Tick Control Technology and Off-Farm Labor Supply in Rural Kenya

Haseeb Ahmed, Benjamin Cowan and Jonathan Yoder

Abstract: Animal husbandry and health management are time-consuming activities for livestock-dependent households in developing countries. This burden on household labor can result in missed off-farm income generating opportunities that can be pivotal for poverty alleviation. This paper provides a reduced-form test to estimate and explore the mechanisms through which a labor saving technology, acaricide spray treatment, is related to off-farm labor supply of agricultural households. Using KEMRI/CDC survey data from 2013-15 with quarterly observations on approximately 1,600 households in 10 villages in the Kisumu region of Western Kenya, this paper shows that the application of acaricide spray treatment temporarily increases the off-farm labor hours of the household. Our individual-level tests indicate that acaricide adoption frees up time for women to work and generate income outside of the household.

JEL Classifications: J22, J24, J43, Q12

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1. Introduction

Off-farm labor supply has been recognized as an important tool for poverty alleviation and income diversification in the rural areas of developing countries (Rozensweig 1988; Hoddinott, Dercon and Krishnan 2005; Reardon 1997; Lanjouw and Feder 2001). Off-farm income generation helps small agricultural households to overcome cash constraints, invest in productivity enhancing inputs like fertilizers and also in capital accumulation (Mathenge and Smale 2013; Rozensweig and Wolpin 1993). Moreover, off-farm labor participation of women can lead to increased bargaining power of women within the household, thereby improving overall household welfare (Schultz 1999; Newman and Canagarajah 2000; Dito 2001).

Subsistence households of rural Kenya spend substantial time on animal husbandry, water collection, firewood collection and other household chores. These activities pose a considerable constraint on the labor allocation of these households. Animal husbandry includes herding and grazing activities, milking, market transactions, and disease prevention and treatment. Average time spent on animal husbandry is about 13-15 hours per week for men and 18-20 hours per week for women in the Kisumu region (Oboler 1985; Kes and Swaminathan 2005; Saito 1994). Higher livestock disease through tick transmission may compel households to spend more time on animal husbandry in terms of disease prevention and treatment (Young, Groocock and Kariuki 1988). Technologies like acaricide spray treatments can potentially reduce the total amount of time spent on disease prevention due to rapid application of each treatment and lower treatment frequency in comparison to manual removal of ticks or other traditional methods. [1] This may allow households to allocate labor thus saved to off-farm income generation or other productive activities, and may increase household net income through effective livestock disease control.

Acaricide application through sprays and dips is less laborious than some of the common methods of tick control in agricultural households including spot-treatments, using razor blades or scissors, and handpicking ticks off the animals (Rajput et al. 2006; De Meneghi et al. 2016;

[1] Acaricide dips are considered to be the most efficient way of tick control when dip tanks or dip runs are available. However, they are not available or used in the region under study.

Mugisha et al. 2005). For a household with a herd size of 10 animals, acaricide spray takes about 20-25 minutes while manual removal and inspection of ticks takes about 2 - 2.5 hours (Bekure et al. 1991; Grandin 1983). Anecdotal evidence suggests that the time taken to manually remove ticks is highly variable and depends on the intensity of tick infestation and compliance of the animals. Moreover, manual removal of ticks is practiced about 2-3 times per week in a typical subsistence household located in the tropics (Lorusso et al. 2013). On the other hand, one spray treatment can remain effective for up to two weeks (De Meneghi et al. 2016). Therefore, acaricide spray treatments are both less time consuming to apply and require a lower frequency of application. This time saved due to acaricide spray adoption may lead to substitution of animal husbandry time with other production activities.

Acaricide spray is not only a labor saving technology, but it can also curtail losses by reducing infections and disease transmission, leading to improved livestock herd productivity and value and farm income (Barnett 1974; Kivaria 2006). It may also improve human health by reducing transmission of zoonoses from livestock to humans and increase nutrient intake in agricultural households (Liu and Marsh 2015; Mosites et al. 2015, Ahmed et al. 2016) The positive correlation between nutritional status (e.g. weight-for-height), caloric intake and wages is well established within the discipline of economics (Deolalikar 1988; Strauss 1986; Boles et al. 2004). Therefore, acaricide treatment can impact labor allocation by saving time, by affecting human health, livestock health, and farm productivity.

The objective of this paper is to explore and examine the relationship between acaricide spray use and off-farm labor supply of agricultural households in rural Kenya. We develop a theoretical model that elucidates the relationship between acaricide adoption and labor allocation within the household. We then estimate these relationships using the KEMRI/CDC longitudinal data from the Kisumu region of Kenya. The paper also examines the effect of acaricide use on off-farm labor supply of men and women and farm and off-farm incomes separately.

Existing literature on technology adoption and labor allocation within farm households demonstrates two opposing outcomes. Investment in farm inputs can increase the marginal product of labor, induce a higher demand for on-farm production activities, and therefore reduce off-farm labor supply of agricultural households (Rosenzweig 1980; de Janvry, Fafchamps and Sadoulet 1991; Ahituv and Kimhi 2002). However, investments in agricultural mechanization and technology adoption have been related to an increase in farmers' off-farm labor allocations and off-farm income in both low-income and higher income countries because they substitute for labor (Barnes and Sen 2003; Ahmed and Goodwin 2016; Binswanger and Braun 1991; Fernandez-Cornejo et al. 2005). Acaricide application, by reducing disease transmission and improving farm income, can potentially make livestock production and the effort exerted on this production more valuable, which may lead to increase in on-farm labor hours. On the other hand, as a labor saving technology, acaricide use can help the households substitute animal husbandry time with other farm or off-farm activities.

The literature on biotechnology adoption for disease management in livestock and labor allocation is scant. This paper contributes to the literature on off-farm labor supply in agricultural households by examining the relationship between livestock tick control practices and off-farm labor at the household as well as individual level. To our knowledge, this has not been done by any previous study. It is worth noting that the opportunities for tick prevention related technology adoption are limited. Acaricide dip tanks are non-operational in the region. Therefore, acaricide hand-spray, manual removal or self-prepared compounds of ethno-botanical extracts are the only available options.[2] The paper also examines the correlation between farm, off-farm and total income and spray-based acaricide use.

This paper finds that acaricide adoption is correlated with an increase in off-farm labor supply and income at the household level. The individual-level tests suggest this effect is concentrated on women of the household. Off-farm labor participation by women has been linked with increased bargaining power and gender equality within the household (Schultz 1999; Dito 2001). The results suggest that disease management practices can have an impact beyond animal health and farm production and can potentially lead to other desirable outcomes.

The article is organized as follows. Section II consists of a theoretical model and the hypothesis to be tested. The econometric model and data are described in Section III and IV respectively. A discussion of results is in section V, and section VI concludes the article.

2. Model of Time Allocation

Our aim is to examine how tick treatment technology can affect the labor allocation of an agricultural household. Acaricide treatments, through prevention of tick-borne diseases like East Coast Fever, which is a major livestock disease in Kenya, can mitigate economic damages and make farm work more profitable (Mahoney and Ross 1972; Gachohi et al. 2012; Di Giulio et al 2009; Marsh et al. 2016). Moreover, adoption of acaricides is a labor saving technology (Rajput et al. 2006; De Meneghi et al. 2016; Lorusso et al. 2013; Grandin 1983) that is more effective than bathing an animal with water (FAO 1993) or removing the ticks by hand (which is often practiced on subsistence farms). This saved labor can either be invested in other farm and household related chores or in off-farm income generating activities.

[2] Livestock dependent communities in Kenya have considerable ethno-veterinary experience. They have been known to prepare anti-tick compounds from different local plants (Wanzala et al. 2012).

We assume that each household behaves as a single entity (Becker 1965), is risk-neutral, and makes production decisions to maximize its income.[3] The tick burden on the farm is observable to the herd owner and is modeled through $\beta \in [0,1]$.[4] A higher β represents a higher tick burden on the farm and lowers the farm production since ticks are associated with loss of blood, milk loss, weight loss, damaged hides, infection, and disease transmission (FAO 1993; Barnett 1974). We assume that the intensity of tick infestation decreases with change in technology from hand-spotting and manual removal to acaricide spray, T, so that $\beta = \beta(T)$, and $\beta_T(T) < 0$, where subscripts represent derivatives.

