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Ex-post Livestock Diseases, and Pastoralists' Averting Decisions in Tanzania

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EX-POST LIVESTOCK DISEASES, AND PASTORALISTS' AVERTING DECISIONS IN TANZANIA

by

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Little is known about the factors affecting pastoralists' livestock vaccination decisions. In this thesis, we use a novel survey-based dataset on pastoralists living in the Ruaha landscape in Tanzania, and employ several econometric approaches to identify the factors affecting pastoralists' decision-making process about livestock vaccination when disease occurrence and severity, vaccination and healthcare access costs and other related variables are known. Results from binary choice models that account for excess zeros indicate that socially and economically active households are more likely to vaccinate their livestock. The results also identify positive marginal effects of illness incidence and having wage earners and in the household on vaccination decisions. The results from mixture models also find that these same variables significantly lower the pastoralist's probability of not vaccinating their livestock. Most notably, increased vaccination cost significantly lowers the probability that pastoralists vaccinate any livestock, as well as the number of vaccinated livestock. These findings have important policy implications considering livestock health education, veterinary service infrastructure, and supply-side management. (JEL codes: D13, D83, Q12, Q13, R28).

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CHAPTER 1: INTRODUCTION

Livestock production plays a crucial role in meeting global nutritional needs, accounts for approximately 40 percent of agricultural GDP, and provides pathways out of poverty for more than one billion people whose livelihoods depend upon livestock directly or indirectly (McPeak et al. 2011; World Bank 2011). Livestock disease is a persistent problem in many developing countries, and Tanzania is not an exception (Perry and Sones 2009), with approximately 60 percent of family-owned livestock suffering from some type of preventable disease like bovine and caprine pleuropneumonia, brucellosis, or foot and mouth disease (Clifford et al. 2008; Covarrubias et al. 2012; Kivaria 2003). Livestock diseases affect pastoralist households through multiple pathways: they contribute to food and nutritional insecurity, loss of wealth and income, and, in the case of zoonotic diseases, can lead to an increased disease burden for humans. Pastoralist households, which rely heavily on livestock as a source of nutrition, store of wealth, and for cultural status (Coppolillo et al. 2009; Hesse and MacGregor 2006; Lybbert et al. 2004), are particularly affected by livestock disease losses.

The likelihood and severity of livestock diseases influence household livelihoods and the burden of losses is often high, especially for households in less developed rural settings where veterinary services are limited (Allport et al. 2005). Preventive measures like vaccination, commonly referred to as averting actions or decisions, can lower the expected loss to disease (Mclnerney 1996). Pastoralists' averting decisions are based on risk preferences, but are likely also shaped by previous experience with disease infection and loss. Their decision mechanism is a complex issue, and likely depends on various socio-economic and household behavioral factors. The literature on livestock keepers' vaccination averting decisions is limited, especially for pastoralist households. In the context of high exposure to livestock diseases (World Bank 2011), we empirically analyze household survey data to identify the factors that likely affect pastoralist averting actions to decrease the likelihood of future disease losses.

This thesis extends the literature on households' averting decisions, incorporating information on households' livestock disease experience through two related aspects. First, we use household survey data to examine the impacts of potential socio-economic and behavioral factors of pastoralists' averting decisions for livestock diseases, i.e., vaccination. In particular, we empirically test two major hypotheses. We test the hypothesis that the vaccination decision and number of vaccinated livestock is positively influenced by prior disease experience, i.e., illness incidence and livestock death in the past twelve months. Another hypothesis relates to vaccination cost. We hypothesize that higher vaccination cost negatively influences the vaccination decision. Second, based on pre-survey qualitative observations and empirical findings, we conclude the thesis with a few policy suggestions on ways to address barriers to vaccination.

Following traditional averting behavior frameworks such as Bontemps and Nauges (2016), we assume that a pastoralist will choose to vaccinate their livestock if the expected utility when vaccinating livestock is higher than the expected utility from not vaccinating. As this decision to vaccinate or not is a latent representation of the relative difference in utility, we use their binary vaccination decision to capture differences in relative expected utility. The decision depends on a variety of economic, community, and behavioral variables. Therefore, in explaining the pastoralists' averting behavior for livestock diseases, we need to consider the role of disease experience and socio-economic factors together with related social beliefs. We assume that the binary vaccination decision and resulting number of vaccinated livestock are associated with previous disease and loss, with the costs of vaccination and travel to access vaccination services, the household head's age and education level, and family and herd size, among other variables. Additionally, we include a control variable for households' social and economic activity with households with at least one cell phone, a wage earner, and a primary school-educated household head considered to be more socially and economically active . Another categorical control variable representing diversified sources of income is also included to identify the effect of wage income on vaccination decisions. The empirical basis of the study is a household survey conducted in 2012 in Pawaga and Idodi divisions bordering Ruaha National Park and community wildlife management areas in Iringa region, Tanzania. We collected household-level data on livestock disease and vaccination and related household and community characteristics using a structured questionnaire to analyze factors influencing households' averting decisions through descriptive and econometric analyses.

We consider an averting decision model where pastoralists' have a binary choice variable that includes the decision to vaccinate or not vaccinate. Maximum likelihood approaches, such as logit and probit estimators, are frequently used as the estimation strategy to examine binary averting decisions. In logistic regression, maximum likelihood estimates can be biased when events are rare. As our binary decision variable consists of few positive actions, we consider three variants of the logistic model that account for rare events in the outcome variable. First, we consider an exact logistic regression model that is appropriate for small samples with dichotomous covariates, but excluded from final analysis as our sample size is considerably high for this estimation. Second, the King and Zeng (2001) bias correction method of logistic estimation is employed. Finally, we use the penalized maximum likelihood estimation procedure proposed by Firth (1993). While another class of estimators, known as zero-truncated procedures, exists that produces more robust estimates, we cannot implement this procedure as it is only suitable for large datasets ($n \geq 2000$) with zero-truncated data.

