Attention and Mitigation of Disease

Theory and Evidence from Tanzania

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Abstract

This thesis seeks to gain a deeper understanding of public good production in developmental settings. This thesis comprises of five chapters. The first chapter provides an introduction and a literature review to build a case for further studies in public good production in general and disease elimination as a public good.

Chapter 2 and 3 study two different public good production games. They both provide some insights into the understanding not only of rabies elimination, which is the focus of the experimental part of this thesis, but also on public good production in general. I then discuss policy implications from these results.

Chapter 4 provides a report on the result of a field experiment conducted in the Morogoro Rural District of Tanzania. We tested two interventions, namely mobile phone text messaging and religious/tribal leaders advertising in raising participation in rabies vaccination campaigns. Results from the experiment show no evidence that each intervention was effective on their own, but they were effective when implemented together. We also found suggestive evidence that operational changes, designed to ease participation, could potentially have a much larger positive impact on participation than the interventions. We then discuss some contextual factors that could explain these results. Chapter 5 concludes.

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Author's Declaration

I declare that, except where explicit reference is made to the contribution of others, that this dissertation is the result of my own work and has not been submitted for any other degree at the University of Glasgow or any other Institution.

Putthi Cheat Lim

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Statement of Conjoint Work

I confirm that Chapter 4,"Raising Participation in Rabies Vaccination Campaigns: Evidence from Tanzania", was jointly co-authored with Professor Sayantan Ghosal, Doctor Katie Hampson, Doctor Tiziana Lembo and Joel Changalucha.

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Chapter 1

Introduction and Literature Review

1.1 Introduction

This chapter attempts to build a case for the studies conducted in this thesis. The ultimate goal of this study is to increase voluntary participation in public good production, specifically rabies elimination in marginalised communities. In this thesis, I try to understand why there has been low participation in rabies vaccination campaigns and design interventions to increase voluntary participation. We have two hypotheses on why this has been the case. Firstly, rabies elimination is a public good and therefore is likely subject to collective action problem. Secondly, in developmental settings, participation in rabies elimination can potentially be a costly activity and it has been unable to capture the attention of potential participants, who have other important tasks to complete.

The next section briefly explains the role that infectious diseases play in the prevalence of poverty and how their elimination can help alleviate poverty. Section 3 presents the economic burden of rabies on the poor, argues why we focus on mass dog vaccination rather than other methods as a means for eliminating rabies and presents some previous studies on canine rabies vaccination. Section

4 discusses some previous studies on public good production, the relevance of rabies elimination as a public good and some theoretical studies on vaccination in game theoretic settings. Section 5 discusses how the lack of attention paid to rabies elimination could have caused low participation. Section 6 concludes by giving a brief summary of how these issues motivated the studies in this thesis.

1.2 Infectious Diseases and Poverty

Infectious diseases pose a major problem for the poor, who are most vulnerable, due to the lack of adequate living standard and proper health care. Similar to the lack of human capital, education (Santos, 2011) and nutrition (Banerjee and Duflo, 2011) which push many poor people into a poverty trap, infectious-disease-based poverty trap may also exist. The lack of basic living standard in the poor community makes them vulnerable to infectious diseases, which in turn cause a loss of productivity and capacity to earn income, when such income is needed to treat the infectious diseases in the first place. An example of this is shown in a study by Babu et al., (2002) conducted in Orissa, India, which showed that chronic lymphatic filariasis causes, on average, a loss of 68 working days per year, which is equivalent to 19% of annual working time; this poses a large burden on the patients and the families of the patients. A report on infectious diseases and poverty by the World Health Organisation (WHO) (2012), mentioned that many problems associated with developing countries only make the problems caused by infectious disease worse for the poor. For example, the lack of quality health care system in poor communities usually cause misdiagnosis and mistreatment of diseases, which waste the resources put forward by poor patients and put their lives at risk. Another example raised by the report showed how financial burden in searching for treatments for a patient means that not enough financial resources is being allocated to other important investments such as, children's education, the lack of which can cause a whole other generation of poverty in the family.

A theoretical model by Bonds et al., (2010) studied, in an epidemiological setting, the existence of poverty trap due to infectious diseases. The underlying assumption of the model was that the key epidemiological parameters (including natural death rate, recovery rate and transmission rate) were determined by income, which was in turn determined by individual health. Two of the key variables in their model were income and productivity. They showed that, depending on the level of productivity, there existed an income level, below which the society converges to a state of high disease prevalence and low income, and above which the society converges to a state of low disease prevalence and high income. In addition, they showed that if the level of productivity was high enough, the society would always converge to the latter state, but if it is too low, the society would always converge to the former state. In their empirical study, which looked at the correlation between income and disease burden, using population-level data over 170 countries, showed that these two variables negatively affected each other. This result supports the idea that low level of income makes a person vulnerable to infectious diseases, which in turn affects the capacity of the person to generate income and hence, cause a poverty trap.

Zoonotic infectious diseases are diseases that can be transmitted from animals to humans, for example, rabies (which our research will be focusing on). Zoonotic diseases account for around 60% of human infectious diseases (Taylor et al., 2001). Zoonotic diseases not only directly affect the health of those infected, it also affect the productivity and income of the poor, especially those in the agricultural sector, who depend on livestocks as a source of income. In spite of this, some zoonotic diseases have been largely overlooked and neglected, unlike other infectious diseases, such as HIV/AIDS and tuberculosis (WHO, 2006), which are seen by governments and funders as posing larger immediate problems. However, it has to be made aware that zoonotic diseases, as in examples given above, can also pose a large daily economic burden on the poor.

The elimination of zoonotic diseases can be a great opportunity to contribute to lifting the poor out of poverty. Firstly, like other infectious diseases, successful elimination means that the poor are less at risk of spending time being ill and unproductive. Having an ill person in a family, not only reduce the patient's productivity, but also that of the person who has to look after the patient and accompany them to the hospital. This means a potential increase in productivity and income if a disease is eliminated. Secondly, it may also alleviate the psychological burden on the poor, which may have a harmful affect on their productivity. For example, a person bitten by a dog and cannot afford post-exposure-prophylaxis, may spend a lot of their mental effort worrying about whether they are at risk of contracting rabies. Thirdly, less income has to be allocated to paying for treatments of diseases and more can be allocated to investment, such as education of children and other assets. The WHO (2006) reported that the cost of treatment for rabies is around US$75 for post-exposure prophylaxis (this may be higher for those who live in remote regions with difficult access to hospitals). This accounts for a large fraction of the annual income for many in the developing world. Lastly, cost-effective control measures of some of the zoonotic diseases have already been identified and successfully implemented in other parts of the world. For example, evidence from the western world showed that rabies can be eliminated through mass dog vaccination. The report by WHO (2006) showed that estimated costs per disability adjusted life year (DALY) averted for zoonotic diseases such as rabies, brucellosis and echinococcosis are less than US$20, which is very low compared to the annual productivity of a potentially infected person.

As described earlier, neglect and prioritisation of other diseases is a barrier to the elimination of zoonotic diseases. Therefore, there is a need to find an economically sustainable way of controlling these diseases.

1.3 Rabies

Rabies is one of the most feared zoonotic diseases that can infect human through exposure to the saliva of infected mammals. If a person is exposed and post-exposure-prophylaxis (PEP) is not administered properly, the person can contract rabies and once the symptoms arise, there is almost no chance of the person surviving the disease. A study by Hampson et al., (2015) estimated that rabies causes around 59,000 human deaths annually, a lot of which, occurs in developing countries. It should also be noted that reported death figures are usually thought to be largely underestimated by many studies, since some victims were not able to report their cases to hospitals and die at home, and also due to weak surveillance system. This section explains the economic costs of rabies, which provides the motivation to eliminate the disease, and argues for the possibility of the elimination of rabies in developing countries through mass dog vaccination campaigns.

1.3.1 Economic Costs

According to an estimation by Hampson et al., (2015), the global annual cost of rabies is estimated to be around US$ 8.6 billion. This figure takes into account productivity losses from premature deaths, direct expenditure on PEP, loss in income while seeking PEP, loss in livestocks due to rabies and the cost of dog vaccination and population management. Such large amount of cost should never be a burden on anyone, especially the poor, who have little ability to cope in the first place. Such lost is highly regrettable since we have understood the way to eliminate rabies and we have seen successful elimination of the disease in the developed world already.

One of the measurements of the burden of rabies is the disability-adjusted life year (DALY), which is defined as the number of years of productivity loss due to induced sickness, disability or death. The report by the WHO (2013) also reported that, in Africa alone, rabies caused a loss of 609,000 DALYs in 2010. This is supported in a study by Sambo et al., (2013), which showed that, in four districts in Tanzania, 78% of the deaths from rabies involved children less than 16 years old. The same study also showed that 86% of the deaths from rabies occurred in subsistence farming families. These unnecessary losses in DALYs is a burden, especially, on the rural families, whose survival relies on the physical labour of each member of their families.