The total household labor time budget, time spent on animal husbandry, and time spent on off-farm labor are represented by, t, F and H, respectively, and w represents off-farm wages. Other types of farm related activities like water and firewood gathering, and time spent on crops are suppressed and considered fixed in the model for clarity and tractability. Animal husbandry time includes time related to milking and handling of milk, disease inspection and prevention, cleaning animal sheds, and other livestock related activities within the household. $\boldsymbol{Z}$ denotes the household and farm specific factors such as land and household size and A is unearned asset

[3] Browning and Chiappori (1998), Udry (1996), Duflo and Udry (2004), Chiappori and Mazzocco (2015) point out the limitations of the unitary model when household consists of more than one member. Differences in bargaining power and risk preferences across individuals of the same household can make unitary model unrealistic. However, the paper examines the effect on total household off-farm labor assuming bargaining power within the household is ex-ante determined; therefore, a unitary model is used. Farmers are assumed to be risk-neutral for tractability. Allowing for risk-aversion does not change the qualitative results of our model.
[4] In a subsistence setting, monitoring tick infestation may be incidental and low-cost. However, if the herd size is large and cattle graze over a large area, monitoring herd tick infestation may be more costly.

income. The paper assumes that leisure is exogenously fixed.[5] The maximization problem can be written as

$$\max_{F,H} \ \pi = Q(F; \beta(T), \boldsymbol{Z}) + wH + A,$$

$$\text{subject to } t = H + F,$$

where $Q(F; \beta(T), \boldsymbol{Z})$ is an increasing function of the household's livestock husbandry labor supply F, and a decreasing function of the tick population, β, on the farm($Q_F > 0$, $Q_\beta < 0$). The second order condition $Q_{FF} < 0$ is sufficient to ensure a maximum.

The first order condition is

$$Q_F(.) - w = 0.$$

Assuming that the implicit function theorem holds, the change in farm labor due to an exogenous change in technology is

$$\frac{\partial F}{\partial T} = -\frac{Q_{F\beta}\beta_T}{Q_{FF}}.$$

Since total household labor time budget is exogenously fixed, $\frac{\partial H}{\partial T} = -\frac{\partial F}{\partial T}$. The denominator in (1) is negative ($Q_{FF} < 0$, due to diminishing returns). The sign on the numerator is ambiguous because of the unknown nature of the relationship between tick intensity and the marginal product of livestock husbandry, i.e., the sign on $Q_{F\beta}$ is ambiguous.

Case 1: $\boldsymbol{Q_{F\beta}} > 0$

$Q_{F\beta} > 0$ is the case where a higher tick burden will make time spent on animal husbandry, especially on disease prevention and treatment, more valuable. In such a case, when

[5] This is also an implication of the assumed separability between production and consumption decisions of an agricultural household. Singh et al. (1986), De Janvry et al. (1991), Pitt and Rosenzweig (1984) etc. provide the details on the separability assumption.

acaricide treatment is applied and tick burden goes down, the marginal value of animal husbandry time declines and households may substitute labor away from animal husbandry. This would imply that $\frac{\partial F}{\partial T} < 0$, and $\frac{\partial H}{\partial T} > 0$ and households substitute labor away from the farm toward off-farm income-generating activities.

Case 2: $\boldsymbol{Q_{F\beta}} < 0$

$Q_{F\beta} < 0$ is the case when a higher tick burden decreases the marginal value of labor applied to livestock and milk production, since a higher tick burden will lead to low livestock productivity. In such a case, acaricide treatments will reduce tick burden and make the marginal value of animal husbandry labor more valuable since reduced tick burden can lead to higher farm profits (Mahoney and Ross 1972; Gachohi et al. 2012; Di Giulio et al 2009). In this case, $\frac{\partial F}{\partial T} > 0$, implying that $\frac{\partial H}{\partial T} < 0$.

The two cases discussed above are illustrated in figure 1. Marginal value of off-farm time is assumed constant at w. Line 1 represents the marginal value of animal husbandry time with the traditional method of tick control (hand-spotting, manual removal, ethno-botanical compounds etc.) and point A denotes the optimal allocation between off-farm time and animal husbandry time. Due to adoption of acaricide, the intercept of marginal value of animal husbandry time will be higher because of time saving nature of the input, but the slope would depend on the cases discussed above. Line 2 represents case 1 where acaricide use leads to substitution away from the farm (Point C). Line 3 represents case 2 where acaricide use leads to higher animal husbandry time (Point B).

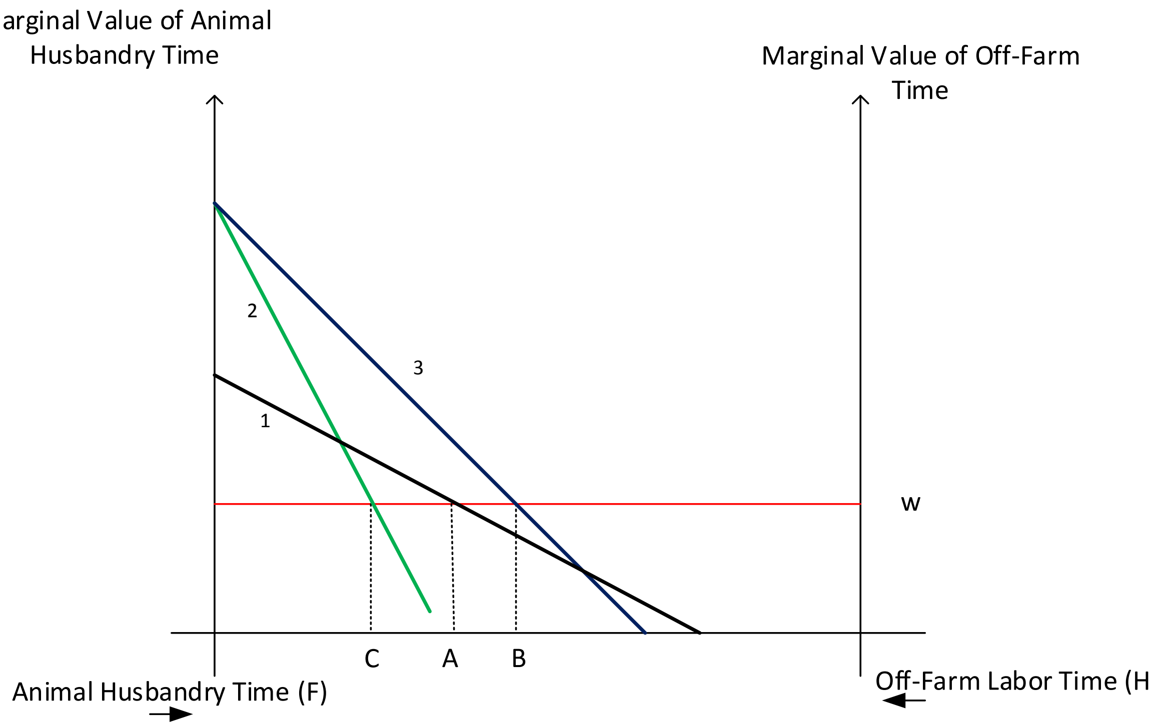

Figure 1: Effect of Acaricide Adoption on Labor Allocation

If acaricide treatment has a positive and significant effect on livestock related output, households may chose to spend more time on livestock production and pursue less off-farm labor (Point B). On the other hand, if acaricide treatments make animals healthy and animal husbandry less labor intensive then households may choose to spend more time off the farm (Point C). The following section describes the data , followed by estimation strategy and results.

3. Data

Our data are drawn from two longitudinal surveys, a Socio-Economic Survey (SES), and Population Based Animal Surveillance Survey (PBASS) conducted in the Kisumu Region, near Lake Victoria, of Kenya.[6] Both of these surveys were conducted in 10 villages of Western Kenya

[6] PBASS was launched by Paul G. Allen School for Global Animal Health in collaboration with the Kenya Medical Research Institute and U.S. Centers for Disease Control and Prevention (known as the KEMRI/CDC Research and Public Health Collaboration) and the University of Washington with a goal to reduce poverty and hunger and improve health and education.

over a period of roughly two years. The socioeconomic survey, which provides labor supply, farm incomes, livestock and non-livestock asset inventory, and household demographics is compiled from quarterly visits to about 1,600 households in 10 villages. The survey period was roughly from February 2013 to July 2015, which gives us 9 quarterly visits. PBASS consists of the biweekly reports of livestock diseases in the same 10 villages as the SES survey.

