**Diagnostic Testing and Vaccine Matching: FMD in Tanzania**

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**Abstract:** Our interest is the private provision of a surveillance measure with public good characteristics that enhances vaccine matching. We examine factors that contribute to household willingness to pay for a diagnostic test collectively purchased at the community level and proposed as a technology to mitigate information externalities on vaccines. Two regions in northern Tanzania were surveyed where an endemic livestock disease, foot and mouth disease, occurs regularly, but where limited control measures exist. We find that resource availability, information networks, veterinary services, and experience with livestock health related technology influence willingness to pay for diagnostic tests.

**Introduction**

Foot and mouth disease (FMD) is one of the prominent livestock diseases that constrain welfare of rural households in Tanzania and across the world (Knight-Jones & Rushton, 2013), with households in northern Tanzania reporting up to three outbreaks a year (Casey-Bryars, 2016). The disease, spreading rapidly and with relative ease between animals, reduces household income and compromises food security through decreased milk production and losses in animal draught power. While the signs and symptoms of FMD are identifiable, the virus comes in seven different strains each requiring the appropriately matched vaccine to protect against the disease. With four strains of FMD circulating in Tanzania (Kasanga et al., 2015), vaccine matching becomes increasingly complex and important to optimize it's impacts. The current and past vaccines available in Tanzania fail to match the diversity of strains, resulting in very low efficacy (if any at all) and inducing high uncertainty in the decision-making process of vaccine adoption (Railey and Marsh, 2017).

In the past, Tanzanian households have reported unsuccessful experiences with FMD vaccines, which were not matched to the appropriate strain. Current diagnostic tests provide proof of a negative, or absence of FMD, but do not identify the strain of FMD. Ideally diagnostic tests need to identify not only animals to be vaccinated, but more specifically, identify the circulating strain of a virus (Knight-Jones et al., 2016). Recent advances in serotype mapping introduces the possibility of then matching vaccines to a specific FMD strain (Bari et al., 2014; Casey, et al., 2016; Kasanga et al., 2015). A diagnostic test that provides the means to detect the presence of the virus (or not) and a specific strain would reduce the uncertainty associated with management of FMD and enhance the likelihood of improving the welfare of the household.

It is interesting and useful to compare vaccination with diagnostic testing. Households pay for vaccines with the anticipation of individually realizing the direct benefit due to protecting

the vaccinated cattle from incurring the disease, and simultaneously providing a positive externality by helping curb the spread of the disease (Brito, Sheshinski, & Intriligator, 1991). Like vaccines, diagnostic testing provides a direct benefit to those individuals administrating the test. Unlike vaccines, the potential positive spillover to other households is in the form of improved knowledge about vaccine matching. In both cases households can realize private benefits to their actions, while providing social benefits to other households albeit along different pathways. Consequently, we framed the question of willingness to pay for diagnostic testing as a new technology with collective or public good characteristics, whereby households contribute to a local fund to purchase the test and service from a government veterinarian, thereby gaining information for themselves and the community about the circulating strain with which to enhance vaccine decision-making.

While public goods by definition are non-excludable and non-rival, the provision of the good often requires community participation and acceptance (Umali, 1994). Framing diagnostic testing as a public good recognizes households have the opportunity to reduce the risk associated with innovative technology through collective action, as successfully demonstrated in agriculture technology adoption (Kassie et al., 2013; Mukasa, 2016; Teklewold, Kassie, & Shiferaw, 2013). Policy frameworks for making health decisions address the externalities associated with public and private provisions (Althouse, Bergstrom, & Bergstrom, 2010; Gersovitz & Hammer, 2003), but lack the quantitative evidence of responses and preferences to health interventions and diagnostic testing (Lin et al, 2013). The limited empirical work evaluating the public good nature of livestock inputs find that actual contributions of labor and money may be less than stated preferences (Kamuanga et al., 2001) and with less than necessary local participation to support the programs (Swallow & Woudyalew, 1994).

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Our study contributes evidence to the use of improved information as a tool for reducing livestock disease uncertainty, and ultimately improving household welfare. It furthers the research on public goods by empirically evaluating the impact of improved technological efficiency through increased knowledge of disease circulation on household decision-making. We also define the drivers behind household decisions of private contributions toward public goods in the face of externalities.

This paper presents the preliminary results from our analysis of willingness to pay (WTP) for diagnostic testing. First, we outline our research methodology, including data collection and empirical model. We use the maximum likelihood estimator for a double-bounded contingent valuation question to evaluate household stated preferences. Next, we present the preliminary results and key findings, followed by a discussion and conclusion of the empirical work.