We extend the analysis to estimate a count data model where the number of vaccinated livestock is considered as the outcome variable. Most households did not administer any vaccinations, and therefore had zero vaccinated livestock. This is due to the presence of both true and excess zeros. There is also a considerable gap between observed zeros (89.29%) and predicted zeros (30% using a Poisson analysis). Moreover, the distribution of non-zero counts (10.71%) shows dispersion with a possibility of over dispersion. In this case, both hurdle and zero-inflated models (with or without over dispersion) can explain the high occurrence of zeros in the outcome variable. The hurdle model assumes a two-step decision-making process and expects a positive number of vaccinated livestock if and only if the household decides to vaccinate. The reason behind this zero in the count outcome variable is structural and depends on the binary first-step vaccination decision. On the other hand, zero-inflated or zero-altered models assume that some pastoralists either do not know about vaccination or do not have the financial ability to vaccinate, which inflates the number of ‘excess’ zeros. Households that have vaccination knowledge and financial ability to vaccinate generate non-zero count values when they choose to vaccinate. Their counterparts are unable to vaccinate due to financial constraints and generate zero count values even though they may want to vaccinate their livestock. The latter leads to ‘true’ zeros. Therefore, we need to consider a few variants of the hurdle and zero-inflated models—for example negative binomial and Poisson—to explain true zeros and excess zeros with or without over dispersed count data simultaneously. We find that negative binomial-logit hurdle (NBLH) and zero-inflated negative binomial (ZINB) models are the most robust techniques to analyze the number of vaccinated livestock based on the Vuong (1989) test, Greene (2012) likelihood ratio test, and various information criteria.

Descriptive analyses provide a summary overview of the livestock vaccination status of three ethnic groups who faced disease in their livestock herds and consequent livestock deaths in the twelve months prior to the survey (see table 2 for details). Even though 49.74 percent of pastoralist households have experienced livestock deaths, only 10.71 percent vaccinated their livestock in the study areas. A higher percentage of the households experiencing livestock disease—compared to households not experiencing disease—vaccinated their livestock, which is uniform across the ethnic groups. A Pearson chi-square test confirms that the difference is not significant among the ethnic groups.

We compare and contrast the findings revealed from the maximum likelihood, hurdle and zero-inflated estimations. Results from zero-inflated models, which explain excess zeros based on household types, indicate that pastoralist households that are socially and economically active, have at least one wage earner , and that are far from the nearest livestock extension officer are less likely than their counterparts to be in the excess zeros group. Additionally, households that experienced livestock illness are less likely to be in the excess zero group. Households facing higher vaccination costs, on the other hand, are more likely to be in the excess zero group. Both maximum likelihood and hurdle models estimate the binary choice of vaccination decision. Results indicate that households who are more socially and economically active and have wage earners are more likely decide to vaccinate their livestock. Pastoralists are more likely decide to vaccinate their livestock if the vaccination cost is low. We also find that higher per capita livestock negatively influences the vaccination decision, suggesting that the more livestock a household owns, the lower the probability that the household vaccinates their livestock. It seems a little bit surprising but not without plausible explanations. Given that pastoralists hold most of their wealth in their livestock, this finding may result from diminishing marginal utility of wealth or changing risk preferences. Pastoralists with more livestock have more options and can either sell or eat the animals at home to cope with the disease occurrence without significantly affecting the sustainability of their herd. The number of ill livestock in the past 12 months, wage earnings and vaccination cost also influence the number of vaccinated livestock positively. A household head older than 30 years of age vaccinated more livestock than their younger counterparts. Additionally, socially and economically active households have more vaccinated livestock than those that are not. Households who experience more livestock deaths due to illness vaccinate fewer livestock. In most cases, we find similar results for separate data specifications in terms of ethnic groups, except Barabaig. Results from the hurdle and zero-inflated models using the pooled data reveal a similar pattern and magnitude.

The rest of the thesis is as follows: Chapter 2 provides overview of pastoralism in Tanzania with a brief literature review. Chapter 3 explains the conceptual framework of pastoralists' averting decision, and resulting output in view of livestock diseases experienced in the past twelve months. Chapter 4 explains the sampling and survey design for data collection and the econometric estimation strategies. Chapter 5 discusses the empirical results and discussions with robustness checks. In the last chapter of the thesis, we conclude with a few policy suggestions based on the major findings.

CHAPTER 2: OVERVIEW AND RELATED LITERATURE

Pastoralism in Tanzania has a long tradition where more than 30% of the land is either pasture-friendly arid or semi-arid land (Fratkin 2001). Over the last few decades, many African pastoral systems have been transformed with increasing agriculture-based development policies, loss of pasture land, and the alteration of communal property system. Only a small portion are now actively oriented with pastoralism as their major economic activity. According to Sandford (2006), the future of pastoralism will be influenced by increasing human populations and decreasing livestock production as well as pastoralists' adaptive capacity to respond to these challenges. In addition to trying to maintain their traditional occupation, pastoralists face a high burden of livestock diseases in this region, which may be increased by climate change (Gustafson et al. 2015). Pastoralists in this area have already experienced the devastating impact of disease on livestock herd production and health. Though traditional and modern preventive options, e.g. vaccination, are available in some areas that are not sufficient enough. Moreover, related socio-economic variables actively influence pastoralist's decision making process. From this perspective, both policy analyst and pastoralist need to understand the socio-economic and behavioral factors of averting decisions, i.e. livestock vaccination, to reveal potential policy implications of practices including livestock health education, veterinary service infrastructure, and supply-side management.

Empirical exercises on household's averting decisions in general and factors affect the decision making process, in particular, have a long tradition in economics, especially in risk perception, decision under uncertainty, and valuation. The potential significance of this averting decisions to livestock vaccination has been well documented in the prior literature. Various theories have been put forward to explain the household's decision to take averting action. First of all, large theoretical works on the averting behavioral model began with the notion that an individual agent tries to minimize the risk of loss due to a specific reason. The averting behavior model can estimate the value of preventing diseases considering any action or expenditures that individuals undertake to avoid any undesirable outcome, for example, livestock illness or death. In contrast, theories of the cost of illness consider only the value of cure from livestock diseases with various direct and indirect costs. Related works on averting action or cost incurred to avoid livestock disease risks has provided insights about the theoretical frameworks on this behavior (Alberini and Krupnick 2000; Bontemps and Nauges 2016; Cropper et al. 2004; Guh et al. 2008; Mclnerney 1996). In addition, both ex-ante and ex-post measures are used where ex-ante estimates prospective costs and ex-post estimates costs of an action that have already happened.

Secondly, there are numerous empirical contributions that investigate socio-economic and demographic factors that affect the decision making process. Some of the studies analyzed impact of risk perception on averting decision models. Other studies employed actual risk components, e.g. intensity, severity, and exposure, to understand the averting decision. While some literature studies evaluate actual averting expenditure, measuring willingness to pay is commonly used. Recently, averting decision-type models explicitly consider a household's beliefs and an individual's behavioral factors to explain the cognitive side of the decision making process. These commonly include a household's beliefs on particular actions, or sometimes social learning. Some studies also estimate stated and revealed behavioral data to check the predictive validity of actual behavior.