Table 1 describes the data and Table 2 provides the mean and standard deviations of household level labor supply (H in the theoretical model) as well as individual off-farm hours worked according to occupation, gender, and occupation-gender categories. The survey asks about the preferred occupation of adults within the households. The mean household off-farm labor supply is about 10 hours a week. The mean off-farm labor hours for non-farm workers (self-employed off-farm and salaried off-farm) is 16 hours greater than the mean off-farm labor hours of farm workers.

About 28% of the respondents in the survey indicate their occupation as non-farm workers while about 72% are farmers. Among the non-farm workers, 58% are males while 42% are females. The average hours worked off the farm by a female non-farmer is slightly higher than a male non-farmer. Men primarily are associated with fishing, wage labor and selling livestock and cash crops. Women, on the other hand, are responsible for their home gardens and they sell the left-over produce after home consumption (Chenyambuga et al. 2010; Okeyo 1979). Market traders are also primarily women in the Luo community of this region of Kenya. They collect the left-over produce from several homes and go to the market and sell these commodities (Suda 1990; Oboler 1985).

Among the sample that identifies themselves primarily as farmers, 57% are women while 43% are men. Traditionally, women are the caretakers of the household owned plots, livestock in *boma* and household chores in the Luo community of Kisumu region; however, these trends have been changing over time especially in the urban and peri-urban areas of Kenya (Suda 1990).

Around 40% of the households in the sample use *acaricide treatment* in a particular time period to treat their livestock for ticks. The histogram in Figure 2 shows the percentage of households and the number of times they adopt *acaricide treatment* over the sample period. 31% of the households that own livestock never use *acaricide treatment* while no households use it for all 9 quarters. However, households that do not report *acaricide treatment* adoption still report administering tick treatments throughout the sample period. They may use traditional methods such as hand-spotting, manual removal of ticks and ethno-medicine as alternatives to acaricide spray. Table 3 reports the frequency of tick treatments for the two methods, i.e., traditional method and acaricide spray method. The monthly mean of tick treatment frequency, when acaricide spray is used, is lower than the monthly mean of frequency with traditional methods. Also, the mean with traditional methods is very likely under-reported since the frequency is censored from above at 5 times a month and 4,320 observations cluster at the value 5. Since acaricide spray takes less time as compared to traditional techniques and also saves time through decreased frequency of treatment, its use may lead to a change in labor allocation within a household.

There is no government program in the region that subsidizes or helps farmers in administering livestock acaricide and vaccination treatments and veterinary drugs and services are considered expensive (Chenyambuga et al. 2010). The average cost of administering these treatments in the sample is 700 Kshs., which is about $7. Considering the traveling and transporting costs and the fact that the average quarterly income in the sample is 9,327 Kshs. ($93), these treatments could post a large fixed cost to these households. The Kisumu region has a tropical climate and the threat of tick infestation and outbreak is consistent throughout the year. Therefore, frequency of *acaricide treatment* does not have a correlation with any specific time of the year as shown in Figure 3.

Table 4 provides the livestock and land ownership details of the households. Almost all the households own poultry. The next most prevalent animal in the sample is cattle. About 78% of the households in our sample own either at least one head of cattle or sheep/goat.

Table 5 provides details on demographic variables as well as individual human capital variables. About 42% of the population in our sample has not received any formal education. Among the ones that have, 44% have only received primary education. About 85% of the households own less than or equal to one acre of land with the average land holding being 0.81 acres.

4. Estimation Framework

The increase or decrease in off-farm labor hours in response to acaricide adoption will depend on the cases discussed in the theoretical model. Our regression model for off-farm labor hours is

$$H_{it} = \alpha + \beta_1 T_{it} + \beta_2 \boldsymbol{X_{it}} + \mu_t + \theta_i + \epsilon_{it}, \quad (1)$$

where H_{it} is the weekly off-farm hours reported by the household i in time period t, and T_{it} is equal to 1 for households that administer acaricide spray in the past month and 0 if they use traditional methods, $\boldsymbol{X}_{it}$ is a vector of control variables, μ_t represents indicator variables for each unique quarter, θ_i are household fixed effects, and ϵ_{it} is the error term.

$\boldsymbol{X}_{it}$ consists of highest educational attainment within a household, household demographics (age of the household head, total adult members of the household, children in the household), and farm size (owned acres). The larger the number of adults within a household, the more on- or off-farm labor they can potentially provide. Similarly, presence of children can decrease the off-farm hours, especially for mothers. However, if children help out with household chores, then their presence may increase off-farm labor supply. Owned acres by the household is also added as a control to proxy for farm size, as the size of the farm can affect labor allocation on and off the farm, though it is potentially endogenous.[7] We also control for highest level of educational achievement within a household, as human capital has been shown to affect off-farm labor supply significantly (Huffman and Lange 1989; Huffman 1980; Fernandez - Cornejo, Hendriks and Mishra 2005). The age of the household head may be correlated with differences in household labor allocation and so is added as a control (Huffman 1980, Huffman and Lange 1989).

A similar regression to the one above is run for men and women separately to test whether the labor allocation of men or women is more responsive to acaricide use. The estimation equation can be represented as follows;

$$h_{jit} = \alpha + \beta_1 T_{it} + \beta_2 \boldsymbol{X}_{it} + \beta_3 \boldsymbol{Z}_{jit} + \gamma_t + \eta_i + e_{ijt}, \qquad (2)$$

where h_{ijt} is the off-farm labor hours of individual j in household i in time t, γ_t represents the time fixed effects, η_i are the household fixed effects and e_{ijt} is the error term. $\boldsymbol{X}_{it}$ is a household level vector and consists of household demographics (age of the household head, total adult members of the household, children in the household), and farm size (owned acres). $\boldsymbol{Z}_{jit}$ controls for individual's human capital and individual's age. Note that the household characteristics and farm characteristics used as controls in the individual regressions are the same as household level regression. The only difference is the vector $\boldsymbol{Z}_{jit}$ which contains individual level human capital and age variables.

[7] Livestock herd size can also be included as a control, but it doesn't change the estimate of our treatment variable. Moreover, it is an endogenous variable, therefore we don't report regressions with herd size like Huffman and Lange (1989).

There are several econometric issues associated with the above regressions. First, acaricide use is a choice and may be endogenous. The households that want to work more off-farm might adopt acaricide spray, leading to potential bi-directional causality. We include household fixed effects and time fixed effects to control for unobserved differences among households and time periods. We control for the confounding factors that may be correlated with the decision to treat through $\boldsymbol{X}_{ivt}$.

Acaricide adoption is a choice, and we estimate a regression to identify factors affecting adoption, and to test for endogeneity of adoption and a potential bidirectional relationship between acaricide spray use and off-farm labor. If acaricide adoption is not correlated with a number of household-level variables, this could indicate random assortment of acaricide use with respect to the dependent variable, conditional on observables. We regress our treatment variable T_{it} on lagged off-farm labor hours, lagged livestock illness, and a set of control variables. The linear probability model can be represented by the following equation:

$$T_{it} = \alpha + \beta_1 \boldsymbol{X_{it}} + \beta_2 H_{it-1} + \beta_3 s_{it} + \nu_t + \theta_i + \mu_{it}. \qquad (3)$$

$\boldsymbol{X_{it}}$ contains household level educational attainment variables, household demographic variables and farm characteristics (as in the household level off-farm supply regression). In addition to these variables, in this regression, crop and livestock sales and herd size variables are included to determine if they are correlated with acaricide adoption. s_{it} represents cattle illness incidence. The main tick-borne disease in the region is East Coast Fever (ECF) which only affects cattle. Therefore, cattle illness may be an important determinant of acaricide use.

H_{it-1} is the lagged off-farm labor supply to assess the extent to which off-farm work in the previous period can lead adoption in the current period. A specification with off-farm labor hours of only females and males of the household is also estimated to ascertain the bi-directional relationship between labor hours of individuals by gender and acaricide treatment.