The monetary costs of rabies also impose a great burden on the poor. The largest monetary burden is the cost of seeking PEP, which is vital to prevent a bite victim from contracting rabies, once exposed to the disease. The same study by Sambo et al., (2013) reported that, some families had to pay between US$40-50 just for indirect costs of PEP alone (this includes the travel cost to and from the hospital, accommodation, communication, the loss of productivity, etc); this is equivalent to almost 20% of average annual income in rural Tanzania. These indirect costs were made worse by the unavailability of PEP and the distance of most of the victims from the nearest hospital. 40% of the patients studied, most of which from the rural area, had to visit up to 5 hospitals to receive PEP. Only 39% of the victims living more than 10 kilometres away from the district hospital received PEP within 7 days. Distance from the nearest hospital makes it particularly difficult for the rural victims to receive the appropriate treatment. It is reported that 78% of the deaths from rabies occurred in areas more than 10 kilometres away from the hospital. The study also estimated that the cost of a 5-dose regimen of PEP could cost up to more than US$100 for a rural Tanzanian. Because of this, not many bite victims were able to receive a full PEP regimen, if any, and more than half of those reported the cost of the vaccine as the main reason for this.

Due to the high cost of PEP as a method of preventing human deaths from rabies and its shortage in the rural area, mass dog vaccination (which will be discussed later) has been proposed by some studies (for example, Fitzpatrick et al., (2014)), as a cost-effective way of preventing human deaths from rabies. If the mass dog vaccination campaigns are successful, which has been proven to be possible through the experience of many developed countries, rabies would be eliminated and the rural communities no longer have to live under fear and the economic burden of rabies.

1.3.2 Basic Epidemiology of Rabies

A key epidemiological parameter of any infectious disease, such as rabies, is the reproductive number (R_0). Hampson et al., (2009) estimated that the reproductive number of rabies in dogs is no more than two, which means that on average, a rabid dog infects no more than two dogs over their life time. Most estimates placed the reproductive number of rabies just above 1, which is the threshold, below which, the disease will die out by itself. This figure can be reduced below the extinction threshold by reducing the number of susceptible dogs. This can be done through mass dog vaccination, which can induce herd immunity.

Herd immunity plays a major role in the elimination of rabies by providing indirect protection to unprotected population, provided a certain threshold of vaccination coverage is met. Figure 1.1 (from Fine et al., (2011)) provides an intuitive explanation of how herd immunity works. The upper diagram (A) shows a situation where there is no immunization whatsoever in the population. In this case, with the reproductive number of 4, the first individual infects four other individuals, who each then infects four other individuals, and everyone in the environment is infected. In the lower diagram (B), where 75% of the individuals in stage 1 and stage 2 are immunised, only one of the four unimmunised is infected, unlike in the first case, where every unimmunised node is infected. In this case, each case causes only one successful transmission. If a slightly greater proportion of the population is immune, the number of incidence will

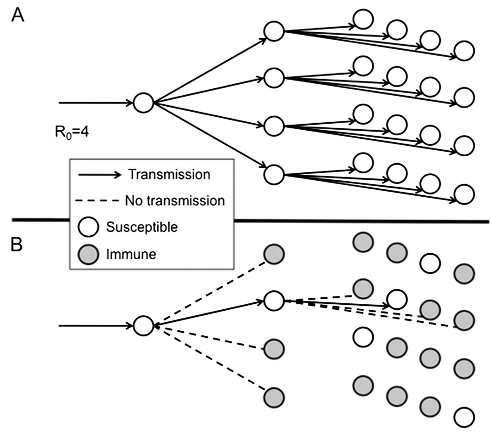


Figure 1.1: Herd Immunity (Source: Fine et al., (2011))

reduce over time to zero. This shows that it is not necessary to achieve full vaccination coverage to eliminate rabies. However, a certain coverage threshold has to be met so that herd immunity can play its part. Fine (1993) provides an expression for the threshold for herd immunity in terms of the reproductive number R_0 as $1 - 1/R_0$.

Given the reproductive number of rabies just above one, dog populations can achieve herd immunity, if the critical vaccination threshold, which is estimated to be between 20% and 45% of the population (Hampson et al., 2009), is met. This means that only 20% to 45% of the population need to be immune to rabies for the whole population to be protected from rabies. However, below this rate, rabies transmission and outbreaks may persist. Due to the demography of the dog population (births of new susceptible pups and deaths of vaccinated dogs, which reduce the coverage rate over time), it has been recommended by several studies (for example Hampson et al., (2009) and Fitzpatrick et al., (2014)) that annual vaccination campaigns should achieve at least 70% coverage so that the proportion of vaccinated dogs does not fall below the critical vaccination threshold. Studies (such as by Coleman and Dye (1996)) have shown that annual vaccination campaigns that achieve the recommended 70% have been largely successful at controlling the spread of rabies. However, not all vaccination campaigns achieved this target, and this left pockets of infected dog populations which can present a risk to other populations.

What these epidemiological parameters show is that rabies is clearly not impossible to be eliminated, especially when compared to other diseases, which have been successfully eliminated. There also exists clear evidence from many developed countries that rabies elimination is possible. This means that the fact that many people are dying from rabies every year and the burden that it puts on the poor is highly regrettable. This motivates this research.

1.3.3 Elimination of Rabies

Many methods have been used to control rabies in the dog population, including dog culling, sterilisation and vaccination (Knobel et al., 2013). However, there is no evidence that dog culling and sterilisation by themselves are effective in eliminating rabies in the long-run and they can also be counter-productive.

Culling is the practice of reducing dog population and hence reduce the number of potential carriers of rabies. This relies on the concept that reducing the dog population density will reduce contacts between dogs and hence, the number of transmissions (Knobel et al., 2013). Even though, this is intuitive, there is no evidence that transmission of rabies within a dog population is significantly affected by dog population density (Hampson et al., 2009, Knobel et al., 2013). Although euthanization of dogs suspected of carrying rabies may be an important part of rabies control programs, there is no evidence that untargeted killing of dogs is successful in controlling rabies in the long-run (Knobel et al., 2013). In addition, such practice is generally considered ethically unacceptable because it means there is a risk of killing uninfected dogs. In addition, the killing of dogs may cause shortage of the supply of dogs. This means that dogs have to be imported to satisfy the demand and this may mean bringing in more infected dogs into the local population. Therefore, the risk of rabies still persists.

Sterilisation of dogs depends on the same concept and has the same problem as the culling of dogs. The insignificant effect of dog population density on the reproductive number, means that sterilisation should have little affect on the transmission of rabies. The resulting shortage of supply of dogs in the local population means more dogs have to be imported to satisfy local demand. Therefore, even if the local sterilized population is free from rabies, if any of the imported dogs are infected, rabies transmission will occur again. However, it should also be noted that a combination of sterilisation and mass dog vaccination has been shown to be successful (Reece and Chawla, 2006).

Mass dog vaccination is a widely accepted means of eliminating rabies and it has been proven to be an effective way for long-term control of rabies. This strategy does not come with the same problems as culling and sterilisation by themselves. However, this does not mean that it does not have its own problems. Problems with the implementation of vaccination policies range from the top level to the low level. At the top level, being one of the neglected tropical diseases, rabies is largely neglected by many governments. Most governments of the developing countries, due to their limited resources, choose to allocate most of their resources on other competing health issues instead. At the low level, there are issues ranging from the organisation of the vaccination campaigns to participation from the communities. Our research is interested in issues at the low level, particularly, the problem of raising awareness and encouraging participation from local communities.

Although mass dog vaccination campaigns have been shown to be potentially effective in controlling rabies, the delivery of the campaigns must meet two criteria. Firstly, it must be sustainable in the sense that it can be implemented at low costs, so that the vaccination campaigns can be carried out regularly with low budgetary requirement. At the same time it must guarantee the highest chance of success. Kaare et al., (2009) studied different strategies for the delivery of the campaigns. They showed that house-to-house vaccination was effective, but costly. On the other hand, the central point strategy, in which villagers had to bring their dogs to a vaccination point for vaccination, was much less costly, but achieved lower vaccination coverage. This was driven by the lack of active participation by community members. If rabies elimination is to be sustained in the long-term, we need a less costly strategy like the central point strategy, but it needs to be much more effective.

Bardosh et al., (2014) conducted an anthropological study relating to local attitudes towards dog vaccination in Kilombero and Ulanga district in Tanzania, to understand the lack of active participation from community members in rabies vaccination campaigns. Figure 1.2 (from Bardosh et al., 2014) provides some of the reported reasons for not participating. Almost a quarter of those who failed to vaccinate their dogs, reported not being aware of vaccination campaigns as the main reason. Gaps in information dissemination may explain the lack of awareness, but limited attention and cognitive capacity, seen by some empirical studies in some poor populations, can make the problem even worse. Other reported reasons such as having the central point too far, unable to find or catch dogs may be partially explained by their lack of commitment. In addition, the study also reported that some members of the communities did not think that they were at risk from rabies. Therefore, raising awareness of the risk and the cost of rabies should be part of the solution to this problem because as people are more aware of the risk and cost of rabies, they would pay more attention to protecting themselves against rabies and the problems discussed earlier would be resolved.

