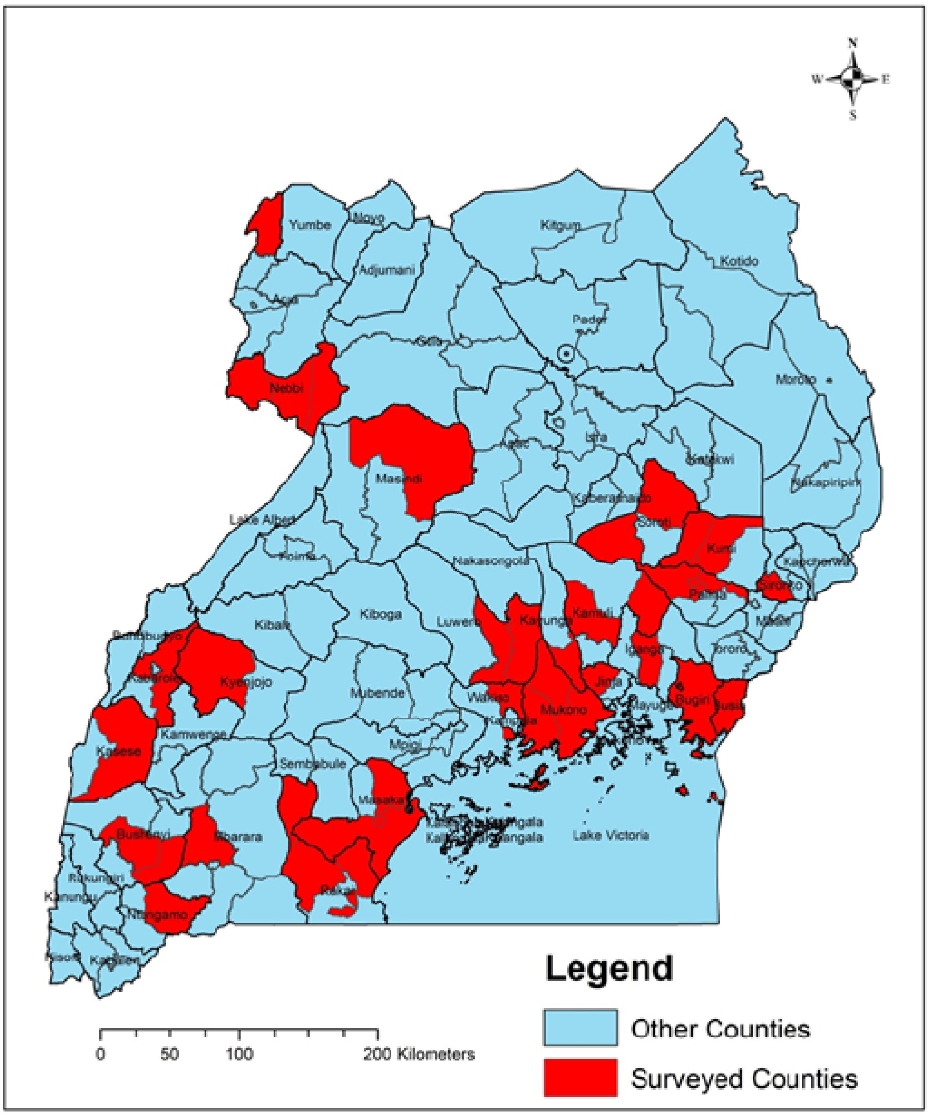
Table 5: Effects on Bednet Ownership and Usage

	Without controls		With controls	
	ITT Estimate	N	ITT Estimate	N
	(1)	(2)	(3)	(4)
Panel A: Net usage by age groups				
Ages 0-5	0.144***	2333	0.127***	2257
	(0.048)		(0.047)	
Ages 6-19	0.097***	7130	0.093***	6905
	(0.026)		(0.026)	
Ages 20-60	0.032	6368	0.017	6210
	(0.027)		(0.027)	
Panel B: Net usage by gender				
Males	0.070***	7859	0.052**	7619
	(0.025)		(0.024)	
Females	0.059**	8322	0.060**	8083
	(0.024)		(0.025)	
Panel C: Net usage by pregnant women				
Pregnant	-0.027	366	-0.054	359
	(0.106)		(0.107)	

Notes: The table reports non-parametric estimates of the impact of program eligibility using the bandwidth of 2 km. Controls included are age and literacy of the household head, presence of a committee member in the household, coverage under BRAC's health program and household distance. Standard errors calculated using the delta method are reported in parentheses. * significant at 10%,** significant at 5%,*** significant at 1%. Source: Authors' estimates from survey data.