This thesis is also related to the literature on the ex-post analysis of behavioral risk analysis (Clemen and Winkler 1999; Goldstein et al. 2004). It is closely related to the studies on technology adoption in agriculture (Adesina and Zinnah 1993; Just and Zilberman 1988; Khanna, Khanna and Zilberman 1997), and benefit-cost analysis decision framework for disease management (Nas 1996; Shwiff et al. 2013). This thesis also contributes the growing literature on averting decision and expenditure models under risks (Bontemps and Nauges 2016; Bosch-Domènech and Silvestre 2010). Since vaccination decision considers socioeconomic and cognitive factors, our results also contribute to the role of averting expenditure and other behavioral factors in determining vaccination decision.

The importance of ex-post analysis of averting decisions to reconcile the empirical evidence in the context of livestock diseases suggests two important components of pastoralists' decision making processes and consequences. The first concerns the decision making process of a rural pastoralist household in Tanzania. Regarding our empirical exercise, first we focus on cases where actions are recorded as a discrete variable and the averting decision is a binary choice. The second concern is about the estimation process where we use ex-post disease information and averting expenditure information instead of ex-post willingness to pay data. In the study, the pastoralist household, rather than an individual, is the unit of analysis in this averting decision model, where the household head with all active members would be responsible for livestock vaccination. The primary objective of this article is to use field-level survey data to understand determinants of averting behavior (vaccination). We then examine the influences of these same factors in determining the number of vaccinated livestock.

CHAPTER 3: A SIMPLE FRAMEWORK OF PASTORALISTS' LIVESTOCK VACCINATION

In the study area, most of the pastoralists have experienced disease-related livestock losses due to different types of diseases, for example, bovine and caprine pleuropneumonia, brucellosis, and foot and mouth disease in the past twelve months. For pastoralists in diverse areas of the world, livestock are an important source of food, wealth, and social status (Lybbert et al. 2004). Mdoe and Mnenwa (2007) and Ouma et al. (2006) also indicate that larger livestock herds bestow prestige upon households in Tanzania. Given the substantial benefits that households derive from livestock, livestock health is important for household wellbeing. In this view, vaccination is one way for pastoralists to safeguard their herd so that they can maintain their food supply (e.g., meat, milk), wealth, and social prestige (Chilonda and Van Huylenbroeck, 2001; Lybbert et al. 2004). One option for livestock disease control involves vaccination to reduce the probability of infection and loss. We further assume that the pastoralists' decision rule is based on maximizing their expected utility by using vaccination to minimize the expected loss due to disease (Wolf 2013).

Maximization of expected utility compares two decisions: vaccinate, v, and not vaccinate, nv. Consider a pastoralist who chooses to vaccinate if her expected utility of vaccinating, EU_v, is higher than the expected utility of not vaccinating, (EU_{nv}): $EU^* = EU_v - EU_{nv} > 0$, where the utility difference, EU^*, is a latent variable. As all attributes that affect preferences cannot be observed, we consider an observable component of utility, Z_i where ${EU_i}^* = Z_i + e_i$. We assume Z_i is linear in the parameters, $X_i\beta$. Thus

$EU_v = Z_v + e_v = X_v\beta + e_v$ and $EU_{nv} = Z_{nv} + e_{nv} = X_{nv}\beta + e_{nv}$, where X_i is the observable component that affects the pastoralists' averting (vaccination) decision, D_v. Rewriting the previous expected utility function as $EU^* = EU_v - EU_{nv} = X'(\beta_v - \beta_{nv}) + (e_v - e_{nv})$, where EU^* is not observed, but we can observe the averting decision. In this case, McFadden (1973) suggested the random utility function for separable decision analysis, which models a binary choice variable, where $D_v = 1$ if the pastoralists vaccinate their livestock, or $D_v = 0$ if not. This specification can be estimated through the following form:

(1) $$D_v = X'\beta + e$$

As the pastoralists' vaccination decision is a sequential, two-stage process, after deciding to vaccinate or not to vaccinate, they decide how many livestock to vaccinate, V_{ls}. Based on equation (1) we can write the following:

(2) $$V_{ls} = \begin{cases} \geq 0 \; if \; D_v = Yes \; (decide\ to\ vaccinate\ by\ 'not\ always\ zero'\ group\ of\ pastoralist) \\ = 0 \; if \; D_v = No \; (decide\ not\ to\ vaccinate\ by\ 'always\ zero'\ group\ of\ pastoralist) \end{cases}$$

Pastoralists who are not concerned about vaccination decide not to vaccinate, with a number of vaccinated livestock always equal to zero. This type of pastoralist generates 'excess' zeros. Other households desire to have positive numbers of vaccinated livestock, but some may have zeros due to several potential constraints, such as a lack of financial ability to pay for vaccination; these observations are known as ‘true’ zeros. In this respect, modeling true and excess zeros is essential to explain all potential situations.

CHAPTER 4: DATA AND METHODOLOGY

4.1 Sampling and Survey Design

The empirical basis of this thesis is a pastoralist household survey conducted in 2012 in Pawaga and Idodi divisions near Ruaha National Park and community wildlife management areas of Iringa region, Tanzania (Figure 2) as part of a larger, long-term study on pastoralist households (Gustafson et al. 2015). As the Iringa Rural district has a large population of pastoralists (NBS 2013) who face a considerable livestock disease threat to heard health and household livelihoods, we selected this area for a field survey to investigate the factors associated with livestock diseases and household vaccination decisions. A two-stage stratified random sampling approach was employed to select the pastoralist households from Pawaga and Idodi divisions. The sampling framework includes ‘village’ as a primary sampling unit, and ‘household’ as the ultimate sampling unit. We randomly selected 196 households from 21 villages to collect necessary information.

A structured questionnaire was employed to collect pastoralists’ household information. We collected data on herd size, livestock vaccination status, herd-level morbidity and mortality data collected by livestock disease signs, and variables that influence the vaccination decision, e.g., vaccination cost, distance to livestock extension officer, and non-livestock sources of income. In addition, information related to household size and residents, and geographical and community characteristics were collected to assess the vaccination status of the study area. We grouped all the households into three different strata based on ethnicity as a post-stratification procedure to capture any potential differences among the ethnicities.