**Data and Methods**

Respondents' stated preferences for diagnostic testing and vaccine matching knowledge are modeled according to the theory of public goods, assuming consumption preferences follow neo-classical properties. To reconcile the incentive incompatibility between utility maximization and voluntary contribution found with public goods, some theoretical interpretation becomes necessary. Instead of pure utility maximization, we assume the decision to privately contribute to a communal fund depends upon household preferences, combined with the household's perceptions of others' contributions based on beliefs about cost-sharing norms (Sugden, 2001). Availability and accessibility of resources, like veterinary services and monetary income, then constrain household preferences. Household perceptions of others and the value of diagnostic testing in relation to other goods remain unobservable outside of controlling for community level characteristics and calculating the WTP values. Community contributions can depend on the

information network within the community, with more densely populated communities interacting more often. Past experiences with vaccination and/or diagnostic testing should result in higher WTP values, while increasing herd sizes provides increasing returns to household contributions.

*Survey Design*

The survey instrument was designed, piloted, and fielded according to standard statistical and econometric approaches. A two-stage sample design followed, first selecting clusters and then households, with selected groups of households more intensively sampled than others to facilitate analysis (Deaton, 1997). We employed a double-bounded contingent valuation method to collect WTP data for a non-market good with public good implications (Hanemann, 1994). The data for this study comes from survey data collected between May 2016 and August 2016 in the Serengeti and Loliondo areas of northern Tanzania. The data includes information on basic demographics, livestock movements, and willingness to pay for control methods for 489 households. After data cleaning and adjustments for missing data, 465 households provided complete diagnostic testing WTP information.

Data from a pretest on over 50 households helped determine the initial price for the question at 4000 Tanzanian shillings (USD 1.90). The second price offered to the households ranged from 500 Tsh (USD 0.24) to 7500 Tsh (USD 3.57). To ensure the reliability of the answers provided and address issues of systematic bias found with high bid acquiescence in the willingness to pay sequence (Hanemann & Kanninen, 2001), we asked a third, open-ended question about the maximum amount the household would pay to have the test performed. For both the willingness to pay sequence and the open-ended question, the enumerators received extensive training on explaining the hypothetical scenario and recognizing when a respondent

did not understand the question. This helps lessen random error from confused or uninterested respondents. Potential limitations of the contingent valuation method that affect the validity include starting point bias and positively skewed responses (Mitchell & Carson, 1989). We alleviate starting point bias by pretesting a variety of bid levels at representative households and consulting local markets.

*Dependent Variable*

We conceptualize a household's contribution level and likelihood of adopting a hypothetical, communal good through the household's stated preference of amount to pay. We assume the price household's agree to pay measures not the actual price household's would pay, or the market price of diagnostic testing, but provides an indirect measure of the value of the good for the household (Brown, 2003).

*Independent Variables*

To measure community level effects, we conceptualize the potential for collective action through the strength of the community network structure. Communities in a densely populated spatial setting demonstrate increased intragroup trust and ability to respond to disease shocks collectively (Caudell, Rotolo, & Grima, 2015). We assess network density by considering the number of households in a given area. Using 1.5 km as a baseline for sub-village boundaries based on satellite images of the sub-villages, this distance encapsulates the immediate threat of FMD, as well as the potential for information diffusion. Each community has a separate density measure, with each household within that community receiving the same density measurement.

Households allocate money based on available resources and preferences for goods. To contribute to diagnostic testing and vaccine matching, households require a liquid income source. While households in Tanzania engage in a number of income generating activities, off-farm

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income captures household access to monetary resources beyond the farm. We differentiate between households in a low-off-farm income bracket (0-25,000 Tsh per month) with those reporting over this amount up to 1 million Tsh (USD 500) per month by using an indicator variable. This representation allows us to distinguish between low- and high-income households and test whether income constrains WTP. To evaluate the effect of information accessibility, we then consider the perceived distance a household resides from government veterinarians. This measure combines household stated distances to the main government veterinary offices with those to the in-field veterinarians (livestock field officers) suggesting households further from these sources will pay less due to limited access (Ahmed, Yoder, & Quinlan, 2016).

Household perceptions of diagnostic testing depend upon herd size and if households knew about diagnostic testing and/or vaccines before receiving a description of the test. Households reported total herd size when asked as an open-ended question with herds ranging from 1 to 530 heads of cattle. The clustering of herd sizes between 1 and 50 heads (mean 42, median 22) necessitates a logarithmic transformation of the variable. We hypothesize households with larger herds receive greater marginal benefits from contributing resulting in higher total contributions. An indicator variable denotes whether households have experience with diagnostic testing and/or vaccines. If a respondent said 'I don't know,' this was counted as a 'no.' We expect experience with technologies like the one proposed in the study will increase household WTP.