Robust standard errors are clustered at the household level to account for the serial and intra-household correlation in errors for all regressions and specifications.

4.1 Instrumental Variable Analysis

The endogeneity problem can potentially be solved through instruments - factors that are correlated with acaricide use but are not correlated with the unobserved components of off-farm hours. We argue that cattle illness incidence and/or access to grazing land could be valid instruments for acaricide use. The relationship between acaricide use and instruments is defined by the first-stage regression as:

$$T_{it} = \alpha + \beta_1 \boldsymbol{X_{it}} + \beta_2 Inst_{it} + \nu_t + \theta_i + \mu_{it}. \qquad (4)$$

We assume that $\boldsymbol{X_{it}}$ is exogenous in both first and second-stage regressions and that $E(\mu_{it}|Inst_{it}, \boldsymbol{X_{it}}) = 0$, which implies that instrument is uncorrelated with unobserved factors that affect acaricide adoption. Since T_{it} is the only endogenous right-hand side variable in Equation (1), the instrumental variable (IV) assumption is that $Cov(Inst_{it}, \epsilon_{it}) = 0$.

We discuss two potential instruments for T_{it}, lagged cattle illness and current cattle illness. $Cov(illness_{it-1}, \epsilon_{it}) = 0$ will be violated if, for example, lagged cattle illness incidence is related to some unobserved household characteristic. Therefore, my IV models include household and time fixed effects. Lagged cattle illness, given household and time fixed effects and other observables, may be an exogenous shock in the past, and therefore can be a valid instrument. Moreover, illness in the past, through its effect on subjective assessment of disease threat, will impact disease management practices, and through this channel impact off-farm labor hours. Similarly, cattle illness in the current period can induce more acaricide application and if

$Cov(illness_{it}, \epsilon_{it}) = 0$, then it could be a valid instrument too. Section 5.2 discusses the results of our instrumental variable analysis as well as potential issues in validity of these instruments.

5. Results

5.1 Off-Farm Hours and Income Results

Table 6 provides the results of household level test of the impact of *acaricide treatment* on off-farm labor hours (Equation 1). Acaricide use is associated with an increase of about 3 hours of off-farm labor per week for a household, corresponding to Case 1 of the theoretical model. *Acaricide treatment* may make animal husbandry less labor intensive through a decrease in application time relative to manual removal and hand-spotting (Grandin 1983; De Meneghi et al. 2016; Mugisha et al. 2005), through curtailing disease spread and transmission which could increase farm effort, and also through decreasing the tick treatment frequency (as indicated by the difference in tick treatment frequency in Table 2). These labor savings can then be allocated to off-farm income-generating activities and/or other farm related activities like water and feed collection. . This result is related to a broader class of literature which suggests that inputs like agricultural mechanization, diesel and kerosene availability, credit availability, human capital and vocational training can help low-income farmers participate in more off-farm income-generating activities and improve their livelihoods (Beyene 2008; Woldenhanna and Oskam 2001; Ahmed and Goodwin 2016; Huffman and Lange 1989; Barnes and Sen 2003). There is no effect of lagged *acaricide treatment* on off-farm labor hours, indicating that treatment has a short-run impact (Column 3, Table 6). The effect of acaricide remains for about a couple of weeks and that could be a reason for a short-lived effect on labor supply. The removal of fixed effects and controls from the regression (Column 2 and 4, Table 6) do not change our treatment effect significantly suggesting that *acaricide use* may not be as endogenous.[8]

Farm and household size variables are not significantly related to off-farm labor hours in the column 2 and 3 of Table 6, but are statistically significant at conventional levels when household fixed effects are not controlled for. The number of *children* are positively correlated with off-farm work in column 2 of Table 6. It is possible that children help out with household chores and that allows other members to work more off the farm. The highest education level in a household is highly related to off-farm activity, consistent with the findings of Huffman and Lange (1989), Yang (1997), Mishra and Goodwin (1997), Joliffe (2004). Age of the household head is also not highly correlated with the off-farm labor hours in our regressions.

The household level regression results with total, off-farm and farm income as dependent variables are reported in Table 7. The findings show that *acaricide treatment* is positively associated with *off-farm income* and the effect is contemporaneous with the treatment. The increase in off-farm earnings due to acaricide use, at the margin, are about $12 per quarter.[9] This is about 10% increase in cash income. If the time savings persist over a month or if households use acaricide spray regularly during the quarter of use, they can see an increase of 10% due to increased off-farm labor effort. Buying acaricide is a fixed cost, and once you have acaricide bottle available, farmer can easily prepare the solution and use it over time until the bottle is finished.

[8] A zero-inflated Poisson regression was also run to account for the zeroes in the dependent variable. ZIP and OLS estimates do not differ significantly, suggesting no need to explicitly account for the zeroes in the dependent variable. We find a treatment effect of 3.31 with ZIP model, which suggests that our linear model is robust.

[9] The effect of acaricide treatment on off-farm earnings becomes $11 if we do not include the observations that report off-farm income of more than $1,000 per quarter.

The paper also investigates the effect of *acaricide treatment* on men and women of the household separately (Table 8). Acaricide use increases the off-farm labor hours of females of the households by about 2.5 hours per week. In our sample, in about 64% of the households, women identify themselves as primary caretakers of livestock. Animal care in the household is primarily the job of women and children of the household and they are involved in cleaning the animals, animal sheds, taking care of vulnerable and sick animals, and milking and handling of milk (Tangka, Jabbar and Shapiro, 2000; Kristjanson et al. 2010; FAO 1991). Women's labor time and flexibility is much more constrained than that of men's because of these household chores (Blackden and Wodon 2006; Berjio 1983).

Further disaggregation of the genders into their preferred occupations suggests that most of this increase in off-farm hours is related to women who identify their primary occupation as self-employed off-farm or salaried off-farm. Market trade of the fish from Lake Victoria and agricultural products from household owned gardens is primarily responsibility of women of the Kisumu region while men are primarily fishermen and do manual labor (Oboler 1985; Okeyo 1979). Acaricide use can make household chores for these women less time consuming, allowing them to invest in off-farm income generating activities. Acaricide use does not have a significant impact on the labor allocation of men of the household.

Individual educational attainment is positively and significantly correlated with *off-farm labor supply*. *College* and *secondary education* levels are significant in both male and female regressions; however, *primary education* is significantly correlated with off-farm labor hours only for males. *Age* and *age squared* are also correlated with *off-farm labor hours*. Younger adults work more off-farm and their off-farm hours decline as age increases. Presence of *children* is associated with an increase in off-farm labor hours of men but not women. This result is consistent with the observation that taking care of children is primarily the job of women in the Luo community.

5.2 Acaricide Adoption and IV Results

Acaricide treatment is a choice and therefore may be endogenous. Table 9 shows the results of a regression that tests whether the adoption of acaricide is significantly related to any specific factor like human capital, farm size or farm sales. The findings in Table 9 (Column 1 and 2) suggest that acaricide treatments are not related to human capital, farm size or livestock sales. This suggests that the treatment variable may not be endogenous in relation to off-farm labor decisions. Such a test has been used by Jack and Suri (2014) to show the exogeneity of their income shocks in the context of Kenyan households.

Another econometric issue discussed in the empirical model relates to the potential bi-directional causality between off-farm hours and acaricide use, i.e., a household that wants to work more off the farm may have a higher rate of adoption of labor saving technology. Table 9 (Column 1 and 2) shows that lagged total off-farm hours of the household and the lagged off-farm hours disaggregated by gender within a household are not related to the adoption of acaricide.

Column 3 and 4 of Table 9 do not include lagged off-farm hours or farm sales and are first-stage regressions for our instrumental variable analysis. *Lagged Cattle sickness* (Column 3, Table 9) as well as current *cattle illness* (Column 4, Table 9) are highly correlated with acaricide adoption. The first stage F-statistic for *cattle illness* as well as *lagged cattle illness* are greater than 10, which suggests the instruments are strong. *Cattle illness* in the current period can increase the acaricide adoption because farmers may use acaricide to make sure ticks do not become a reason of spreading the disease further. Similarly, *lagged cattle illness* may alter the subjective assessment of disease threat for herd-owners and may lead to increase in the use of *acaricide treatment*.