4.2 Estimation Strategy

We use a two-stage estimation strategy to examine the factors affecting households' decision-making processes and outcomes. We analyze the effects of socio-economic, behavioral, demographic and group variables on pastoralists' binary averting decision and the number of livestock vaccinated. Finally, we employ various robustness checks to examine the consistency of the estimated results.

According to equation (2), the decision variable is a binary output where $D = 1$ if the i^{th} household vaccinates their livestock, and $D = 0$ if they do not. This binary decision outcome can be modeled using various econometric estimations. Variants of maximum likelihood estimators (MLEs), such as the probit, are frequently used technique to model binary dependent variables. In addition, logistic regression, another variant of MLE is consistent, but only unbiased for large sample sizes; that is, estimates can be biased when sample size is small. Pre-estimation descriptive statistics on survey data reveals that 21 out of 196 (10.71% of total) respondents reported vaccinating livestock. As our binary decision variable consists of very few positive responses, we consider three different logistic approaches that account for rare events in the dependent variable. First, we consider an exact logistic regression model that is appropriate when the dependent variable is binary and sample size is small. As our sample size is around 200, and the number of degrees of freedom of the regression model is high, we don't report these results. Second, we employ King and Zeng's (2001) bias correction method for logistic estimation, which incorporates the probability of rare events. Finally, we use the penalized maximum likelihood procedure proposed by Firth (1993) to reduce small-sample bias in maximum likelihood estimation. Firth's method is an alternative to the exact logistic regression method when there are rare events (Heinze and Schemper 2002). We also estimate the marginal effects of the covariate, which is the expected instantaneous rate of change in the outcome variable as a function of a marginal change in that covariate, holding all other covariates in the model constant. Then, we compare the marginal effects and related model fit statistics (see Table 4) of four MLEs of pastoralists' averting decisions. We do not consider any variants of zero-truncated techniques because they predict zero counts even though there are no zeros in the outcome variable. Most notably, this estimation procedure is only recommended for large datasets.

The second part of the econometric estimation examines the impacts of the same set of regressors on the number of vaccinated livestock as the second sequence of pastoralist's averting decision making (vaccination). For this purpose, we consider the proportion of zeros in the outcome variable and the distribution of nonzero counts. Since the outcome variable has many zero observations, it may be that 'true' zeros—pastoralists' choices not to vaccinate made after weighing the costs and benefits of vaccinating—are conflated with 'excess' zeros, which reflect households that would never consider vaccinating. Preliminary descriptive statistics find a considerable over-dispersion in the outcome variable where the variance of the number of vaccinated livestock is quite high relative to its mean. Following Cameron and Trivedi (2009), we also test the null hypothesis of equidispersion through auxiliary regression, and find some evidence of overdispersion, though it is not statistically significant. There is also a considerable gap between observed zeros (89.29%) and predicted zeros (30%) through Poisson analysis. In this case, both Hurdle and zero-inflated models with or without overdispersion are suitable to explain the high occurrence of zero in the observed outcome variable.

The reason behind excessive 'zero' observations in count data models is generally explained by two separate views. If we consider the averting decision-making process as a two-step, sequential process, the 'hurdle' model can better explain the decision tree and the outcome data. The hurdle model is "a modified count model in which the two processes generating the zeros and the positives (count data) are not constrained to be the same" (Cameron and Trivedi 1998, pp. 137). The hurdle model assumes that all zero observations are from one structural source. In this case, we assume that only concerned pastoralists (due to disease information) vaccinate livestock, and their counterparts do not consider vaccinating their livestock. Hence, the zero observations arise only from the unconcerned pastoralist. Symbolically,

$$(3) \quad E(ls_i = x_i) = \underbrace{Pr(not\ vaccinate) * 0}_{generates\ zero\ observation} + \underbrace{Pr(vaccinate) * 1}_{generates\ count\ observation}$$

Letting ls be the number of vaccinated livestock by the i^{th} household where $Pr(not\ vaccinate)$ presents the probability that i^{th} household will exist in the zero-vaccination state, and $Pr(vaccinate)$ turns into the probability for nonzero (count)-vaccination state. Assume that $Pr(ls_i = x_i = 0) = \varphi$ and $Pr(ls_i = x_i \geq 1) = (\frac{1-\varphi}{1-e^{-\lambda}})(\frac{\lambda^{x_i} e^{-\lambda}}{x_i!})$, where λ is a truncated Poisson distribution. On the other hand, standard zero-inflated count data models assume that the zero observations are generated from both structural and sampling sources. In this context, separate examinations for true zeros and excess zeros are essential for predicting count observations, and to predict membership in the excess zero group.

Zero-inflated models are generally a finite mixture model, the first part predicts the excess zeros in 'always zero' pastoralist group, and second part of which predicts the number of vaccinated livestock in 'not always zero' pastoralist group. Across the study area in Tanzania, we find most of the households have zero vaccinated livestock, which is due to the presence of both true (generated by 'not always zero' group of pastoralist) and excess zeros (generated by 'always zero' group of pastoralist).

$$(4) \quad E(ls_i = x_i) = \underbrace{Pr(not\ vaccinate) * 0}_{generates\ certain\ zero} + \underbrace{Pr(vaccinate) * E(ls = x|vaccinate)}_{generates\ count\ observation\ with\ excess\ zero}$$

The plausible reasons for having true zeros due to deciding not to vaccinate, are basically two-fold: i) either they prefer alternative uses of the infected livestock, e.g., eating the meat in the household, or selling the livestock to others; or ii) any other financial and geographical constraints limit vaccination, e.g. distance to vaccination services or low availability or high costs of vaccines. In some cases, both reasons may contribute. Therefore, we consider variants of the negative binomial model, which includes Poisson, zero-inflated Poisson and zero-inflated negative binomial to correct for the excess zeros and over-dispersion problem simultaneously (Lambert 1992**).**

Though the response variable **(**figure 1**)** shows a Poisson distribution with inflated zeros, we cannot consider the basic Poisson regression model as this model assumes equality between mean and variance. As the data contain significant numbers of households choosing not to vaccinate, comprising both true and excess zeros, some variant of the zero-inflated model, such as zero-inflated negative binomial (ZINB) and zero-inflated Poisson (ZIP) estimation, are typically employed to correct the excess zeros and over-dispersion problem. All zero-inflated models consider two possible data generating processes. The first process with probability φ_i generates only zero counts, whereas the second process with probability $1-\varphi_i$ generates positive counts from either a Poisson or negative binomial model. Specifically,