Finally, when performing the survey, we attempted to control for inexperience with diagnostic testing and vaccines by presenting households with a simplified visual of the vaccine process, accompanied by a short narrative on the complicated nature of FMD. About five

households in each village for a total of 43 households received the visual aid and explanation before responding to the willingness to pay questions.

*Summary Statistics*

Households in our study maintain around 42.19 head of cattle (median 22) (Table 1). Of these households, 45 percent have some previous knowledge of diagnostic testing and/or vaccines. Over half of the households receive limited or no income from off-farm activities (65 percent), with perceived distances from government veterinarians ranging from 0 kilometers (within the community) to 50 kilometers (mean 7.86 km, median 3.0 km). At the village level, communities range from few households within a 1.5 km radius (7.07 households) to a more urban center (67.15 households). Household responses to the open-ended WTP question (collected but not included in the regression analysis) ranged from 0 Tsh to 20000 Tsh (USD 9.52) for a mean of 4260 Tsh (USD 2.03) (median 4000 Tsh~USD 1.90) and a standard deviation of 3184 Tsh (USD 1.52).

**Preliminary Results**

Using a maximum likelihood estimator adjusted to account for the two-bid responses (Hanemann, Loomis, & Kanninen, 1991), the reported model coefficients reflect the marginal effects taken at the mean value of that variable, with the resulting WTP a linear function of the maximization of the reported values (López-Feldman, 2013). We determine the model of best fit through a comparison of Bayesian information criterions and Wald chi-square statistics. The results indicate general household willingness to pay for diagnostic testing. Table 2 presents the results from the current econometric model.

Previous experience with the technology in question and availability of household monetary resources has statistically significant and economically important implications for

household WTP at the 1 percent significance level. Households with lower levels of off-farm monthly income have a lower WTP for diagnostic testing when compared to households with income over 25,000 Tsh per month. The difference in the two is 1923 Tsh (USD 0.92), or the equivalent of 5 cows when considering household contributions per head of cattle at 406 Tsh (USD 0.19). In contrast, having experience with some form of diagnostic testing and/or cattle vaccinations in the past year increases household WTP. Those households with predefined expectations regarding diagnostic testing and vaccinations have WTP values 1145 Tsh (USD 0.55) higher than those with no previous experience.

The remaining model coefficients additionally affect preferences at differing levels of statistical and economic significance. The variable to account for the differences in communities based on the assumption population density affects information diffusion and group cohesion contradicts our predictions. At the 5 percent significance level, an additional household within a 1.5 km radius decreases WTP for communal diagnostic testing by 28 Tsh (USD 0.01). Similarly, at the 1 percent significance level, an increase in the distance of government veterinary services by the equivalent of one kilometer increases household WTP by 80 Tsh (USD 0.04) instead of decreasing WTP. The marginal effects from these two variables have minimal economic implications in comparison to the other determinants.

Including herd size to account for discrepancies in cattle holdings does not provide statistically significant or economically influential results. Controlling for whether households received a brief introduction to FMD, vaccine matching, and diagnostic testing through visual aids appears to affect household decisions. At the 10 percent level of significance, the portion of the households receiving the visual aid report lower WTP values by 1278 Tsh (USD 0.61) than those who did not receive the information.

Of the 465 households with complete responses to the willingness to pay sequences, 65 percent indicate they would pay for diagnostic testing to be performed by a livestock field officer at some price point (Table 3). The calculated WTP price for diagnostic testing from the double bounded maximum likelihood estimator averages around 6202 Tsh (USD 2.94) with a standard error of 245 Tsh (USD 0.12) and a median of 6145 Tsh (USD 2.93). The average WTP per head of cattle equals 406 Tsh (USD 0.19) with a median of 277 Tsh (USD 0.13). In comparison, household WTP values for routine and emergency vaccines offered as private goods per cow, average 4070 Tsh (USD 1.94) and 5484 Tsh (USD 2.61) respectively (Railey and Marsh, 2017). The calculation of the vaccine average values used the same estimation technique, differing by presenting the good as dependent only on the household's individual preferences with clearly defined property rights and minimal externalities.