Table 10, column 1 provides results of our instrumental variables estimates with instrument being *cattle illness*. The results suggest that adoption of acaricide spray leads to an increase in 2.78 hours per week in off-farm hours of the household. Cattle illness can directly decrease the off-farm effort by increasing the on-farm effort. Therefore, this instrument may bias the coefficient on *acaricide treatment* downward. We can interpret this coefficient as a lower bound of the effect of *acaricide treatment*. Similarly, column 2 provides results of our instrumental variables estimates with instrument being *lagged acaricide treatment*. The effect is 4.29 with this instrument. This instrument is better that current illness in the sense that it does not directly affect off-farm hours and exogeneity condition may not be violated in this instance. Hausman-Wu-Durbin tests were conducted for all the IV regressions, and we consistently fail to reject the exogeneity of *acaricide treatment*.

Because of concerns surrounding our instrumental variables and the plausibility of acaricide treatment being exogenous, given fixed effects and observables, we prefer our OLS regression to instrumental variable regressions, even though it may suffer from endogeneity bias.

Conclusion

Infectious disease management and off-farm labor supply and income are important elements in the everyday life of an agricultural household in developing countries. The adoption of biotechnology as a superior, less labor-intensive method of managing livestock disease risk may reduce economic losses and allow farmers to re-allocate their labor. The link between adoption of disease control technologies and labor allocation is poorly understood and this paper explores the pathways through which labor allocation is related to changes in disease management practices, tick control practices particularly, in the tropical Kisumu region of Western Kenya. The paper shows that technology adoption for livestock disease control has side benefits other than managing livestock disease risk and improving livestock production.

This article shows that acaricide spray adoption and use benefits small-holder livestock owners primarily as a labor saving technology because it allows an increase in off-farm labor supply and income of the households. Off-farm labor market activities are considered pivotal in improving the livelihoods of agricultural households and appropriate livestock disease management strategies can help these households participate more in the non-farm sectors.

At the individual level, these treatments are associated with an increase in off-farm hours of women of the household while the labor allocation of men remains unchanged. An increase in women's' off-farm labor supply may result in more gender equality within the household and promote welfare for the overall household (Pitt and Khandker 1998; Schultz 1999; Newman and Canagarajah 2000).

References

Ahituv A., and Kimhi A. 2002. Off-farm work and capital accumulation decisions of farmers over the life-cycle: The role of heterogeneity and state dependence. *Journal of Development Economics* 68 (2): 329-353.

Ahmed, Haseeb, Jonathan Yoder, and Robert Quinlan. 2016. Risk perceptions, management practices, and demand for livestock antibiotics among agropastoralists. Washington State University. School of Economic Sciences, Working Paper # 2016-17. http://ses.wsu.edu/wp-content/uploads/2016/10/WP2016-17.pdf.

Ahmed, M., and B. Goodwin. "Agricultural Mechanization and non-farm labor supply of farm households: Evidence from Bangladesh." AAEA conference, 2016. http://ageconsearch.umn.edu/bitstream/236131/2/Mechanization_Mansur.pdf

Barnes, D., and M. Sen. 2003. "The Impact of Energy on Women's Lives in Rural India." Washington, D.C.: UNDP/World Bank Energy Sector Management Assistance Programme.

Barnett, S.F. 1974. Economical aspects of tick-borne disease control in Britain. *Bull. Off. int. Epiz.*, 81(1–2): 167–182.

Becker, Gary S. "A Theory of the Allocation of Time." *The Economic Journal*, 1965: 493-517.

---- "Economics of the Family. Marriage, Children and Human Capital." *University of Chicago Press*, 1973.

Berio, A.J. 1983. *Time Allocation Surveys*, Paper presented at the 11th International Congress of Anthropology Sciences, Vancouver, Canada

Blackden, C.M. and Wodon, Q. (2006), Gender, Time Use and Poverty. An Introduction in C.M. Blackden and Q. Wodon, Gender, Time Use and Poverty in Sub-Saharan Africa. (pp 1-5). http://siteresources.worldbank.org/INTAFRREGTOPGENDER/Resources/gender_time_use_pov.pdf

Beyene, A. 2008. Determinants of off-farm participation decisions of farm households in Ethiopia. *Agreko* 47(1): 158-161.

Binswanger, H. P., & Von Braun, J. (1991). Technological change and commercialization in agriculture: the effect on the poor. *The World Bank Research Observer*, 6(1), 57-80.

Boles, M., Pelletier, B. and W. Lynch. "The relationship between health risks and work productivity." *Journal of Occupational and Environmental Medicine*, 2004: 737-745.

Brito et al. 2011. " Evaluation of the Efficacy of Acaricides Used to Control the Cattle Tick, Rhipicephalus microplus, in Dairy Herds Raised in the Brazilian Southwestern Amazon". *Veterinary Medicine International*. **doi**: 10.4061/2011/806093

Browning, M. and P.A. Chiappori. 1998. Efficient intrahousehold allocations: A general characterization and empirical tests. *Econometrica* 66:1241–1278.

Caudell, MA, Quinlan, MB, Subbiah, M, Call, DR, Roulette, CJ, Roulette, JW, Roth, A, Louise Matthews, L, and Quinlan, RJ. (2016), 'Antimicrobial Use and Veterinary Care among Agro-pastoralists in Northern Tanzania', Manuscript available from author.

Chenyambuga S W, Waiswa C, Saimo M, Ngumi P and Gwakisa P S 2010:Knowledge and perceptions of traditional livestock keepers on tick-borne diseases and sero-prevalence of *Theileria parva* around Lake Victoria Basin. *Livestock Research for Rural Development. Volume 22, Article #135.* Retrieved September 7, 2017, from http://www.lrrd.org/lrrd22/7/chen22135.htm

Chiappori, Andre-Pierre, et. al. "Marriage Market, Divorce Legislation and Household Labor Supply. " *Journal of Political Economy*, 2002

de Janvry, Alain, et al. "Peasant Household Behavior with Missing Markets: Some Paradoxes Explained." *The Economic Journal*, 1991: 1400:1417.

De Meneghi, D., Stachurski, F., & Adakal, H. (2016). Experiences in Tick Control by Acaricide in the Traditional Cattle Sector in Zambia and Burkina Faso: Possible Environmental and Public Health Implications. Frontiers in Public Health, 4, 239. http://doi.org/10.3389/fpubh.2016.00239

Deolalikar, A.B. "Nutrition and Labor Productivity in agriculture: Estimates for Rural South India." *The Review of Economics and Statistics*, 1988: 406-413.

Di Giulio G, Lynen G, Morzaria S, Oura C, Bishop R. 2009. "Live immunization against East Coast fever - current status." *Trends Parasitol*. 25: 85-92.

Dito, B. "Intra-household labor supply, agricultural shocks and women's bargaining power." CSAE conference, 2001. **DOI**: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.192.7873&rep=rep1&type=pdf

FAO. 1991. *Maasai herding - An analysis of the livestock production system of Maasai pastoralists in eastern Kajiado District, Kenya.*

FAO. 1993. *Sustainable control methods for ticks and tick-home diseases in Africa.* http://www.fao.org/wairdocs/ilri/x5485e/x5485e0j.htm

Fernandez-Cornejo, J., Hendriks, C., and A. Mishra. "Technology adoption and off-farm household income: The case of herbicide-tolerant soybeans." *Journal of Agricultural and Applied Economics*, 2005: 549-563.

Gachohi, J., Skilton, R., Hansen, F. Ngumi, P. and P. Kitala. 2012. "Epidemiology of East Coast Fever (*Theileria Perva* Infection) in Kenya: Past, Present and the Future." *Parasites and Vectors*. 5:194. **DOI:** 10.1186/1756-3305-5-194

Grandin B E. 1983. *Labour data collection*. In: Stewart R A (ed.), Pastoral systems research in sub-Saharan Africa. Proceedings of the workshop held at ILCA, Addis Ababa, Ethiopia, 21 to 24 March, 1983. ILCA (International Livestock Centre for Africa), Addis Ababa, Ethiopia. pp. 305-319.

Heckman, J. (1979). Sample Selection Bias as a Specification Error. Econometrica, 47(1), 153-161. doi:10.2307/1912352

Hoddinott, J., Dercon. S., and P. Krishnan. "Networks and Informal mutual support in 15 Ethiopian Villages." International Food Policy Research Institute, Washington DC. 2005.