The study also reported that members of the communities believed that no more than half of the dog population is vaccinated. They believed that there

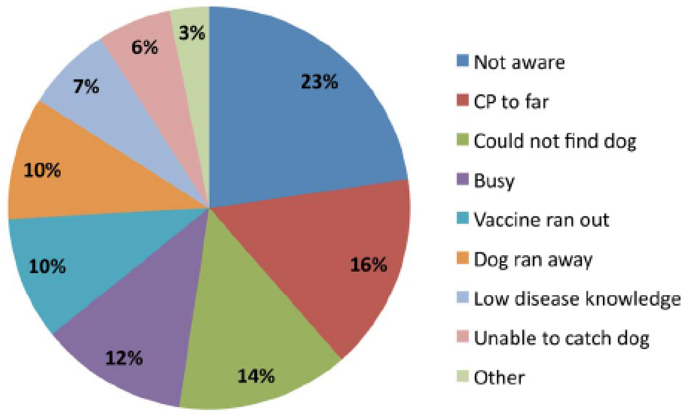


Figure 1.2: Reasons for not participating (Source: Bardosh et al., (2014))

were fewer responsible than irresponsible dog owners, who did not take care of their dogs very well, which facilitated the spread of the disease. This perception might have le some to think that vaccinating their dogs cannot reduce their risk of contracting rabies enough to worth the opportunity costs of doing so. This was because their participation is perceived to be worthless as they would not be able to reach the 70% threshold. This result is a suggestive evidence of an underlying collective action problem. This problem is typically seen in public good production problems, where each individual would not participate in the production of the public good if they think that their participation has little effect on the production of the public good. In this sense, the elimination of rabies can be considered as a public good. This problem will be discussed further in the next section.

1.4 Disease Elimination and Public Good

As discussed above, the elimination of any disease is a public good in the sense that once any disease is eliminated everyone benefits and it requires participation from many individuals. Therefore, the study of disease elimination can reasonably be placed in the context of public good production and deserves the same focus on dealing with collective action problem.

There have been only a few known literatures on vaccination in a game theoretic setting. Bauch and Earn (2004) and Poletti et al., (2012) studied the effect of risk perception on vaccination uptake in an epidemiological setting. The model by Bauch and Earn (2004) showed that in equilibrium, vaccination level is higher if the perceived risk of infection is increased. Poletti et al., (2012) studied a more general model on how people take cautionary actions in response to changes in their risk perceptions. They showed that people tend to take more cautionary actions, which include reducing contacts or taking vaccination, if the perceived risks of infection is higher.

Brito et al., (1991) studied the affect of vaccination policies at a macro-level. Specifically, they compared the outcome of different vaccination policies: free-choice, compulsory vaccination and subsidies and taxation. They showed that there exists a threshold of cost of vaccination, such that those whose cost is below the threshold will vaccinate and those whose cost is higher than the threshold will not vaccinate. They also showed that the free-choice policy is superior in terms of social welfare to compulsory vaccination. However, the free-choice policy cannot reach the optimum level of vaccination. The intuition behind this is that, by imposing compulsory vaccination, those with high costs of vaccination are forced to incur the high costs, even though in the free-choice policy, they could have benefited from partial protection (from other vaccinated individuals) without having to incur the costs. They also showed that the socially optimum level of vaccination can be reached by subsidising the vaccinated and taxing the unvaccinated.

Although the results by Brito et al.(1991) showed that taxation and subsidisation can achieve the optimum level of vaccination, it's applicability in the case of rabies elimination is questionable. Firstly, it may not be practical to collect the information about who vaccinated their dogs and who did not. Secondly, such policy requires a lot of attention from the governments, of which rabies, as one of the neglected tropical diseases, has little. Thirdly, the costs of such policy may far outweigh the revenue from taxation and since rabies is a disease that harms the poor the most, taxing the poor who do not vaccinate their dogs may make their situation even worse. Fourthly, subsidisation can be costly and may not be sustainable in the long-run. Subsidisation by providing free vaccines have been shown to be ineffective in contexts where other participation costs of participants are high (Kaare et al., 2009). In addition, even if subsidisation, in general, can induce greater participation, it means that the participation is driven by financial factors that cannot be sustained in the long-run without continued financial support. For these reasons, our research focuses on a different set of interventions which induces voluntary participation.

Both theoretical and empirical literature on voluntary contribution mechanisms in public goods have provided some useful insights into factors that affect voluntary contribution. Green and Laffont (1977) and Groves and Looeb (1975) showed in a theoretical analysis that communication of true preferences can improve participation in public good production. Isaac and Walker (1988a) showed, in an experiment, that group size had little effect on participation in public good production and that what mattered more was the marginal return of one's contribution to the public good. Isaac and Walker (1988b) showed, in another experiment, that non-binding communication lead to a decrease in free-riding behaviour and an increase in the provision of a public good. Croson et al., (2005) showed that reciprocity, matching and conditional cooperation are present in the behaviour of participants in public goods game. Experiments in the public good literature are mostly under laboratory conditions. Alston and Nowell (1996) questioned the applicability of voluntary contribution mechanism, studied in laboratory conditions, in natural settings. These experimental literatures provide some useful insights by identifying selected social factors which are mechanisms through which participation can increase. The experimental part of my thesis is focused on a field experiment that takes place in a real world situation. This slightly differs from the literatures discussed above because the social factors described above are all likely to be present to some extent. Therefore, instead of looking at specific mechanisms that are likely to induce participation, my study is more focused on designing general policies that can overcome collective action problem given those mechanisms.

In many cases, collective action problem in disease elimination is overcome through the private benefit of vaccination itself. For many diseases, the direct private benefit of vaccination typically outweighs the cost of vaccination because vaccination provides complete protection to those who vaccinate. The main reason for many people to vaccinate against diseases such as smallpox was that it gave them protection against the deadly disease. The elimination of smallpox was just an externality of a high level of participation. Zoonotic diseases, such as rabies, does not have this advantage. Rabies vaccination may provide a small marginal private benefit to individuals by protecting their dogs against the deadly disease, but the individuals are still susceptible to being infected by other dogs. This makes the elimination of rabies and other zoonotic diseases much more prone to collective action problem than other diseases. For this reason, in this thesis, I try to understand the lack of participation in rabies vaccination campaigns in a public good setting, with discussions on how to overcome collective action problem by trying to induce voluntary participation.

1.5 Attention Allocation

As discussed above, the problem of rabies elimination is generally set in rural communities, where community members tend to be poor and marginalised. One of our working hypotheses, is that the poor have many important daily tasks that compete for their attention, and in most cases, they would pay most attention to tasks that affect their immediate and short-term needs such as grazing their livestock, making money and finding food, and they would pay less attention to less immediate needs with long-term benefits such as vaccinating their dogs. We believe that this, at least partially, explains the lack of participation in rabies vaccination campaigns.

Kahneman (1973) provided a theory of limited capacity of attention. In his argument, individuals have only a limited amount of attention that are then allocated to specific tasks. Tasks that receive sufficient attention are performed and completed well. Tasks that do not receive sufficient attention are completed with lower quality or does not get completed at all. This is because when insufficient attention is given to the task, signals or relevant information related to the task are neglected or undetected because not enough attention was allocated to the task. In the case of rabies elimination, the immediate importance of many daily tasks put a strain on attention allocated to long-term benefits such as rabies vaccination and elimination.

Empirical studies such as by Mani et al., (2013) and Shah et al., (2012) showed that the effect of limited capacity of attention on the poor is real. Mani et al., (2013) showed that financial burdens harm the cognitive ability of the poor far more than that of the rich. They showed that the poor performed a lot worst than the rich in experimental tasks even if they put as much or even more effort. Shah et al., (2012) showed that the poor tend to focus too much on some problems and neglect other equally or even more important problems. This behaviour explained how the poor tend to engage in over-borrowing by borrowing at excessively high interest rates because they focused too much on achieving short-term liquidity at the expense of future financial well-being.

Banerjee and Mullainathan (2008) provided a theoretical study on allocation of attention. They studied a case where an individual has to decide to pay attention to problems at home or at work. They showed that individuals with high productivity would allocate their full attention to problems at work, while those with low productivity would allocate their full attention to problems at home. The intuition here is that for individuals with high productivity, allocating full attention to problems at work would provide enough compensation to offset their problems at home. On the other hand, those with low productivity find it optimal to allocate attention to their problems at home because even if they allocate full attention to problems at work, it would not be enough to offset their problems at home. The decision to vaccinate against rabies in rural settings may suffer from the same problem. It is may be of more short-term benefit to perform daily income-generating tasks than to vaccinate one's dogs. Therefore, many people with immediate short-term needs would allocate their full attention to the former rather than the latter task. In the context of rabies elimination in developing countries, where many have reasons to pay attention to their immediate needs, such present-bias can be a significant factor driving the low vaccination coverage.

For this reason, we believe that any interventions that are effective in raising participation in canine rabies vaccination campaigns need to be informative and make salient the importance of rabies elimination and the risk that rabies pose to the livelihood of each community. We believe also that the interventions need to be direct, in the sense that it does not require too much attention from those exposed the interventions to notice and remember what they learn from them.

1.6 Conclusion

This chapter has shown that infectious diseases pose an unnecessary economic burden on the marginalised communities. The elimination of some of those diseases have been proven to be possible and would be very beneficial to those communities. Failure to eliminate infectious diseases stem from many different factors. In this research, we only focus on voluntary participation, which has been a significant contributing factor to the failure of rabies vaccination campaigns. It has been hypothesised that the failure of local community members to voluntarily participate in the vaccination campaigns is due to two key factors: collective action problem and the failure to pay attention to rabies elimination.