$ls_i \sim \begin{cases} o\ with\ probability\ \varphi_i \\ g(ls_i|x_i) with\ probability\ 1-\varphi_i \end{cases}$ where the probability of $g(ls_i|x_i)$ is the following:

$$(5)\quad Pr(LS_i = ls_i|X_i, Z_i) = \begin{cases} \varphi(\gamma' Z_i) + \{1-\varphi(\gamma' Z_i)\} g(0|x_i) & if\ ls_i = 0 \\ \{1-\varphi(\gamma' Z_i)\} g(ls_i|x_i) & if\ ls_i > 1 \end{cases}$$

Here γ is the vector of zero-inflated coefficients to be estimated, and Z_i' is the vector of zero-inflated covariates. Theoretically, the negative binomial (NB) incorporates the general Poisson model, whereas the ZINB model incorporates the ZIP model. The ZINB (ZIP) model consists of two separate models, a negative binomial (Poisson) model to predict the count data and the logit or probit model to predict the excess zeros. Then it combines both models by adjusting the probabilities of count information in the Poisson regression for observations that are true zeros. For our purpose, a logit model is employed to predict pastoralists' vaccinated livestock data for true zeros. After that, a negative binomial (Poisson) model is generated to predict excess zeros.

Considering the descriptive features of the dataset, we estimate two different models and use post-estimation tests to determine which fits the data better. Significant z-test statistics from the Vuong (1989) test reveals that either the ZINB or ZIP model would be preferred to the standard negative binomial model. However, a significant likelihood ratio test between ZINB versus ZIP models proposed by Greene (2012) reveals that data are over-dispersed, and that the ZIP model is more appropriate than the ZINB model. Finally, we compare all four estimated models, following Long and Freese (2014), based on AIC, BIC, and Vuong test statistics to find the preferred model(s).

We consider that the vaccination decision and resulting number of vaccinated livestock is associated with socioeconomic variables. According to Raullt and Krebs (2014), a household's vaccination decision depends on prior experiences with relevant outcomes, such as disease occurrence and the degree of severity. The expected cost of disease avoidance and preventive expenditure are other influencing factors in this analysis (Chilonda and Van Huylenbroeck 2001). Moreover, the decision is likely influenced by households' geographical locations. Under this framework, equation (2) can be modeled through the following vaccination equation that describes the number of vaccinated livestock equation (3), which is influenced by associated factors included in right-hand side:

(6) $D_v, V_{ls} = f(Z_{ed}, Z_{cc}, Z_{hc};\ \beta, \varepsilon),$

where Z_{ed} is the vector of disease information consisting of livestock illness and death in the past twelve months; Z_{cc} is the vector of livestock vaccination and travel costs to access veterinary services; Z_{hc} represents the vector of pastoral household's characteristics. The estimated parameters are captured by β, the vector of coefficients for exogenous variable x, whereas the error term, ε presents the combined effect of the omitted variables of the estimation model (Freedman 2005). We also include a dummy variable as 'socially and economically active household' ($S\&E\_d$) that has been constructed from three other variables- household head has at least a primary school education level, household with at least one wage earner, and household with at least one cellphone. Equation (6) is the basis of our empirical estimation. Econometric estimation strategies, presented in chapter 4, are employed to reveal the vaccination equation to test and predict how socio-economic and behavioral factors affect pastoralists' vaccination decisions.

CHAPTER 5: EMPIRICAL RESULTS AND DISCUSSIONS

In this chapter, we present the variables included in the maximum likelihood and mixture models (see Table 1), and descriptive statistics of vaccination status in terms of livestock illness and death. We also present and explain the econometric estimations of the vaccination decision model and number of vaccinated livestock model with related discussions followed by robustness checks.

5.1 Descriptive Statistics

Descriptive statistics presented in Table 2 provide a summary overview of the livestock vaccination status of three ethnic groups who faced disease infection and deaths in the past twelve months. Even though 49.74% of households have experienced livestock deaths, only 10.71% vaccinated their livestock in the study areas. A higher percentage of the households experiencing livestock disease—compared to households not experiencing disease—vaccinated their livestock, which is uniform across the ethnic groups. The percentage of vaccination is lower, around 11% of studied households, for households that experienced more livestock deaths than their counterparts. We also find that a higher percentage of pastoralists did not vaccinate their livestock who experienced livestock deaths. The difference is small, but a slightly higher percentage of pastoralists who experienced livestock illness vaccinated their livestock than those who experienced livestock deaths. However, a Pearson chi-square test shows that the difference is not significant among the ethnic groups. The ratio of vaccinating and not-vaccinating households shows the same pattern for the pastoralist who experienced both livestock illness and death simultaneously.

5.2 Econometric Results

We report the results from both maximum likelihood estimations for pastoralists' averting decision and mixture models for the number of vaccinated livestock. All full reported models presented in this chapter include a wage earner dummy, and a socially and economically active household dummy to account for the extra monetary income and social heterogeneity in terms of livestock assets.

First, we report the results of maximum likelihood estimations to check the factors affecting vaccination decision in table 3. Furthermore, we compute essential model fit indicators to compare the relative quality of all estimated models and to reveal a parsimonious and robust model following Long and Freese's (2014) procedure. We find that the results from a penalized logit and bias corrected logit are more appropriate from theoretical and econometric backgrounds, although we also report standard logit and probit estimations for comparison. As the coefficients of maximum likelihood estimations are not easily explainable, we calculate the marginal effects to measure the instantaneous rate of change of continuous variables and discrete change of dummy variables, respectively. Moreover, we also compare the results of hurdle mixture models that predict the vaccination decision. In every case, the magnitude and level of significance are found to be quite similar.

Table 3 and part 2 of table 4 show that the marginal effect of illness incidence on vaccination decision is positive and significant at the 1% level. We also find a statistically significant difference in the means of the number of illness incidents between vaccinating (21.112) and not-vaccinating (9.382) groups of pastoralist. This result supports our initial conjecture and hypothesis that states that experienced livestock illness events influence pastoralists to decide to vaccinate their livestock. This result also corresponds to theoretical evidence on decision under actual risk components provided by Dijkhuizen et al. (1994); Fox et al. (2007), Kahneman and Tversky (1979) and experimental evidence cited in Chilonda and Huylenbroeck (2001). Additionally, we find the impact of the number of dead livestock is not statistically significant in our specified model, and the mean difference, reported in table 1, is also insignificant for both vaccinated (15.085) and not-vaccinated (10.113) groups of pastoralist. Therefore, we do not find support for the hypothesis that livestock deaths increase the number of livestock vaccinated.