Huffman, Wallace E. "Farm and Off-farm Work Decisions: The Role of Human Capital." *The Review of Economics and Statistics*, 1980: 14-23.

Huffman, W.E., and Lange, M.D. "Off-farm work decisions of husbands and wives: Joint decision making." *The Review of Economics and Statistics,* 1989 (7): 471-480.

Ito, Takahiro, and Takahashi Kurosaki. "Weather Risk, Wages in Kind, and the Off-farm Labor Supply of Agricultural Households in a Developing Country." *American Journal of Agricultural Economics*, 2009: 697-710.

Joliffe, Dean. "The Impact of Education in Rural Ghana: Examining Household Labor Allocation and Returns On and Off the Farm." *Journal of Development Economics*, 2004: 287-314.

Kes, A. and Swaminathan, H. "Gender and Time Poverty in Sub-Saharan Africa" in Gender, Time Use and Poverty in Sub-Saharan Africa, The World Bank, 2005.

Kivaria, F.M. " Estimated direct economic costs associated with tick-borne diseases on cattle in Tanzania." *Tropical Animal Health & Production*. 38(4):291-299, May 2006. doi: 10.1007/s11250-006-4181-2

Kristjanson, P., Waters-Bayer, A., Johnson, N., Tipilda, A., Njuki, J., Baltenweck, I., Grace, D., and MacMillan, S. 2010. Livestock and Women's Livelihoods: A Review of the Recent Evidence. Discussion Paper No. 20. Nairobi, Kenya, ILRI.

Lanjouw, P., and G. Feder. 2001. "Rural Non-Farm Activities and Rural Development: From Experience Towards Strategy." Rural Development Strategy Background Paper No. 4. World Bank, Washington, DC.

Liu, M., and Marsh. T.L. Linking livestock health to household food consumption and nutrition. AAEA 2014 Conference Paper.

Lorusso et. al. 2013. "Ixodid ticks of traditionally managed cattle in central Nigeria: where Rhipicephalus (Boophilus) microplus does not dare (yet?)." Parasites and Vectors., 6: 171. DOI: 10.1186/1756-3305-6-171

Mahoney, D.F. & Ross, D.R. 1972. Epizootiological factors in the control of bovine babesiosis. Aust. Vet. J., 48: 292–298.

Marsh, Thomas, Jonathan Yoder, Tesfaye Deboche, Terry McElwain and Guy Palmer. Forthcoming (2016), 'Pastoralists' decisions on livestock vaccination translate into increased human capital and increased school attendance by girls', *Science Advances*.

Mathenge, M.K., and M. Smale. "Off-farm income and fertilizer investments by small-holder farmers in Kenya." 4th International Conference of the African Association of Agricultural Economists. 2013. DOI: http://ageconsearch.umn.edu/bitstream/161470/2/Mary%20K.%20Mathenge%20and%20Melinda%20Smale.pdf

Mishra, Ashok K, and Barry K Goodwin. "Farm Income Variability and Supply of Off-farm Labor." *American Journal of Agricultural Economics*, 1997: 880-887.

Mosites, Emily M., Rabinowitz, P., Thumbi, M., Montgomery, J., Palmer, G. et al. (2015). The Relationship between Livestock Ownership and Child Stunting in Three Countries in Eastern Africa Using National Survey Data. PLoS One, 10, e0136686

Mugisha A, McLeod A, Percy R and Kyewalabye E. 2005. Strategies, effectiveness and rationale of vector-borne disease control in the pastoralist system of south-west Uganda. *Tropical Animal Health and Production* 37: 479 – 489.

Newman, C., and S. Canagarajah. 1999. Gender, Poverty and non-farm employment in Ghana and Uganda. World Bank Policy Research Working Paper Series No. 2367. Washington DC.

Oboler, R.S. (1985). Women, Power and Economic Change: The Nandi of Kenya. Stanford University Press. pp 198-225.

Okeyo, A. (1979). Women in the Household Economy: Managing Multiple Roles. *Studies in Family Planning,* 10(11/12), 337-343. doi:10.2307/1966089

Pitt, M.M. and S.R. Khandker (1998). The Impact of Group Based Credit Programs on Poor Households in Bangladesh: Does the Gender of Participants Matter? *Journal of Political Economy* 106 (5): 958-996. https://doi.org/10.1086/250037

Rajput, Z. I., Hu, S., Chen, W., Arijo, A. G., & Xiao, C. (2006). Importance of ticks and their chemical and immunological control in livestock . *Journal of Zhejiang University. Science. B, 7*(11), 912–921. http://doi.org/10.1631/jzus.2006.B0912

Reardon, T. (1997). Using evidence of household income diversification to inform study of the rural nonfarm labor market in Africa. *World development*,25(5), 735-747.

Rosenzweig, Mark R. "Neoclassical Theory and Optimizing Peasant. An Econometric Analysis of Market Family Labor Supply in a Developing Country." *The Quarterly Journal of Economics*, 1980: 31 - 55.

Rosenzweig, M.R., Wolpin, K.I., 1993. Credit market constraints, consumption smoothing, and the accumulation of durable production assets in low-income countries: investments in Bullocks in India. *Journal of Political Economy* 101 (2), 223 – 244, April.

Saito, K.A., with contributions from H. Mekonnen and D. Spurling. 1994. “Raising the Productivity of Women Farmers in Sub-Saharan Africa.” Washington, D.C.: The World Bank.

Schultz, T.P. 1999. Women's role in agricultural household: Bargaining and human capital. Economic Growth Center, Yale University. http://www.econ.yale.edu/~pschultz/cdp803.pdf

Solomon Bekure, de Leeuw P N. Grandin B E and Neate P J H (eds). 1991. Maasai herding: An analysis of the livestock production system of Maasai pastoralists in eastern Kajiado District, Kenya. ILCA Systems Study 4. ILCA (International Livestock Centre for Africa), Addis Ababa, Ethiopia. 172 pp.

Sperling L. 1987. *The labour organisation of Samburu pastoralism.* Thesis, McGill University, Montreal, Canada.

Strauss, J. "Does better nutrition raise farm productivity?" *Journal of Political Economy*, 1986: 297-320.

Suda, CA. "Division of Labor by Gender and its Implication for the Status of Women in Siaya District, Western Kenya" African Urban Quarterly, 1990: 256-267.

Tangka F.K., Jabbar M.A. and Shapiro B.I. 2000. Gender roles and child nutrition in livestock production systems in developing countries: A critical review. Socio-economic and Policy Research Working Paper 27. ILRI (International Livestock Research Institute), Nairobi, Kenya.

Woldenhanna, T., Oskam, A., 2001. Income diversification and entry barriers: evidence from the Tigray region of Northern Ethiopia. Food Policy 26, 351-365.

Wycliffe Wanzala, Willem Takken, Wolfgang R. Mukabana, Achola O. Pala, Ahmed Hassanali, Ethnoknowledge of Bukusu community on livestock tick prevention and control in Bungoma district, western Kenya, Journal of Ethnopharmacology, Volume 140, Issue 2, 27 March 2012, Pages 298-324, ISSN 0378-8741, https://doi.org/10.1016/j.jep.2012.01.021.

Yang, Dennis T. "Education and Off-farm Work." *Economic Development and Cultural Change*, 1997.