In the following chapters, I try to understand this problem and derive policy implications from two different game theoretic models. I then test the effectiveness of two interventions designed to overcome both collective action and attention problem: the use of mobile phone text messaging and religious/tribal leaders in mobilising participation in canine rabies vaccination campaigns in the Morogoro Rural district of Tanzania.

Chapter 2

Signalling in Threshold Public Good Game

2.1 Introduction

Olson (1965) argued that even if a group can work together to achieve a common interest, rational and self-interested individuals would not always act to achieve the common good. However, many public goods require voluntary contributions from many of its beneficiaries to be produced. Many economic literatures, such as by Palfrey and Rosenthal (1984) and Medina (2007), showed the persistence of the free-riding equilibrium where no one cooperates in the production of public goods, which support Olson's argument. Many empirical literatures do not show such extreme result, but they show that under-provision of public goods is prominent in many contexts.

The production of public goods are important at many levels. At a local level, people can benefit greatly from public goods, ranging from the construction and maintenance of infrastructures to the eradication of diseases. At a global level, examples of public good include the reduction of greenhouse gas emissions and global peace and security.

A lot of these public goods rely on participation from its beneficiaries to be produced. A popular way to mobilise participants and to increase demand for a public good is through public awareness campaigns where an authority or institution with an interest in a particular public good informs potential participants about the benefit of the public good. This can be seen in, for example, vaccination campaigns (Rabies (Kaare et al., 2009), Pertussis (Clarke et al., 2015) and childhood diseases (Barham and Maluccio, 2009)) and campaigns to reduce greenhouse gas emissions (Sampei and Aoyagi-Usui, 2009). These type of awareness-raising campaigns are not as successful as we may want them to be. Clarke et al., (2015) showed that even though most South Australians being studied understood the severity of Pertussis, very few were vaccinated against Pertussis, and increasing awareness about the availability and effectiveness of vaccines did not increase vaccination coverage to a desirable level. Barham and Maluccio (2009) showed that an additional intervention, namely conditional cash transfers, was needed to increase vaccination coverage to a desirable level. Sampei and Aoyagi-Usui (2009) showed that mass-media campaign in Japan raises public concern about greenhouse gas emissions for a short period only. These examples show that not all awareness-raising campaigns succeed at mobilising enough participants for a public good to be produced.

In this chapter, I attempt to understand why such awareness-raising campaigns do not always work in the context of voluntary participation in public good production. I do this by analysing a simple threshold public good production model with interaction between agents and a policy-maker. In my model, a certain number of agents need to participate in producing the public good for it to be produced. The policy-maker can send some signal (in the sense of signalling by Spence (1973)), which may or may not be informative depending on their strategy, to the agents. In this model, the public good can be of high or low benefit and I assume that only the policy-maker knows the true type of the public good. I believe this is a reasonable assumption because in practice, there tend to be an institution or an organisation, who are much better informed than individuals due to their expertise, trying to convince individuals to contribute to the public good.

The choice to focus on threshold public goods is because they are comparable to disease elimination as a public good, which is the focus of this thesis. In the context of disease elimination, the threshold of the public good is the threshold for herd immunity to be achieved. Extensive experimental literatures have looked at mechanisms that can increase participation in threshold public good. Cadsby and Maynes (1999) showed that money-back guarantee increases participation, higher threshold discourages participation in the absence of money-back guarantee and higher rewards can increase participation. Marks and Croson (1998) studied the effect of rebates on participation in threshold public good production. They showed that rebates can increase participation if excess contribution is used to provide additional public good. These studies provide some useful insights into some tools that can be used to increase participation in threshold public goods. However, in an uncontrolled environment such as rabies vaccination, the applicability of these tools is limited. In my model, I look at how signalling, which is typically used to motivate participation, actually affects participation in threshold public good production and what can be done to improve the outcome.

The result of my model shows that the effect of signalling is rather limited. Signalling or any awareness-raising policy will only go so far as to make an equilibrium, where the public good is produced, part of the equilibrium set, but it does not eliminate the free-riding equilibrium from the equilibrium set. An equilibrium selection argument, namely stochastic stability (Young, 1993) suggests that the free-riding equilibrium is most likely to prevail. The tracing procedure (Harsanyi and Selten, 1988), on the other hand, provides conditions for a desirable equilibrium to be achieved. This suggests that there is an underlying collective action problem and that a good policy should not only target raising awareness about the benefit of the public good, but it should also target solving or overcoming collective action problem in some way.

The main contribution of this model is that it adds a designer (or policy-maker) to a threshold public good game and apply equilibrium selection arguments. This is particularly relevant in many cases where there usually is a policy-maker who tries to convince their community members to participate in public good production. The result of this model explains and provides a prediction of the outcome of their interaction, which can then be used as a guideline for policy-design.

This chapter is organised as follows. Section 2 lays out the model. Section 3 analyses the equilibria of the model. Section 4 discusses two different equilibrium selection arguments, the tracing procedure and stochastic stability. In section 5, I discuss the implication of the results, some policy implications and a case study is presented to show the relevance of the model being studied. Section 6 concludes.

2.2 Model

In this section, I describe the main model. I study a three time period ($t = 0, 1, 2$) model with two types of players, the policy-maker (PM) and a group of n agents, where N denotes the set of n agents.

I assume that there are only two types of public good, low-benefit, which yields B_L for everyone if produced, or high-benefit, which yields B_H, where $B_H > B_L$. The probability that the benefit of the public good is $b = B_H$ is $P(b = B_H) = p$ and this is common knowledge. It is assumed that the policy-maker is able to observe the true type of public good, and they can send some public signal

$s \in \{s_L, s_H\}$, where s_L denotes a low-cost signal and s_H a high-cost signal. The agents, on the other hand, do not observe the public good type, but they rely on the public signal from the policy-maker to update their beliefs about the benefit of the public good. The agents can then choose whether they want to participate in the production of the public good. If at least m agents choose to participate, the public good is produced. It is assumed that $m \leq n$.

For simplicity, the pay-off of an agent i is denoted by:

$$EU_i(b, x, s) = \begin{cases} E(b|s) - \gamma_i x_i & \text{if} \sum_{j=1}^{n} x_j \geq m \\ -\gamma_i x_i & \text{if} \sum_{j=1}^{n} x_j < m \end{cases} \tag{2.1}$$

$E(b|s)$ is the agent's expectation of the public good given the signal s sent by the policy-maker. $x_i \in \{0, 1\}$ denotes the action of agent i, where $x_i = 1$ indicates that agent j participates in the production of the public good and $x_i = 0$ indicates otherwise. $x = (x_1, ..., x_n)$ denotes the action profile of all agents. γ_i denotes the cost that agent i incurs if he chooses to participate. This means that an agent's decision whether to participate or not depends only on the expected net pay-off from doing so.

Similarly, the pay-off of the policy-maker is denoted by:

$$U_{PM}(b, x, s) = \begin{cases} b - c(s) & \text{if} \sum_{i=1}^{n} x_i \geq m \\ -c(s) & \text{if} \sum_{i=1}^{n} x_i < m \end{cases} \tag{2.2}$$

It is assumed that $c(s_L) = 0$ and $c(s_H) > 0$. The policy-maker's pay-off function indicates that the policy-maker is only interested in getting the public good produced and balancing it with the cost of signalling.

The timing of the game is as follows:

- *Time* $t = 0$: Nature chooses the type of public good $b \in \{B_L, B_H\}$.
- *Time* $t = 1$*:* The policy-maker observes the type of the public good and chooses a public signal $s \in \{s_L, s_H\}$.

- *Time $t = 2$:* All agents observe the public signal and choose whether to participate or not in the production of the public good. If at least m agents choose to participate, the public good is produced and everyone benefits.

2.3 Equilibrium Analysis

The solution concept is Perfect Bayesian Equilibrium. The strategy of agent i is a pair $(x_i(s_L), x_i(s_H))$, which contains his choice of action as a function of the observed public signal from the policy-maker. The policy-maker's strategy is a pair $(s(B_L), s(B_H))$ which indicates the policy-maker's choice when the public good is either B_L or B_H, respectively. I will first study the agents' decision problem at $t = 2$, followed by the policy-maker's signalling strategy at $t = 1$. Throughout this chapter, I assume that if an agent is indifferent between participating and not participating, he will always choose to participate.

2.3.1 Agents' Decision Problem at $t = 2$

At $t = 2$, all agents will have observed the public signal from the policy-maker and will have established their beliefs about the type of the public good. At this stage, they will play an n-person game among themselves to determine whether the public good is produced or not.

Within this game, an agent i's decision depends not only on their expected value of the public good $E(b|s)$ but also on three possible events:

$$A : \sum_{j \in N \setminus \{i\}} x_j = m - 1$$

$$B : \sum_{j \in N \setminus \{i\}} x_j < m - 1$$

$$C : \sum_{j \in N \setminus \{i\}} x_j \geq m$$

Event A indicates that without i's participation, exactly $m-1$ other agents participate in the production of the public good. In event A, i is the pivotal agent, because his decision determines whether the public good is produced or not. In events B or C, on the other hand, i is not the pivotal agent, because, respectively, the public good is not produced or produced regardless of i's action. This means that i's decision has to take into account the probability that each of these events occur. Denote $P(e|x_{-i})$ as the probability that event $e = A, B$ or C happens, given the action profile of all agents apart from i.