It is sometimes argued that monetary income such as wage earnings from family members positively affects the probability that households take measures to avoid risky events. In this study, we find that having at least one wage earner has a positive and significant impact on the vaccination decision. Moreover, pastoral households who are socially and economically active are more likely to vaccinate their livestock, which is significant at the 10% level. Across the study area, pastoralists who are educated, financially able and may have better access to information are more likely vaccinate their livestock. This is also consistent with empirical evidence obtained in the study by Covarrubias et al. (2012).

On the other hand, we also observe that higher per capita livestock has negative and significant impacts on vaccination decision at 1% level. The result simply conveys that pastoralist households owning a higher number of livestock per family member are less likely vaccinate their livestock. Though it seems counterintuitive, there are a few potential explanations. Pastoralists with higher livestock per capita have more options to either sell sick livestock in nearby markets or eat at home to minimize disease risk and consequent deaths. Given that livestock represent a store of wealth, it may represent a decreasing marginal utility of wealth. Risk attitudes may also change with wealth level, but in practice, eliciting risk attitude under a certain circumstances determined exogenously. We therefore need to make assumptions on the possibility of different risk attitudes of pastoralists in view of livestock diseases incidences and death. Vaccination cost also has a negative impact on averting decisions. When the price of a vaccine is higher, households are less likely to vaccinate. We also compute related model fit indicators for all four estimations. Finally, the predicted probabilities do not change much across the models.

Table 4 presents the marginal effects of the mixture models in two separate but consecutive parts. First we consider the estimations of predicting the vaccination decision for hurdle models, and excess zero group of the zero inflated models. Then we consider the results of the model of the number of vaccinated livestock. Results reported in part 2 of zero-inflated models determine whether the observed count is zero. It indicates that socially and economically active pastoralists are less likely to be in the always zero group. Additionally, pastoralists who experienced higher incidences of livestock illness and resided comparatively far from the livestock extension offices are less likely than their counterparts to be in always zero group. Conversely, the higher the vaccination cost, the more likely the household is in excess zero group.

Considering zero inflated models, we know that pastoralists who are not in the excess zero group, have decided to vaccinate have at least few vaccinated livestock. So, we compare the findings revealed from the two variants of hurdle and zero-inflated models that predicts the number of vaccinated livestock (see part 1 of table 4). The number of vaccinated livestock is influenced positively by the number of livestock illnesses experienced by the household in the past twelve months. This may be because pastoralists feel more risk of losing their livestock asset when they face frequent incidences of illness. Moreover, the predicted probability of vaccinated livestock is higher for the pastoralist who has at least one wage earner. Monetary income, especially from wage earners, increases the financial ability to vaccinate more livestock to cope with future disease risks. We further find that higher vaccination costs increase the number of vaccinated livestock.

We also find that a few variables in the model have significantly negative impacts on the predicted number of vaccinated livestock. Both Poisson and negative binomial variants of hurdle and zero-inflated model reveal similar predictions. As per part 1 of table 4, household head older than 30 years have less vaccinated livestock than their counterparts. The estimated coefficient of the dummy variable for socially and economically active households is negative and significant at the 10% level. More active households would have fewer vaccinated livestock compared to those who are not active. The most justified explanation of this finding-they know alternative options to cope or minimize the diseases incidences and severity. Moreover, households that experienced more livestock death have a significantly lower number of vaccinated livestock. In addition, we only find significant marginal effects in case of Poisson estimations for per capita livestock and travel cost dummy. However, negative binomial estimations predict statistically insignificant marginal effects that indicate a lower level of robustness to generalize the impacts of the variables in determining the number of vaccinated livestock.

5.3 Robustness Check

In both discrete choice and count data models, estimations related to livestock deaths are not significant, and vaccination cost contradicts the predictions of conventional theories. Moreover, few marginal effects of both components of mixture models show same direction which is opposite in general. All these queries require further investigation through several robustness checks.

As a part of post-estimation robustness checks, we estimate both models under different specification that includes the set of covariates regarding households' prior disease experience, vaccination and travel cost, and household characteristics successively to check the consistency. Following Barslund (2007), we consider disease information as a set of core variables, and others as the set of non-core covariates. In every step, we find consistent results with a few exceptions. Further, we also estimated other variants of the hurdle model, reported in Table 4 including Poisson-bias corrected logit, Poisson-penalized logit, negative binomial-bias corrected logit, and the negative binomial-penalized logit due to the presence of excessive zeros. We also calculate the predicted probabilities of all estimated models that do not meaningfully change. Moreover, we run regressions on data that pool data for the three ethnic groups together. In most cases, we find similar results in terms of relationship, magnitude and significance level for every alternative data specifications, except for the Barabaig ethnic group. We, then, perform Hausman (1978) specification test by controlling *ex-post* disease information, cost lines, and household's characteristics to check the consistency and conditional heterogeneity. We additionally compute all models with robust standard errors to reduce any heteroskedasticity incidence following Cameron and Trivedi (2009). These estimations confirm the robustness of main results in table 2, 3 and 4. The detail results are not reported in the main text, but codes are available in respective Stata do-file.

CHAPTER 6: CONCLUSIONS AND POLICY IMPLICATIONS

Vaccination is a key tool for livestock disease risk management (Keeling et al. 2003), but little is known about what factors drive pastoralists' vaccination choices. This study contributes to the existing literature in several ways. We used primary data generated from surveys with pastoralists in the Iringa region of Tanzania, and analyzed household-level as well as community-level information to address two of our general research questions on the factors influencing the vaccination decision. We employed multiple empirical procedures to explore the robustness of pastoralists' vaccination decisions and number of vaccinated livestock given livestock diseases and deaths experienced in the last twelve months and other economic, social and behavioral variables.

We find that pastoralist households that are socially and economically active and have at least one wage earner are more likely to decide to vaccinate their livestock. Moreover, the occurrence of livestock illness also has a significant positive impact on averting decision. We also find consistent results from a few variants of mixture models, for example hurdle and zero-inflated models where the same set of variables predicts that pastoralists are less likely to be in the excess zero class. We further find that a high prevalence of livestock illness, higher vaccination cost, and wage earners in the household are positively related to the number of vaccinated livestock. On the contrary, higher numbers of dead livestock due to diseases, high travel cost in terms of distance from extension offices, and households with older heads of household have significantly lower number of vaccinated livestock.