Young, A., Groocock, C., & Kariuki, D. (1988). Integrated control of ticks and tick-borne diseases of cattle in Africa. *Parasitology*, *96*(2), 403-432. doi:10.1017/S0031182000058388

Figure 2: The percentage of households and the number of times they adopt *acaricide treatment* over the sample period

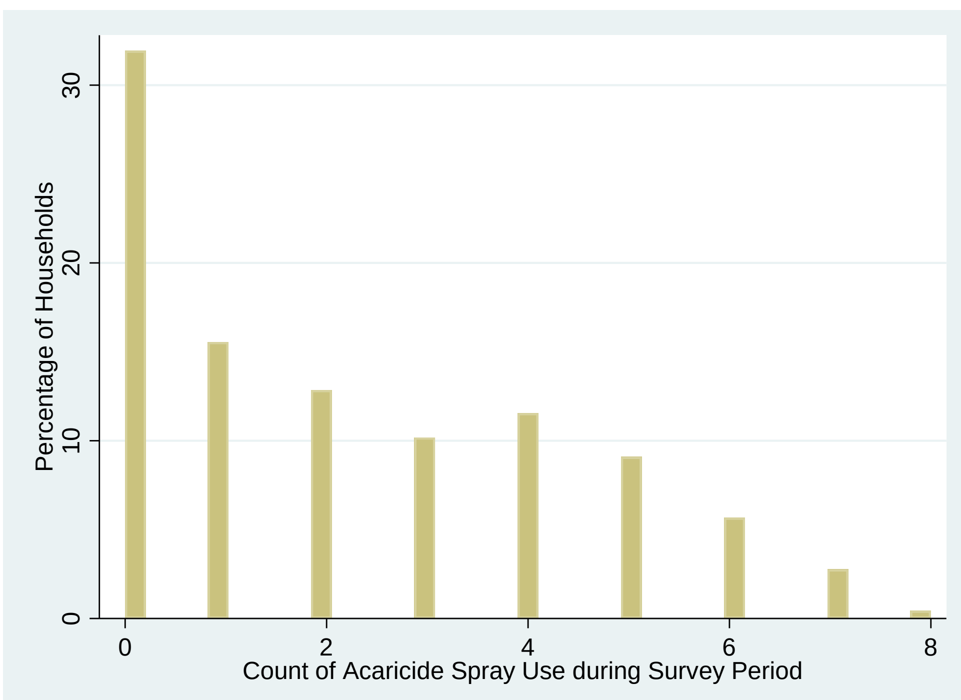

Figure 3: Average Acaricide Use Per Quarter

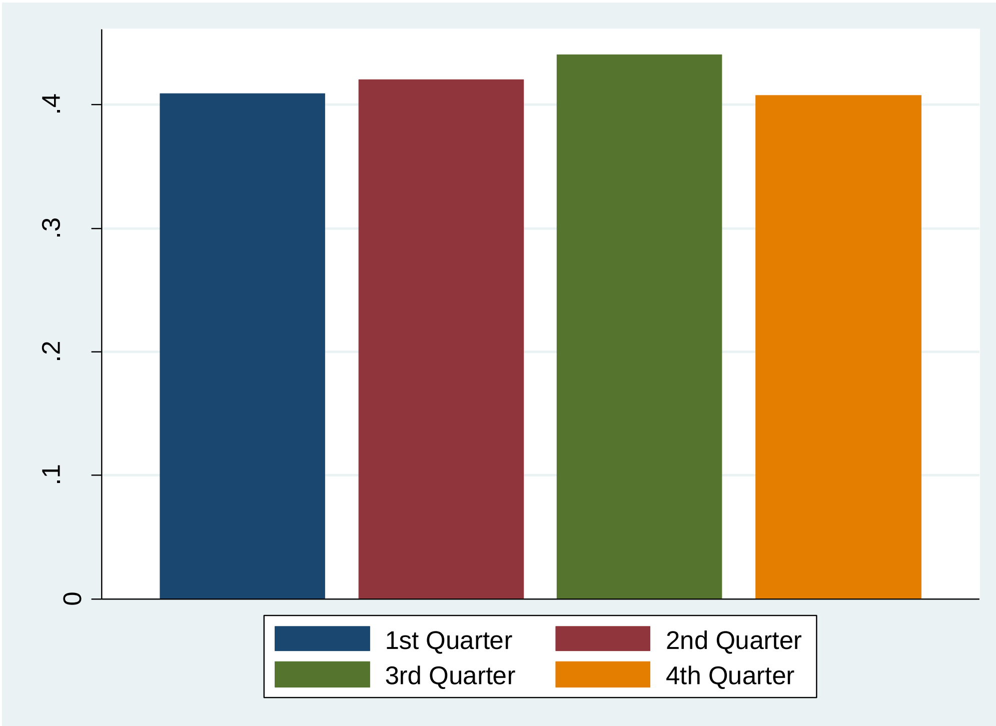

Table 1: Variable Descriptions

Variable	Description
Off-Farm Labor Supply	This is the total time (in Hours) spent per week on income generating activities off the farm. In Table 5, we use the household level off-farm hours, while in Table 6, we use individual level off-farm hours.
Acaricide Treatment	Indicator variable = 1 if a household administers acaricide via spray, 0 otherwise.
Owned Acres	Land owned by the household in acres.
Primary Education	Indicator variable = 1 if highest education attainment is primary school, 0 otherwise. In household level regressions, the household's highest education attainment is used while in individual level regressions, individual's highest educational attainment is used.
Secondary Education	Indicator variable = 1 if education attainment is secondary school, 0 otherwise. In household level regressions, the household's highest education attainment is used while in individual level regressions, individual's highest educational attainment is used.
College Education	Indicator variable = 1 if education attainment is college education, 0 otherwise. In household level regressions, the household's highest education attainment is used while in

	individual level regressions, individual's highest educational attainment is used.
Children	Number of children under the age of 10 in a household
Adult HH members	This is total members of the household minus the children.
Cattle Illness	The number of cattle reported sick in a household within last three months
Animal Sales	Quarterly revenues (in Kenyan Shillings) from selling livestock and their products.
Crop Sales	Quarterly revenues (in Kenyan Shillings) from selling crops.
Off-Farm Earnings	Total quarterly income (in Kenyan Shillings) generated via off-farm activities.
Farm Earnings	Crop sales plus animal sales
Age of Household Head	This is the age of the household head.
Age Squared	The square of the age of the household head.
Access to Grazing Land	Indicator variable = 1 if the household has access to grazing land, 0 otherwise.
Herd Size	The number of cows, goats, sheep, bullocks, donkeys, heifers and calves.
Farmers	Individuals who indicate their primary occupation as farming. They could be livestock or crop farmers.
Off-Farm Workers	Individuals who indicate their primary occupation as off-farm workers. They could be self-employed workers or salaried workers.

Table 2: Off-Farm Hours and Occupational Distributions

Category	% Population (as % of total sample)	Mean Off-farm Hours	Standard Deviation
Household	-	10.25	26.29
Off-Farm Workers	27.85	17.49	28.04
Farmers	72.15	1.03	6.7
Total Males	43.56	3.55	14.36
Total Females	56.44	2.72	12.54
Male Off-Farm Workers	9.31	16.17	27.37
Female Off-Farm Workers	7.17	19.23	28.78
Male Farmers	35.25	0.64	5.33
Female Farmers	48.24	1.01	7.35

Table 3: Acaricide Use and Monthly Tick Treatment Frequency

Tick Treatment Method	No. of Observations	Mean treatment frequency per month
Acaricide Treatment	3,942	1.7
Traditional Method	5,017	4.9*

*Two Sample t-test suggests that the mean treatment frequency with and without acaricide treatment is significantly different (P-value < 0.001). Moreover, the number of tick treatments per month are censored from above at 5 in the survey, suggesting that actual mean treatment frequency per month is higher than 4.9.

Table 4: Households' Livestock Ownership

Livestock Category	Number of observations	% of total sample
Poultry	10,523	85.45
Sheep	2,492	20.25
Goats	4,528	39.20
Calves	3,269	26.54
Heifers	2,451	21.45
Bullocks	1,745	15.34
Cows	5,580	48.25

Table 5: Household Demographics, Income, Land Ownership and Human Capital

Variables	Mean	Standard Deviation	Min	Max
Children	1.29	1.35	0	8
Adult HH members	4.45	2.34	1	18
Owned Acres	0.812	6.73	0	625
Crop Sales (Kshs.)	202.8	2,325	0	133,500
Animal Sales (Kshs.)	1,024	5,312	0	267,000
Herd Size	8.61	11.45	0	200
Off Farm Income (Kshs.)	8,021	20,845	0	721,000
Illness Incidence	0.226	0.689	0	10
Primary Education	0.44	0.49	0	1
Secondary Education	0.12	0.45	0	1
College Education	0.2	0.23	0	1
Age of Household Head	50.95	15.45	15	80