Given the probability $P(e|x_{-i})$ and agent i's expectation of the public good $E(b|s)$, agent i's expected payoff from choosing $x_i = 1$ is

$$EU_i(b, (x_i = 1, x_{-i})) = P(A|x_{-i})(E(b|s) - \gamma_i) + P(B|x_{-i})(-\gamma_i) + P(C|x_{-i})(E(b|s) - \gamma_i)$$

and the agent's expected payoff from choosing $x_i = 0$ is

$$EU_i(b, (x_i = 0, x_{-i})) = P(A|x_{-i})(0) + P(B|x_{-i})(0) + P(C|x_{-i})E(b|s)$$

Agent i chooses $x_i = 1$ only if $EU_i(b, (x_i = 1, x_{-i})) \geq EU_i(b, (x_i = 0, x_{-i})$:

$$(P(A|x_{-i}) + P(C|x_{-i}))(E(b|s) - \gamma_i) - P(B|x_{-i})\gamma_i \geq P(C|x_{-i})E(b|s)$$

Rearrange:

$$P(A|x_{-i}) \geq \frac{\gamma_i}{E(b|s)}$$

From this, we can obtain agent i's decision rule as follows:

$$x_i^* = \begin{cases} 1 & \text{if } P(piv|x_{-i}) \geq \frac{\gamma_i}{E(b|s)} \\ 0 & \text{if } P(piv|x_{-i}) < \frac{\gamma_i}{E(b|s)} \end{cases} \tag{2.3}$$

where $P(piv|x_{-i}) = P(A|x_{-i})$. Implicitly, condition (2.3) implies that for an agent to participate in the production of the public good, it must be true that $E(b|s) \geq \gamma_i$. According to (2.3), in equilibrium, there are only two possible responses in pure strategy from the agents to any strategy of the policy-maker, either x^* is such that $\sum_{i \in N} x_i = 0$ or $\sum_{i \in N} x_i = m$.

Lemma 1: For some $E(b|s)$ derived from the policy-maker's signal s, there are only two possible collective responses from the agents in pure strategy, either $\sum_{i \in N} x_i = 0$ or $\sum_{i \in N} x_i = m$.

Proof for this result follows directly from the decision rule (2.3). For any outcome $0 < \sum_{i \in N} x_i < m$, all participants are non-pivotal, which contradicts (2.3). For any outcome $\sum_{i \in N} x_i > m$, there are $\sum_{i \in N} x_i - m$ participants who are non-pivotal, which also contradicts (2.3). The outcomes $\sum_{i \in N} x_i = 0$ and $\sum_{i \in N} x_i = m$ are the only outcomes in pure strategy that satisfy (2.3).

From here onwards, I call the outcome, where there is no participation, the free-riding equilibrium and one, where there is enough participation for the public good to be produced, a threshold equilibrium. Note that in cases where $\gamma_i \geq E(b|s)$ for at least m agents, both outcomes can be strict Nash equilibria. This suggests that there exists an underlying collective action problem in this setting. The next natural question is which of these equilibria is more likely to prevail. This will be discussed in the next section.

2.3.2 Policy-maker's Decision Problem at $t = 1$

The policy-maker's strategy will depend on the participation costs of all agents. To assist in analysing the policy-maker's decision problem, I introduce additional notations: $\bar{M} = \{i \in N : pB_H + (1-p)B_L \geq \gamma_i\}$, $M_{LH} = \{i \in N : B_H > B_L \geq \gamma_i\}$ and $M_L = \{i \in N : B_H \geq \gamma_i > B_L\}$.This subsection will identify conditions under which the policy-maker chooses a pooling strategy or a separating strategy. For ease of exposition, I will provide an intuitive explanation of how the equilibria are derived and I will leave the technical details to the Appendix for interested readers.

As explained in the previous subsection, the agents' response which corresponds to the free-riding equilibrium always exists. In this case, the policy-maker's best response is to choose the pooling strategy (s_L, s_L). This is part of a perfect Bayesian equilibrium because the free-riding outcome can also be a best response to (s_L, s_L). On the other hand, the pooling strategy (s_H, s_H) can never be part of an equilibrium, because it is no more informative to the agents than (s_L, s_L), which means it should not influence the behaviour of the agents, therefore the policy-maker will strictly prefer the strategy (s_L, s_L) to (s_H, s_H). The pooling strategy (s_L, s_L) can also be met with a response where the public good is produced if $|\bar{M}| \geq m$, which is also an equilibrium.

The separating strategy (s_L, s_H) can be part of an equilibrium where the response from the agents is such that exactly m agents choose the strategy $(x_i(s_L) = 0, x_i(s_H) = 1)$. This clearly means that in this equilibrium, it is only possible to produce B_H. This equilibrium holds under two conditions: a) if $c(s_H) > B_L$, and b) if $|M_{LH}| \geq m$ and $|M_{LH}| - |M_H| < m$. If condition a) does not hold, the policy-maker would be willing to choose s_H when $b = B_L$. Condition b) means that the production of the public good requires the participation of at least some of the agents who are willing to produce B_H only and not B_L.

On the other hand, the separating strategy (s_H, s_L) cannot be part of an equilibrium. This is because in this model each action by the policy-maker has no direct influence on the utility of the agents and the policy-maker's strategy influences only the beliefs of the agents. Since I am using Perfect Bayesian Equilibrium as the solution concept, the agents' beliefs and response when the policy-maker's strategy (s_L, s_H) should mirror those of when the policy-maker's strategy is (s_H, s_L). In addition, since it is assumed that $c(s_H) > c(s_L)$ and $B_H > B_L$, for the strategy (s_H, s_L) to be feasible for the policy-maker it must be true that $B_H > B_L > c(s_H) > c(s_L)$. If this is true, and given the beliefs generated by the strategy (s_H, s_L), then the policy-maker would choose s_L instead of s_H when $b = B_L$. Therefore, the separating strategy (s_H, s_L) cannot be part of an equilibrium.

Proposition 2.1: This game has three types of Perfect Bayesian Equilibrium:

- There always exists a pooling equilibrium where the policy-maker chooses (s_L, s_L) and m agents choose $(x_i^*(s_L) = 0, x_i^*(s_H) = 0)$. This equilibrium is sustained if the off-equilibrium-path beliefs of more than $n - m$ agents is such that $\mu(B_H|s_H) < \frac{\gamma_i - B_L P(piv|x_{-i})}{P(piv|x_{-i})(B_H - B_L)}$.

- If $|\bar{M}| \geq m$, there exists a pooling equilibrium where the policy-maker chooses (s_L, s_L) and all agents choose $(x_i^*(s_L) = 1, x_i^*(s_H) = 0)$, if their off-equilibrium-path beliefs are $\mu(B_H|s_H) < \frac{\gamma_i - B_L P(piv|x_{-i})}{P(piv|x_{-i})(B_H - B_L)}$, or $(x_i^*(s_L) = 1, x_i^*(s_H) = 1)$, if they have off-equilibrium-path beliefs of $\mu(B_H|s_H) \geq \frac{\gamma_i - B_L P(piv|x_{-i})}{P(piv|x_{-i})(B_H - B_L)}$.

- If $|M_{LH}| \geq m$, $|M_{LH}| - |M_H| < m$ and $c(s_H) > B_L$, there exists a separating equilibrium where the policy-maker chooses the strategy (s_L, s_H) and exactly m agents choose the strategy $(x_i^*(s_L) = 0, x_i^*(s_H) = 1)$.

2.4 Equilibrium Selection

The equilibrium analysis section above shows that in some settings, there exist multiple equilibria. The existence of multiple equilibria means that these outcomes are uninformative as it provides little predictive power. Equilibrium selection arguments, including the tracing procedure (Harsanyi and Selten, 1988) and the concept of stochastic stability (Young, 1993) will be used to identify which equilibrium is most likely to prevail and the conditions under which they prevail.

2.4.1 Tracing Procedure

The tracing procedure is an equilibrium selection method developed by Harsanyi and Selten (1988). Although the game being studied is not a perfect information game, the sub-game played by the n agents, which we are most interested in, is a perfect information game, taking the agents' expected value of the public good $E(b|s)$ as given.

To apply the tracing procedure in this problem, I introduce additional notations. Denote Γ as the sub-game played by the n agents. Denote $\sigma = (\sigma_1, ..., \sigma_n)$ as the mixed strategy profile of all agents where σ_i denotes the probability that agent i chooses $x_i = 1$. Denote $\beta = (\beta_1, ..., \beta_n)$ as the prior strategy combination which represents the agents' mutual expectation of each other's strategies. Denote $\beta_{-i} = (\beta_1, ..., \beta_{i-1}, \beta_{i+1}, ..., \beta_n)$ as agent i's subjective belief about the other agents' strategies. It is assumed that all β_i's are independent of each other. The only restriction for β is that all β_i can only be convex combinations of i's equilibrium strategies[1].