Finally, we propose a few lessons relevant to policy based on our findings. First, lowering the cost of vaccination would likely increase pastoralist's vaccination decision. As proposed by McLeod and Rushton (2007), a vaccination support program would be helpful for low-income pastoralists. Second, government and NGOs can invest in frequent and extensive livestock health education and management, training, and infrastructure, which would be beneficial for both pastoralist households and extension officers (Allport et al. 2005; Perry et al. 2013). Though pastoralists have traditional knowledge, training on emerging diseases and treatments should positively influence vaccination uptake. Third, infrastructure development for vaccination support programs and convenient delivery systems are essential to help low-income pastoralists (Mazet et al. 2009). Currently there are no commercial veterinarians or dispensaries operating in many rural parts of Tanzania, even though the Tanzanian government intended to phase out government veterinary services (except in the case of public goods) in favor of private practices over a decade ago (Gustafson et al. 2015). Fourth, convenient access to information (e.g., veterinary services, market price) through mobile phones would increase the awareness of disease, treatment options, and vaccination decisions. In this respect, Wolf (2005) suggests the same.

Our study considers static-type models based on cross-sectional data. We are therefore unable to provide dynamic explanations of the decision-making process of pastoralists on livestock assets and disease risk management, where an appropriate panel study can reveal time-dependent changes. Moreover, this exercise does not capture spatial elements that may be relevant. Future research can address these shortcomings.

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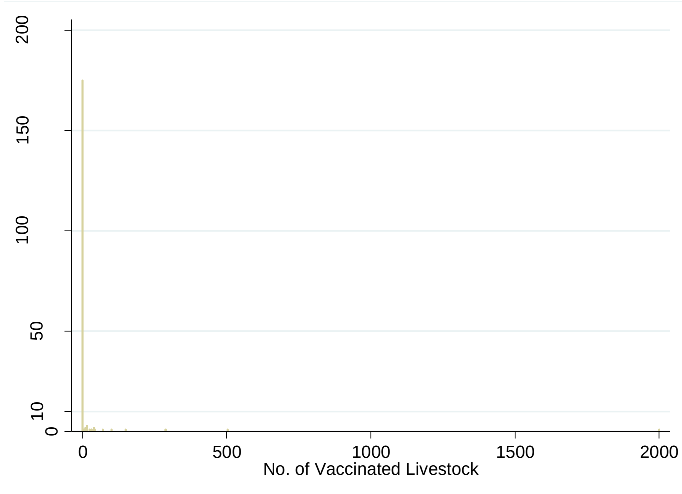

Figure 1. Distribution of Vaccinated Livestock

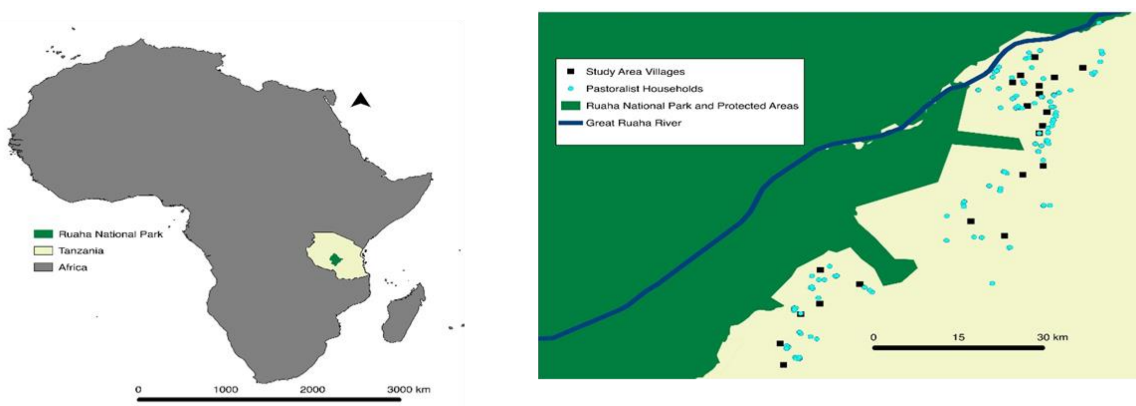

Figure 2. Map of the Study Area

Appendices

Table 1. Description of Model Variables

Variable	Description	Livestock vaccination status		
		Vaccinated $\bar{X}(sd)$	Not vaccinated $\bar{X}(sd)$	Pooled $\bar{X}(sd)$
Dependent variables				
vac_ls_d	Indicator variable of livestock vaccination status (1 if vaccinated, 0 if not)	-	-	0.107(0.310)
vac_ls	Number of vaccinated livestock (in TLU) in the past 12 months	162.933***(437.377)	0.000(0.000)	17.457(148.906)
Ex-post diseases information				
ill_ls	Number of livestock's ill incidence in the past 12 months	21.111***(44.488)	9.382(9.208)	10.639(17.084)
$dead\_ls$	Number of died livestock (in TLU) in the past 12 months	15.085(29.669)	10.113(14.440)	10.645(16.695)
$pcls$	Per capita livestock (in TLU)	14.284***(47.906)	4.251(5.087)	5.326(16.376)
Costs of vaccination				
vac_cost	Vaccination cost (in TZS) for infected livestock	3.97e+7(2.02e+7)	1.61e+7(1.2e+6)	1.86e+7(3.46e+7)
$travel\_cost\_d$	Indicator variable of travel cost of vaccination (1 if distance is medium to high, 0 if none to low)	3.333*(0.967)	2.823(1.138)	2.878(1.130)
Household characteristics				
age_group_d	Indicator variable of household (HH) head's age (1 if HH head's age more than 30 years, 0 if unknown and less than 30)	0.810(0.402)	0.777(0.417)	0.781(0.415)
$wage\_d$	Indicator variable of household's wage earners (1 if HH has at least one wage earner, 0 if not)	0.190**(0.402)	0.051(0.222)	0.066(0.249)
$S\&E\_d$	Indicator variable of socially and economically active household (1 if primary educated HH head with at least one cellphone has extra earnings from different sources like wage labor, remittance, selling cultural goods, 0 otherwise)	0.190**(0.402)	0.057(0.233)	0.071(0.258)

Notes: ***, ** and * represents the level of significant at 1%, 5% and 10% of the t-test for equality of means of the vaccinated and non-vaccinated pastoralist household.