Table 6: The Effect of Acaricide Treatment on Total Household Off-Farm Labor

Dependent Variable *Off-farm Labor Supply*	(1)	(2)	(3)	(4)
Acaricide Treatment (T)	3.52*** (0.67)	3.33*** (0.78)	0.215 (0.903)	3.38*** (0.76)
Adult HH Members	0.943*** (0.144)	-0.20 (0.36)	-0.058 (0.39)	-
Children under 10	0.297 (0.37)	1.66*** (0.58)	1.26* (0.663)	-
College Education[a]	10.08*** (1.71)	10.07*** (2.44)	7.27*** (2.81)	-
Secondary Education[a]	0.487 (1.04)	3.44** (1.47)	2.90* (1.66)	-
Primary Education[a]	0.039 (0.886)	-0.687 (1.14)	-0.979 (1.25)	-
Age of Household Head	-0.265*** (0.05)	0.13 (0.078)	0.168** (0.08)	-
Age Squared	0.0006** (0.0003)	-0.0005 (0.0004)	-0.0005* (0.0003)	-
Owned Acres	-0.034*** (0.0078)	-0.0016 (0.005)	0.0004 (0.005)	-
R-Square	0.04	0.02	0.003	0.01
Observations	8,758	8,758	6,817	9,159
Household Fixed Effects	**No**	**Yes**	**Yes**	**Yes**
Time Fixed Effects	**Yes**	**Yes**	**Yes**	**Yes**
Lagged Treatment	**No**	**No**	**Yes**	**No**

All standard errors are clustered at the household level.
***, **, * indicated significance at 1%, 5% and 10% respectively

Table 7: Effect of Acaricide Treatment on Income (in Kenyan Shillings)

	Off Farm Earnings	Off Farm Earnings	Farm Earnings	Farm Earnings	Total Income	Total Income
Acaricide Treatment	1297.88**	544.3	156.64	151.02	1415.3**	706.10
	(516.1)	(508.7)	(157.2)	(166.1)	(551.61)	(488.5)
Adult HH Members	619.3***	791.1***	22.28	47.5	647.2**	756.4***
	(219.00)	(229.7)	(291.3)	(87.36)	(267.5)	(256.3)
Children	427.96	281.4	-51.82	-116.06	369.5	568.2*
	(262.13)	(281)	(89.00)	(106.5)	(279.3)	(301.1)
College Education	4516.23***	4168.3***	43.5	98.5	4,577.7**	4,019.4**
	(1324.2)	(1355.5)	(448.5)	(514.4)	(2,196.3)	(2002.2)
Secondary Education	-1035.64	591.4	-24.48	45.09	-1,065.3	447.8
	(933.3)	(946.6)	(316.5)	(359.4)	(1308.04)	(996.8)
Primary Education	-2008.0**	-662.3	22.8	-61.91	-1,891.1	-535.6
	(858.5)	(864.4)	(291.2)	(328.4)	(1187.03)	(758.09)
Age of Household Head	94.89	156.44**	-30.90	-31.63	62.6	123.8*
	(68.73)	(61.03)	(21.29)	(22.61)	(69.7)	(65.4)
Age Squared	-0.434	-0.553**	0.148	0.12	-0.28	-0.42
	(0.293)	(0.257)	(0.09)	(0.1)	(0.26)	(0.26)
Owned Acres	-6.40	-11.9	-0.94	-0.89	-8.34	-9.22
	(25.3)	(23.2)	(8.58)	(8.81)	(12.2)	(9.44)
R-Square	0.44	0.42	0.005	0.002	0.43	0.412
Observations	8,757	6,821	8,757	6,811	8,753	6,817
Household Fixed Effects	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Time Fixed Effects	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Lagged Tick Treatment	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**

All standard errors are clustered at the household level.
***, **, * indicated significance at 1%, 5% and 10% respectively

Table 8: Impact of Acaricide Treatment on Off-Farm Labor Hours of Men and Women

Dependent Variable *Off-Farm Labor Supply*	All Males	Off-Farm Male	Farmer Males	All Women	Farmer Women	Off-Farm Women
Acaricide Treatment	-0.07	0.07	0.035	2.47***	0.488**	8.65***
	(0.306)	(1.82)	(0.186)	(0.48)	(0.233)	(2.13)
Adult HH Members	-0.589	1.56***	0.07	-0.19*	0.017	0.574
	(0.65)	(0.92)	(0.09)	(0.105)	(0.169)	(1.39)
Children	1.51**	0.358	0.147	0.21	0.040	1.058
	(0.678)	(0.82)	(0.128)	(0.128)	(0.385)	(2.22)
Own Age	0.289***	1.16***	0.014	0.42***	0.067**	1.03**
	(0.096)	(0.36)	(0.038)	(0.039)	(0.026)	(0.42)
Age Squared	-0.0023*	-0.012***	-0.00013	-0.004***	-0.0005**	-0.015**
	(0.0012)	(0.0044)	(0.00035)	(0.0005)	(0.0002)	(0.005)
College Education	5.62***	4.61	1.56	1.84*	0.77	2.85
	(1.43)	(5.88)	(1.12)	(1.005)	(1.38)	(7.8)
Secondary Education	2.38**	-1.31	0.74	1.15**	0.304	3.13
	(1.10)	(5.8)	(0.589)	(0.487)	(1.04)	(6.92)
Primary Education	2.23***	1.59	0.499	0.24	-0.035	2.94
	(0.022)	(5.65)	(0.55)	(0.34)	(0.27)	(6.55)
Owned Acres	0.004	-0.009	-0.09	-0.01***	-0.5	-0.63
	(0.008)	(0.259)	(0.146)	(0.002)	(1.08)	(0.8)
R-Square	0.04	0.08	0.01	0.02	0.01	0.05
Observations	12,353	2,208	10,145	15,096	13,474	1,623
Household Fixed Effects	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Time Fixed Effects	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**

All standard errors are clustered at the household level.
***, **, * indicate significance at 1%, 5% and 10% respectively.

Table 9: Acaricide Treatment Regressions - Linear Probability Model

Dependent Variable: *Acaricide Treatment*	(1)	(2)	(3)♣	(4)
Lagged Cattle Illness	0.038***	0.034***	0.039***	-
	(0.031)	(0.008)	(0.013)	
Cattle Illness	-	-	-	0.053***
				(0.012)
Lagged Off-farm hours	0.00008	-	-	-
	(0.00012)			
Lagged Off-farm hours[a] *(Women)*	-	0.00023	-	-
		(0.0002)		
Lagged Off-farm hours[b] *(Men)*	-	-0.00002	-	-
		(0.0002)		
Primary Education	0.033	0.0075	0.004	-0.001
	(0.024)	(0.019)	(0.019)	(0.019)
Secondary Education	0.006	-0.007	0.004	0.0014
	(0.027)	(0.022)	(0.02)	(0.022)
College Education	0.019	0.0017	0.011	0.008
	(0.04)	(0.03)	(0.031)	(0.031)
Adult HH members	0.018***	0.026***	0.016***	0.015***
	(0.007)	(0.006)	(0.005)	(0.005)
Children	0.004	-0.0006	0.006	0.005
	(0.008)	(0.007)	(0.006)	(0.006)
Total Animals	0.0005	0.0005	-	-
	(0.0005)	(0.0003)		
Farm Sales	-0.0001	-0.0002	-	-
	(0.001)	(0.0001)		
Age of Household Head	0.0016	0.004	0.0034	0.0008
	(0.0015)	(0.007)	(0.0001)	(0.0008)
Age Squared	0.00018	0.0002	0.00018	0.0002
	(0.001)	(0.001)	(0.001)	(0.001)
Owned Acres	-0.0005**	-0.0004**	-0.0001	-0.0008
	(0.0002)	(0.0002)	(0.0013)	(0.003)
Household Fixed Effects	**Yes**	**Yes**	**Yes**	**Yes**
Time Fixed Effects	**Yes**	**Yes**	**Yes**	**Yes**

Table 10: Effect of Acaricide Treatment on Total Household Off-Farm Labor (IV-Regressions)

Dependent Variable *Off-farm Labor Supply*	(1)	(2)
Acaricide Treatment	2.78 (2.92)	4.29 (5.31)
Durbin-Wu-Hausman Test (P-values) H_o = Treatment is exogenous	0.593	0.603

In column (1), the excluded instrument is *' Cattle Illness'*, in column (2), the excluded instrument is *'Lagged Cattle Illness'*. Both instruments are statistically significant in the first stage in all regressions.