Define an auxiliary game, Γ^λ, where $0 \leq \lambda \leq 1$, as a game where the expected utility of each agent is as follows:

$$EU_i^\lambda(\sigma_i, \sigma_{-i}) = \lambda EU_i(\sigma_i, \sigma_{-i}) + (1-\lambda)EU_i(\sigma_i, \beta_{-i}) \tag{2.4}$$

where

$$EU_i(\sigma_i, \sigma_{-i}) = E(b|s)P(\sum_{i\in N} x_i \geq m|\sigma_i, \sigma_{-i}) - \gamma_i\sigma_i$$

and

$$EU_i(\sigma_i, \beta_{-i}) = E(b|s)P(\sum_{i\in N} x_i \geq m|\sigma_i, \beta_{-i}) - \gamma_i\sigma_i$$

$P(\sum_{i\in N} x_i \geq m|\sigma_i, \sigma_{-i})$ and $P(\sum_{i\in N} x_i \geq m|\sigma_i, \beta_{-i})$ are probabilities that $\sum_{i\in N} x_i \geq m$ given (σ_i, σ_{-i}) and (σ_i, β_{-i}) respectively.

[1] For example, an agent i whose only equilibrium strategy is $x_i = 0$ must have $\beta_i = 0$. Whereas, an agent j whose equilibrium strategies consist of both $x_j^* = 0$ and $x_j^{**} = 1$ may have $0 \leq \beta_j \leq 1$.

Notice that at $\lambda = 1$, the expected utility function (2.4) is synonymous with the agents' utility function (2.1), but adapted to allow for mixed strategies. At $\lambda = 0$, each agent's expected utility relies completely on his own action and his subjective beliefs β_{-i} about the other agents' strategies.

In a similar way as we derived the agents' decision rule (2.3), we can also derive the agents' decision rule in the game Γ^{λ} as:

$$\sigma_i^* = \begin{cases} 1 & \text{if } \lambda P_i(piv|\sigma_{-i}) + (1-\lambda)P_i(piv|\beta_{-i}) \geq \frac{\gamma_i}{E(b|s)} \\ 0 & \text{if } \lambda P_i(piv|\sigma_{-i}) + (1-\lambda)P_i(piv|\beta_{-i}) < \frac{\gamma_i}{E(b|s)} \end{cases} \tag{2.5}$$

The tracing procedure begins by studying the agents' best responses to β at $\lambda = 0$ and how they change as λ increases to 1. The outcome of the tracing procedure relies heavily on β. Suppose we are in a state where strictly less than m agents have $\gamma_i \leq E(b|s)$. The only possible outcome is an equilibrium where all agents choose $\sigma_i^* = 0$ because the only possible β's are such that all agents' best responses are $\sigma^*(\beta_{-i}) = 0$. Suppose we are in a state where at least m agents have $\gamma_i \leq E(b|s)$. In this state, it is clear from the definition of β, that we can always find some β such that at least m agents choose $\sigma_i^*(\beta_{-i}) = 1$. If β is such that exactly m agents choose $\sigma_i^*(\beta_{-i}) = 1$, the final outcome will be such that exactly the same m agents choose $\sigma_i^* = 1$. The result is more interesting if β is such that more than m agents choose $\sigma_i^*(\beta_{-i}) = 1$. If this is true, this means that for at least some agent i, the probability that he is pivotal given the strategy of others σ_{-i} must be $P(piv|\sigma_{-i}) = 0$. This is because more than m agents have chosen to participate. Therefore, as λ increases from 0 to 1, $\lambda P(piv|\sigma_{-i}) + (1-\lambda)P(piv|\beta_{-i})$ decreases for all agents who chose $\sigma_i^*(\beta_{-i}) = 1$. This means that as λ increases to 1, more and more agents will change their best responses from $\sigma_i^* = 1$ to $\sigma_i^* = 0$. This process continues until only m agents remain, at which point $P(piv|\sigma_{-i})$ jumps to 1 and $\lambda P(piv|\beta_{-i}) + (1-\lambda)P(piv|\sigma_{-i}) = 1$. This leads to the following result:

Proposition 2.2: For any β such that at least m agents choose $\sigma_i^*(\beta_{-i}) = 1$, the tracing procedure always ends in a threshold equilibrium. Otherwise, it will always end in the free-riding equilibrium.
Proof: This result follows immediately from the preceding argument.

2.4.2 Stochastic Stability

The equilibrium selection concept, stochastically stable equilibrium (Young, 1993) will be applied here in a similar way as by Ghosal and Proto (2009). The underlying assumption of this equilibrium selection concept is that when there are multiple equilibria, players may make mistakes or experiment with different actions. The stochastically stable equilibrium is one which is most robust to such mistake or experimentation. It is intuitive that the free-riding equilibrium is most likely to be most robust to such mistake. The smallest number of mistakes that it takes to move from the free-riding equilibrium to a threshold equilibrium is $m - 1$. This number is required so that there exists at least one agent whose best response is to participate. However, it needs only one mistake to move in the opposite direction. This leads to the following result:

Proposition 2.3: The free-riding equilibrium is the stochastically stable equilibrium if the public good has any threshold $m > 2$.
Proof: See appendix.

2.5 Discussion

2.5.1 Key Implications of the Results

The results of the analyses above have several important implications. The first key result is the persistent existence of the free-riding equilibrium. This is true regardless of the agents' posterior on the benefit of the public good. This suggests that it is always possible that there is insufficient voluntary participation in the production of the public good even if everyone believes that it is very beneficial to them. This is consistent with the argument by Olson (1965).

The second key result is that the separating strategy by the policy-maker can be crucial in allowing the threshold equilibrium to exist, but it does not rule out the existence of the free-riding equilibrium. This suggests that even if a policy-maker is able to convince potential participants that the public good is beneficial to them, there is still a chance that they will collectively fail to produce the public good. This identifies one key role of the policy-maker as a conveyor of information. But it also identifies another quality that the policy-maker and participants need, that is the ability to coordinate collective action.

The third result worth mentioning is the persistent existence of the first type of equilibrium mentioned in Proposition 2.1, in which the policy-maker chooses the pooling strategy (s_L, s_L) and the agents always choose not to participate. This equilibrium suggests that even if it is crucial to convince participants that a public good is beneficial, a policy-maker may not even try to do so, if they think that the participants are not able to coordinate to produce the public good. This can be seen from two different perspectives. Firstly, it suggests that if the policy-maker expects that the participants will fail to act collectively, then they won't even try to convince the participants to participate. Secondly, if the policy-maker thinks that they themselves do not have the ability to coordinate collective action among the participants then they won't even try to convince the participants. This can be driven by different factors such as weak social institutions and weak leadership from the side of the policy-maker that make them unable to coordinate collective action among the participants. Examples of these are provided in the subsection below.

The fourth result shown in the equilibrium selection argument using the tracing procedure shows the importance of participants' prior beliefs over each other's action. One important implication of this result is that as long as participants believe that others are participating to a high enough probability but not too high, then we always end in a threshold equilibrium, where the public good is produced. Note however that the tracing procedure assumes that participants collectively make decisions by gradually adjusting their beliefs over other participants' action. In reality, this may or may not be the case and require additional experimentation to show if this is the case.

The final result shown was that the free-riding equilibrium is the stochastically stable equilibrium. This suggests that without any instrument or tool to coordinate collective action among participants, the production of the public good will most likely fail. It also suggests that even if it happens that the threshold equilibrium is selected, it is still likely to diverge to the free-riding equilibrium if there is nothing to reinforce it.

2.5.2 Policy-Implication

The most important policy-implication from this result is that it is not enough just for the policy-maker to make salient the benefit of the public good to their community members or attract their attention, but it is just as, if not more, important that they ensure that their community members can overcome collective action problem. That is, a community needs strong institutional factors, whether from within the community itself or from outside, that induce cooperation.

This result may explain the inability of communities with weak institutions to provide public goods. While interventions to inform participants are readily available in most cases, strong institutions are more difficult to come by, especially in developing countries (Fiszbein and Lowden (1999)). For this reason, in responding to the question of who should provide public good, Ghatak (1998) suggests that rather than delegating this responsibility to local governments, the voluntary sector, including non-governmental organisations (NGOs) should form partnership with the local governments. As argued by Ghatak (1998), this is because NGOs tend to have a stronger ability to reach out to relevant interest groups and gather trust and participation from local beneficiaries. Note however, rather than disregarding the importance of local governmental institutions, this argument simply argues that some responsibilities should be delegated to NGOs who can be more effective in some roles and provide assistance to local institutions. Note also that it is not always true that local institutions are not strong enough to deal with collective action problems. There are plenty of examples of strong governmental institutions (see Fitzgerald and Wolak (2016)) that have been successful on their own.

Another question one may ask is what an institution needs or needs to do to succeed in garnering voluntary participation in public good production. Several literatures have discussed many different things that a local institution can do to increase voluntary participation. Kosfeld et al., (2009) showed how sanctioning institutions are effective in increasing cooperation in public good production. Although, such institutions have been shown to be effective, questions may arise on whether such policy, such as sanctioning, is a moral way to induce cooperation, especially in developmental settings where potential participants experience many limitations.

One example of an institutional factor that may be suitable in developmental setting is trust. A person in a community that trusts itself to be able to collectively deliver a public good is more likely to participate in collective action. A person that trusts its local institution to convince other members of the community to participate in collective action, is also more likely to participate. This is because, in both cases, they know that their effort will not be in vain. Rompf et al., (2017) conducted a study on collective action in the case of recycling. They studied two different categories of trust: institutional trust, defined as “trust in the reliability, effectiveness and legitimacy of public institutions”, and generalized social trust, defined as trust in the actions of other people in the society. They showed that both categories of trust are effective in raising participation in recycling behaviour. They also showed that institutional trust not only increases participation, but it also lowers the negative effect of increasing cost. Their argument on trust is consistent with the result of the tracing procedure which suggests that if individuals trust (or believe) that others are participating, to some extent, in the public good production, then they will participate too.