Appendix

Figure A1: Survey Area



Source: Authors' illustration.

Table A1: Discontinuity in controls

	HH age	HH literacy	Committee Member	Health Coverage
Below threshold	0.152	-0.002	0.012	0.034
	(1.089)	(0.035)	(0.038)	(0.029)
N	3172	3164	3120	3241

Notes: The table reports non-parametric reduced form estimates using the bandwidth of 2 km. Standard errors calculated using the delta method are reported in parentheses. * significant at 10%,** significant at 5%,*** significant at 1%. Source: Authors' estimates from survey data.

Table A2: Program Activity in last 6 months

	Bandwidth=2		Bandwidth=1.5		Bandwidth=3	
	(1)	(2)	(3)	(4)	(5)	(6)
Eligible	0.430***	0.414***	0.386***	0.382***	0.439***	0.430***
	(0.033)	(0.033)	(0.040)	(0.040)	(0.026)	(0.027)
Controls	No	Yes	No	Yes	No	Yes
Observations	3241	3122	2489	2394	4476	4318

Notes: This table shows the discontiniuity in the agriculture extension program activities using the non-parametric method described in the text. Controls included are age and literacy of the household head, presence of a committee member in the household, coverage under BRAC's health program and household distance. Standard errors calculated using the delta method are reported in parentheses. * significant at 10%,** significant at 5%,*** significant at 1%. Source: Authors' estimates from survey data.

Table A3: Effect on Malaria: Parametric Estimates

	Household Level	Individual Level					
		Ages 0-5	Ages 6-19	Ages 20-60	Males	Females	Pregnant
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Panel A. Without controls							
Below threshold	-0.136**	-0.166*	-0.136*	-0.164**	-0.169**	-0.147*	-0.290**
	(0.062)	(0.099)	(0.084)	(0.080)	(0.081)	(0.082)	(0.135)
R^2	0.01	0.01	0.01	0.01	0.01	0.01	0.02
Observations	7207	5090	15794	14197	17337	18544	736
Panel B. With controls							
Below threshold	-0.146**	-0.163*	-0.141*	-0.171**	-0.174**	-0.151*	-0.291**
	(0.061)	(0.098)	(0.081)	(0.077)	(0.079)	(0.079)	(0.129)
R^2	0.02	0.01	0.01	0.01	0.01	0.01	0.04
Observations	6947	4941	15313	13838	16838	17985	726

Notes: This table shows the effect of eligibility for the agricultural extension program on malaria intensity at the household level and malaria incidence at the individual level using a second order polynomial. All regressions include the distance from the cutoff, its square and interactions with the indicator for being below the cutoff. Standard errors clustered at the village level are reported in parentheses. Controls in Panel B include the age and literacy of the household head, presence of a committee member in the household, coverage under BRAC's health program and household distance. * significant at 10%,** significant at 5%,*** significant at 1%. Source: Authors' estimates from survey data.

Table A4: Individual level Effects on Malaria: Alternative Bandwidths

	Bandwidth=1.5		Bandwidth=3	
	ITT Estimate (1)	N (2)	ITT Estimate (3)	N (4)
Panel A: Age groups				
Ages 0-5	-0.137**	1730	-0.108***	3220
	(0.057)		(0.040)	
Ages 6-19	-0.083***	5391	-0.075***	9956
	(0.028)		(0.020)	
Ages 20-60	-0.083***	4899	-0.075***	8779
	(0.028)		(0.020)	
Panel B: Gender				
Males	-0.106***	5934	-0.093***	10914
	(0.026)		(0.019)	
Females	-0.102***	6318	-0.082***	11581
	(0.026)		(0.019)	
Panel C: Pregnant				
Pregnant	-0.273**	277	-0.177**	490
	(0.120)		(0.090)	

Notes: The table reports non-parametric estimates of the impact of program eligibility using the bandwidths of 1.5 km and 3 km. Standard errors calculated using the delta method are reported in parentheses. * significant at 10%,** significant at 5%,*** significant at 1%. Source: Authors' estimates from survey data.