**Conclusion**

The results presented in this paper contribute to growing research on the need for improved surveillance to ensure accurate vaccine matching, specifically adding information regarding decision-making at the household level for new livestock health technologies (Marsh et al., 2016). Our preliminary results find when considering implementing diagnostic testing in the field, the limited accessibility of veterinary services increases the price households would pay for diagnostic testing. Households appear to recognize that with fewer tests to perform and more reliable information, the burden on animal health workers to interpret and recommend treatments decreases, enhancing the quality and breadth of service provision, thus, directly benefiting marginalized households. Households value the information from diagnostic testing, especially those with past experiences with modern livestock technologies. The use of a visual aid to further educate households on FMD related inputs had unexpected results. The study communities

generally come from highly researched areas in regions with a high prevalence of modern livestock treatment usage (Bastola, 2015; Casey-Bryars, 2016; Caudell et al., 2017), potentially confounding the effects of the visual aid. Households not receiving the visual aid could have increased expectations for the effectiveness of the product because the complicated nature of FMD has not been delineated clearly, or households developed expectations about modern technology from another source.

While we anticipated densely populated communities would pay more for diagnostic testing as a result of denser information networks, these communities instead may represent the role of urbanization. We attribute the effect of living in more rural communities on WTP to either the need for households to rely on neighbors for information in the absence of services, or conversely because the absence of others reduces the effect of free riding. The distribution of tribal affiliation in accordance with community boundaries could further complicate the WTP values. A more direct focus on measures of community collective action would illuminate whether community differences stem from household structures and regional prices, or resource accessibility and community identity.

More broadly speaking, diagnostic testing that identifies specific strains provides the opportunity to mitigate information externalities, thereby more efficiently controlling and treating diseases with enhanced vaccine matching. Presenting the test as having public good implications acknowledges household stated preferences for the test as a reflection of the household's own total value potentially including perceptions of others' contribution capacity. In the context of livestock health in regions with endemic diseases like FMD, perceptions toward communal-led actions are necessary to evaluating the plausibility of control options at a national scale.

Our study is limited to estimating household WTP values for a hypothetical scenario. Further research should apply alternative methodologies (e.g., choice experiments) and evaluate the varying contributions across communities, as well as explore the potential for diagnostic testing to reduce other livestock inputs at the individual and community level. With an increasingly interconnected world, whereby FMD infection in one country can negatively implicate surrounding regions, and dramatically disrupt domestic and international trade, diagnostic testing offers novel and valuable information to the farmer and system of veterinary services. The appropriateness of diagnostic testing as a control measure, especially with the potential for vaccine matching, has implications for livestock management systems in general, from possibly lowering antibiotic use for post-infection treatment to reducing herd sizes to compensate for disease losses.

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**Appendix**

Table 1 Descriptive Statistics

| Variable | Description | Mean | Std. Dev. | Median | Min | Max |
|---|---|---|---|---|---|---|
| Flowchart | Information visual aid is provided (1=yes; 0=no) | 0.09 | 0.29 | 0 | 0 | 1 |
| Herd Size | Reported cattle owned by household | 42.00 | 58.65 | 20.00 | 1 | 530.00 |
| Off-Farm | Monthly off-farm income (1=0-25,000 Tsh; 0= > 25,000 Tsh) | 0.67 | 0.47 | 1 | 0 | 1 |
| Dist to Services | Reported distance in kilometers to gov't vet services | 7.86 | 11.61 | 3.00 | 0 | 50.00 |
| Density | Households within a 1.5 km radius | 28.26 | 18.81 | 24.74 | 7.07 | 67.15 |
| Exposure | Experience with diagnostic testing and/or vaccination (1=yes; 0=no) | 0.45 | 0.50 | 0 | 0 | 1 |

n=465

Table 2 Econometric Results

| Variable | Marginal Effects (SE) | |
|---|---|---|
| Flowchart | -1278.47 | * |
| | (770.89) | |
| Herd size† | 279.80 | |
| | (210.20) | |
| Off-Farm | -1922.85 | *** |
| | (505.19) | |
| Dist to Services | 79.66 | *** |
| | (22.14) | |
| Density | -28.50 | *** |
| | (12.47) | |
| Exposure | 1145.22 | ** |
| | (446.62) | |
| Constant | 6152.42 | *** |
| | (818.55) | |

Significance * 0.10; ** 0.05; *** 0.01

† Log of variable

USD 1=2100 Tsh

Table 3 Calculated WTP averages

| | Mean WTP | SE | 95% Confidence Interval | | 'Yes' Response |
|---|---|---|---|---|---|
| Double-Bounded | 6202.03 | 245.21 | 5691.45 | 6652.64 | 65%* |
| Open-Ended | 4260.47 | 147.66 | 3970.30 | 4550.64 | 95%^ |

*Responded 'yes' to at least one of the double-bounded bid questions

^Provided a value greater than zero