Giddens (1990) argued that the link between institutional trust and participation in collective action is due to the intrinsic beliefs among those with high institutional trust that the actions and behaviours of others are regulated and there exists standards and rules that are followed by all. Social trust, on the other hand, promotes cooperation by creating a perception of trustworthiness and that it should be reciprocated by all individuals (Romf et al., 2007 and Sønderskov, 2011). These arguments suggest that a policy-maker maybe more effective in garnering participation in public good production if they have a stronger ability to build trust from and among his community members.

Trust was just an example of many institutional factors that could potentially improve collective action. Different institutional factors may also be needed for different types of public goods (for examples, the need of social capital in environmental planning (Rydin and Pennington, 2010) and property rights in the adoption of agricultural and natural resource management (McCulloch et al., 1998)). Social institutions, such as social trust (as discussed above), economic and social heterogeneity (Adhikari and Lovett, 2006) and social norms and the ability to communicate it (Thomas and Sharp, 2013), have also been shown to influence participation in collective action. It is also a role of the policy-maker to continually strengthen these institutional factors to sustain collective action.

2.6 Conclusion

In conclusion, my model suggests that signalling, even if perfectly informative about the benefit of the public good, is not enough to guarantee the production of the public good. There are cases where signalling can help ensure that a threshold equilibrium is part of the equilibrium set, but signalling alone cannot eliminate the free-riding equilibrium from the equilibrium set. It was shown that the free-riding equilibrium is a stochastically stable equilibrium, which means that without any mechanism to solve collective action problem, it is likely to prevail over the threshold equilibria. However, it was also shown using the tracing procedure that the agents' prior beliefs affect the outcome of the game and it provides some conditions, under which a threshold equilibrium will be selected over the free-riding equilibrium.

The key implication of this result for voluntary public good production, is that policies targeted at raising awareness, such as advertising campaigns, alone is not enough to guarantee sufficient participation in public good production. I argue that along with such intervention, a policy-maker needs to be able strengthen their governing and social institutions in such a way that strengthens trust and cooperation.

2.7 Appendix

2.7.1 Perfect Bayesian Equilibria

In this section, I show how the Perfect Bayesian Equilibria of my model was derived. Denote $\mu(B_H|s)$ as the agents' posterior beliefs that the public good is B_H after s is observed.

Pooling Equilibrium (s_L, s_L)

Suppose the policy-maker plays the strategy (s_L, s_L). This strategy is not informative to the agents, by Bayes' rule, their posterior beliefs after observing s_L will be the same as their prior; $\mu(B_H|s_L) = p$. The agents' expectation of the benefit of the public good is then $E(b|s_L) = pB_H + (1-p)B_L$. As shown in Section 3, there are only two possible types of collective response from the agents in pure strategy, either $\sum_{i \in N} x_i = 0$ (free-riding) or $\sum_{i \in N} x_i = m$ (desirable).

The collective response from the agents depend on the cost profile of the agents. If $|\bar{M}| < m$, the only possible outcome is all agents choose $(x_i(s_L) = 0, x_i(s_H) = 0)$. This is because there are not enough agents willing to voluntarily support the cooperative equilibrium. If $|\bar{M}| \geq E(b|s_L)$, both the free-riding and the desirable equilibrium are possible, because both outcomes comply with the decision rule (2.3). If the collective response of the agents is such that all agents choose $(x_i(s_L) = 0, x_i(s_H) = 0)$, the policy-maker will maintain the same pooling strategy (s_L, s_L) if at least $|N| - m + 1$ agents hold off-equilibrium-path beliefs such that $\mu(B_H|s_H) < \frac{\gamma_i - B_L P(piv|x_{-i})}{P(piv|x_{-i})(B_H - B_L)}$. If this condition holds, there always exist a pooling strategy where the policy-maker chooses (s_L, s_L) and the agents choose the strategy $(x_i(s_L) = 0, x_i(s_H) = 0)$. On the other hand, if the outcome $\sum_{i \in N} x_i = m$ is reached, this means that the public good will be produced when s_L is observed by the agents. Therefore, there is no reason for the policy-maker to choose s_H in any case, as this will only increase their cost. The pooling strategy (s_L, s_L) with m agents choosing the strategy $(x_i(s_L) = 1, x_i(s_H) = 0)$ or $(x_i(s_L) = 1, x_i(s_H) = 1)$ is also a pooling equilibrium.

Pooling Equilibrium (s_H, s_H)

Under the strategy (s_H, s_H), by Bayes' rule, the agents' posterior beliefs and collective response mirror that of (s_L, s_L). This means that any outcome that can be achieved with (s_H, s_H) can also be achieved with (s_L, s_L) which is a strictly less costly strategy than (s_H, s_H). Therefore there cannot be a pooling equilibrium where the policy-maker chooses the strategy (s_H, s_H).

Separating Strategy (s_L, s_H)

If the policy-maker chooses the separating strategy (s_L, s_H), the agents' posterior beliefs will be $\mu(B_H|s_L) = 0$ and $\mu(B_H|s_H) = 1$. The collective response from the agents depend on their cost profile. If $|M_{LH}| < m$, the only response from the agents will be such that all agents choose the strategy $(x_i(s_L) = 0, x_i(s_H) = 0)$, because not enough agents can voluntarily participate in the production of either public good.

If $|M_{LH}| \geq m$ and $|M_{LH}| - |M_H| < m$, which means that at least an agent from M_H is needed for the public good to be produced, it is impossible for the public good of type B_L to be produced. There are two possible collective responses from the agents, either all agents choose the strategy $(x_i(s_L) = 0, x_i(s_H) = 0)$ or exactly m agents choose $(x_i(s_L) = 0, x_i(s_H) = 1)$ and the other agents choose $(x_i(s_L) = 0, x_i(s_H) = 0)$. In the former case, the policy-maker will respond with the strategy (s_L, s_L), which means that there is no separating equilibrium where the policy-maker chooses (s_L, s_H) and the agents choose $(x_i(s_L) = 0, x_i(s_H) = 0)$. In the latter case, the policy-maker will maintain the same strategy if $c(s_H) > B_L$, otherwise the policy-maker will be willing to choose s_H instead when $b = B_L$, given the posterior beliefs of the agents. If $c(s_H) > B_L$, there exists separating equilibria, where the policy-maker chooses (s_L, s_H) and exactly m agents choose $(x_i(s_L) = 0, x_i(s_H) = 1)$ and the other agents choose $(x_i(s_L) = 0, x_i(s_H) = 0)$. There exists exactly $\frac{|M_{LH}|!}{m!(|M_{LH}|-m)!}$ such equilibria.

If $|M_{LH}| > m$ and $|M_{LH}| - |M_H| \geq m$, which means that agents from M_H

are not needed for the public good to be produced, there are three possible outcomes. Firstly, the agents may again choose the strategy, $(x_i(s_L) = 0, x_i(s_H) = 0)$, in which case, the policy-maker will change their strategy to (s_L, s_L). Secondly, we may reach an outcome where exactly m agents from the set $M_{LH} \setminus M_H$ choose the strategy $(x_i(s_L) = 1, x_i(s_H) = 1)$. In this case, the policy-maker will want to divert to the strategy (s_L, s_L), because they do not need to use the more costly signal s_H for the public good to be produced when $b = B_H$. Thirdly, we may reach an outcome where exactly m agents choose the strategy $(x_i(s_L) = 0, x_i(s_H) = 1)$, but at least 1 of the m agents are from the set M_H. In this case, the policy-maker will have no incentive to deviate to any other strategy. Therefore, this can be a Perfect Bayesian equilibrium.

Separating Strategy (s_H, s_L)

The strategy (s_H, s_L) cannot be part of a Perfect Bayesian Equilibrium. This is simply because the posterior beliefs of the agents will be $\mu(B_H|s_L) = 1$ and $\mu(B_H|s_H) = 0$ and under the assumption that $c(s_H) > c(s_L)$, the policy-maker will always prefer s_L over s_H for all possible responses from the agents when $b = B_L$. Therefore, the separating strategy (s_H, s_L) cannot be part of a Perfect Bayesian Equilibrium.

2.7.2 Equilibrium Selection: Stochastic Stability

I apply the stochastic stability concept (Young, 1993) here in a similar way as Ghosal and Proto (2009), except that my model deals with n individual agents instead of a continuum of agents of unit measure.

Let g denote the normal form game played by the agents. The concept of stochastic stability assumes that agents may make mistakes when taking action or they may experiment with different actions with some small probability

ε. Agents then optimally respond to the mistakes that they observe[2]. Denote $g(\varepsilon)$ as the perturbed game. As discussed above, there are two types of equilibria in the game g, the free-riding equilibrium (denote as type a_1) and an equilibrium where exactly m agents participate in the production of the public good (denote as type a_2). There can be more than one type a_2 equilibria. The question we try to answer is which of these is stochastically stable. Young (1993) defines stochastically stable states as states with the least resistance.