Table 2. Ex-post Livestock Diseases and Vaccination Status

Ethnic group	Livestock's illness incidence				Pearson χ2 (p-value)	Livestock's death				Pearson χ2 (p-value)
	Experienced		Not experienced			Experienced		Not experienced		
	Vaccinate	Not vaccinated	Vaccinate	Not vaccinated		Vaccinate	Not vaccinated	Vaccinate	Not vaccinated	
Barabaig	6.00	35.00	0.00	1.00	0.227	5.00	16.00	3.00	20.00	0.855
	(18.60)	(81.40)	(0.00)	(100.00)	(0.633)	(23.81)	(76.19)	(13.04)	(86.96)	(0.355)
Massai	12.00	109.00	0.00	1.00	0.110	6.00	54.00	6.00	56.00	0.004
	(9.92)	(90.08)	(0.00)	(100.00)	(0.740)	(10.00)	(90.00)	(9.68)	(90.32)	(0.952)
Sukuma	1.00	29.00	0.00	0.00	-	0.00	17.00	1.00	12.00	1.353
	(3.33)	(96.67)	(0.00)	(0.00)		(0.00)	(100.00)	(7.69)	(92.31)	(0.245)
Total	21.00	173.00	0.00	2.00	0.243	11.00	87.00	10.00	88.00	0.053
	(10.82)	(89.18)	(0.00)	(100.00)	(0.622)	(10.20)	(88.78)	(10.20)	(89.90)	(0.817)

Notes: Figures in parentheses are percentage of household.

Table 3. Marginal Effects of Maximum Likelihood Estimations for Pastoralists' Averting Decisions

Variable	Logit	Probit	Bias Corrected Logit	Penalized Logit
	dy/dx (se)	dy/dx(se)	dy/dx(se)	dy/dx(se)
Illness incidence	0.007**(0.003)	0.007**(0.003)	0.069(0.045)	0.079**(0.035)
Dead livestock (in TLU)	0.001(0.001)	0.001(0.001)	0.007(0.010)	0.010(0.011)
Per capita livestock	-0.002(0.004)	-0.002(0.006)	-0.216***(0.039)	-0.044*(0.027)
Vaccination cost (in TZS)	0.058* (0.033)	-0.066*(0.040)	-0.138(0.409)	-0.705*(0.397)
Travel cost dummy	0.080*(0.044)	0.082*(0.047)	0.887(0.635)	0.957(0.631)
Age group dummy	0.042(0.047)	0.050(0.053)	0.391(0.602)	0.465(0.622)
Wage earner dummy	0.110**(0.052)	0.129**(0.063)	1.449**(0.643)	1.495**(0.656)
S&E active HH dummy	0.105**(0.052)	0.127**(0.063)	1.407**(0.637)	1.450**(0.666)
Log likelihood	-55.349	-55.363	-	-38.972
LR χ^2	22.55	22.52	-	-
Wald χ^2	-	-	-	19.78 (0.011)
Pseudo R^2(p>χ^2)	0.169(0.004)	0.169(0.004)	-	-
Sample size	195	195	195	195

Notes: 'dy/dx' and 'se' indicates marginal effect after regression and standard error, respectively. *p<0.10, **p<0.05, ***p<0.001.

Table 4. Marginal Effects of Mixture Models for No. of Vaccinated Livestock by Pastoralist

Variable	Poisson-Logit Hurdle (PLH)	Negative Binomial-Logit Hurdle (NBH)	Zero-Inflated Negative Binomial (ZINB)	Zero-Inflated Poisson (ZIP)
	dy/dx (se)	dy/dx (se)	dy/dx (se)	dy/dx (se)
Part 2: Predicting number of vaccinated livestock (count data)				
Illness incidence	0.011**(0.005)	0.014(.011)	0.014(0.011)	0.011**(0.011)
Dead livestock (in TLU)	-0.010***(0.001)	-0.009***(0.003)	-0.009**(0.003)	-0.010***(0.001)
Per capita livestock	-0.002***(0.003)	-0.003(0.008)	-0.003(0.008)	-0.002(0.003)
Vaccination cost (in TZS)	0.711***(0.094)	0.622***(0.159)	0.621***(0.159)	0.711***(0.094)
Travel cost dummy	-0.327***(0.136)	-0.285(0.240)	-0.285(0.240)	-0.327***(0.136)
Age group dummy	-0.923***(0.075)	-0.976(0.216)	-0.976***(0.216)	-0.923***(0.075)
Wage earner dummy	0.724***(0.080)	0.640***(0.203)	0.639**(0.203)	0.724***(0.080)
S&E active HH dummy	-0.302***(0.109)	-0.225***(0.230)	-0.224(0.229)	-0.301***(0.109)
Part 1: Predicting vaccination decision (for PLH, NBH) and excess zeros (for ZIP, ZINB)				
Illness incidence	0.086**(0.039)	0.085**(0.039)	-0.086**(0.039)	-0.086**(0.039)
Dead livestock (in TLU)	0.013(0.012)	0.013(0.013)	-0.013(0.013)	-0.013(0.012)
Per capita livestock	-0.029(0.058)	-0.029(0.058)	0.029(0.058)	0.029(0.058)
Vaccination cost (in TZS)	-0.814*(0.445)	-0.814*(0.445)	0.814*(0.445)	0.815***(0.445)
Travel cost dummy	1.131*(0.683)	1.131*(0.683)	-1.131*(0.683)	-1.131***(0.683)
Age group dummy	0.591(0.669)	0.591(0.669)	-0.591(-0.669)	-0.591(0.669)
Wage earner dummy	1.561**(0.708)	1.561**(0.708)	-1.561**(0.708)	-1.561**(0.708)
S&E active HH dummy	1.490**(0.709)	1.490**(0.709)	-1.491**(0.709)	-1.491**(0.709)
/lnalpha	-	-2.512***(0.570)	-2.513***(0.570)	-
alpha	-		0.081(0.046)	-
Nonzero observations	21		21	21
Log likelihood	-142.997	-141.430	-141.437	-143.005
LR χ^2	-		64.760	10038.470(0.000)
Wald χ^2	16.200 (0.0400)	16.200(0.400)	-	-
LR Test ($\overline{\chi^2}$)	-		3.140(0.038)	-
$z(p - val)$ of Voung Test	-		3.540(0.000)	4.410(0.000)
Sample size	195	195	195	195

Notes: 'dy/dx' and 'se' indicates marginal effect after regression and standard error, respectively. *p<0.10, **p<0.05, ***p<0.001.