Denote $M = \{i \in N : E(b|s) \geq \gamma_i\}$. Suppose we are in a state where $|M| \geq m$, so that there exist both types of equilibrium. Suppose we are in any of the a_2 equilibria. To move from any of these states to the free-riding equilibrium, the minimum number of mistakes required is one. This is because if a participating agent makes a mistake, there can be two outcomes, either one of the non-participating agents responds by choosing to participate, in which case we move to another type a_2 equilibrium, or one of the participating agents choose to not participate because they are no longer pivotal, in which case we take a zero resistance path towards the free-riding equilibrium. This argument holds for transitions from any of the type a_2 equilibria to the free-riding equilibrium. This means that the resistance of the free-riding equilibrium equals the number of a_2 equilibria, $\frac{|M|!}{m!(|M|-m)!}$.

The next step is to find the resistance of the type a_2 equilibria. Suppose again that we are in any of the a_2 equilibria. To move from an a_2 equilibrium to another of the same type, it always require at least one mistake. This is because they are all strict pure strategy equilibria, which means there can be no path of zero resistance between them. Suppose that we are in the free-riding equilibrium. To move to any of the a_2 equilibria requires a minimum of $m - 1$

[2]Young (1993) assumes that agents take a sample of history of play of size k and choose their action optimally. Theorem 1 of Young (1993) sets the upper limit of k. For simplicity and without loss of generality, I assume that $k = 1$.

mistakes. This is required so that there is at least one other agent whose best response is to participate. This means that the resistance of each of the type a_2 equilibria is at least $\frac{|M|!}{m!(|M|-m)!} - 1 + m - 1$. We can derive the condition for which the free-riding equilibrium is the unique stochastically stable equilibrium by setting $\frac{|M|!}{m!(|M|-m)!} < \frac{|M|!}{m!(|M|-m)!} - 1 + m - 1$. Therefore, the free-riding equilibrium is stochastically stable if $m > 2$. Note that this was derived using the lower limit of the resistance of each type a_2 equilibrium only. If $|M| - m$ is large, the lower limit of m for the free-riding equilibrium to be stochastically stable can be lower.

Chapter 3

Public Good Game with Incomplete Information and the Dynamic of its Production Function

3.1 Introduction

Public goods and collective action in general are very important to many levels of our society. At a global level, we need to work together to tackle global warming and climate change. On the other extreme, at a local community level, community members need to work together to, for example, construct roads and irrigation systems, to improve their livelihood. In developmental settings, public goods are particularly important because its potential beneficiaries usually cannot afford private alternatives to the public goods. However, public good production at almost any level and collective action in general are prone to collective action problem.

Literatures such as by Libecap (1994), Olson (1965) and Ostrom (1998, 2007 and 2010) discussed how difficult it is to succeed in collective action and how complex collective action is in terms of the number of variables that could influence its likelihood of success. These variables include, for example the ability to build coalitions, group (population) size, heterogeneity of participants' preferences, the ability to communicate and other structural factors. Yet, not all literatures agree on how these variables affect the success of collective action. For instance, Olson (1965) argued that collective action is more likely to succeed in smaller groups than in larger groups. Agrawal (1996) provided an evidence that showed otherwise. Oliver and Marwell (1988), on the other hand, argued that the effect of group size on collective action is context dependent, specifically it depends on participation costs and the heterogeneity of participants' preferences. Clearly, understanding collective action is challenging and it needs clear and detailed analyses of the effect of each of the structural factors.

One structural factor that many literatures on collective action tend to disregard is the dynamic of a public good's production function. Some of the few known literatures that analyse of how the production function can affect the outcome of a public good game include Oberschall (1980, 1994), Marwell and Oliver (1991, 1993) and Oliver et al., (1985). They showed that the outcomes of public good games with different production functions can have very different results and dynamics and that they may require different solutions. However, their analyses were set in an informal setting and in the context of social movements instead of a more general setting.

To show how public goods with different production function shapes require different solutions, I raise two examples. Berger (2003) and Shepherd (1992) showed that maintaining peace amongst nomadic pastoralists require a more institutional solution, which was to build the capacity of leaders to manage resources and resolve conflicts, and an educational solution that involved raising awareness was ineffective. In the case of disease elimination, it has been shown that an effective policy comprises both raising awareness and the reduction of participation cost (Beyenne et al., (2018), Castillo-Neyra et al., (2017) and Castillo-Neyra et al., (2019)).

In this chapter, I study how the shape of a public good's production function affect voluntary participation in its production. However, I do so in a game theoretic context, which can give a more detailed and analytical result than the studies mentioned above. This chapter follows from the previous chapter in the sense that I will be looking at public good production of different types (production function shape), which provides some insight into the relevance of a structural factor in public good production. In addition, I make a more realistic assumption that participants incur different participation costs and that they do not know the participation costs of each other, except the distribution of the cost. The assumption that private costs of participation is private knowledge and that only its distribution is common knowledge, is more realistic than the assumption of complete information. In practice, individuals may have an idea or a rough estimate of what others' participation costs are, but they do no always know the exact values. From a technical and theoretical perspective, there are two key advantages of assuming incomplete information. Firstly, it provides a more easily interpretable equilibrium. Examples of these can be seen in Morris and Shin (1998) and Ghosal and Thampanishvong (2013). Both of these studies showed that the existence of threshold equilibria where each agent's action depends on their private information about themselves. Secondly, it can be used to narrow down the set of equilibria (Morris and Shin, 2001). Morris and Shin (1998) and Ghosal and Thampanishvong (2013) showed that assuming incomplete information can lead to unique equilibrium, but as I will show below, there are cases where there can still be multiple equilibria.

Results from my analysis show that the set of equilibria of this game is dependent on the shape of the public good's production function. I show that there always exists at least one symmetric threshold equilibrium, in which an agent participates if his participation cost is below a certain threshold and not participate otherwise. When the production function is concave, there always exists a unique symmetric threshold equilibrium. When the production function is convex, there exists a unique symmetric threshold equilibrium if the benefit of the public good is small, but there can be up to three equilibria, including one where everyone participates, when the benefit of the public good is large enough. When the production function is a step-function, the equilibrium set depends on what the threshold for public good production is. An interesting feature when the production function is a step-function is that the free-riding equilibrium, in which no one participates in the public good production always exists, except when the production function is such that only one person is needed to produce the public good. As an extension, I show that if the production function is s-shape, the set of equilibria is similar to the case when the production function is a step function when it has a very steep section. However, if it does not have a particularly steep section, or it is closer in shape to a linear function, then there exists only one threshold equilibrium.

From these results, I also provide some policy implications for different cases of public good. One policy that can be effective in many cases is the reduction of private participation cost. Such policy may include, for example, subsidies, but such policy can be very costly. Other policies that do not involve cost reduction can also be effective in some cases. I argue that when the public good has a concave production function, a good policy should target at reducing private cost of participation, because other policies such as advertising to increase salience or perceived benefit of a public good tend to have only a very limited effect. When the production function is convex, a good policy should be to make the collective benefit of the public good salient and focus on getting participants to commit to participating at a higher cost. When the production function is a step function, I argue that a combination of policies is needed. It should make the collective benefit of the public good salient, encourage full participation instead of just enough to produce the public good, reduce participation cost and convince participants to commit to participating.

The organisation of this paper is as follows. The next section provides a layout of the model being studied. Section 3 analyses the equilibria of the model. Section 4 discusses some extensions I made to the analysis of the model, which includes a comparative static analysis and a brief discussion on the outcomes of the public good game when the production function is s-shape. Section 5 provides a general discussion which includes the policy implications of the results in Section 3 and 4, and some case studies. Section 6 concludes.

3.2 Model

There is a group of n agents indexed by $i \in \{1, ..., n\}$. Each agent i has two action choices denoted by $a_i \in \{0, 1\}$. $a_i = 1$ indicates agent i choosing to participate in producing the public good and $a_i = 0$ indicates otherwise. Agent i incurs a private cost c_i if he chooses to participate. c_i is independently and uniformly drawn from $[0, 1]$. c_i is known only to i. Only the distribution from which c_i's are drawn is common knowledge.

The assumption of a finite number of agents is used here because I am more interested in the collective action or public good production at a local level, where participation is generally required from a relatively small number of people. One may alternatively assume a continuum of agents. However, this suggests that there is a large number of agents and the contribution of each agent in the public good production is insignificant (Aumann et al., (1987)), which is not always the case in developmental settings, where each individual unit of participation is actually significant.

In addition, I could have allowed positive private net benefit because some may obtain direct private benefit from participating in public good production (for example, see Andreoni (1990)). However, it is obvious that those who can obtain positive private net benefit from participating will always participate in public good production and we are more interested in understanding the decision of those with positive participation costs. Hence, I restrict my analysis to those with positive participation costs only.

Denote $r_{-i} = \frac{\sum_{I \neq i} a_I}{n}$ as the proportion of agents apart from i who choose to participate in the public good production. Denote $r = r_{-i} + \frac{a_i}{n}$ as the total proportion of agents participating. Denote $P(r)$ as the probability that the public good is successfully produced given r. It is assumed that $P(.)$ is strictly increasing in r, except when $P(.)$ is a step function, where, by definition, $P(.)$ can only be increasing, and $P(1) = 1$. If the public good is successfully produced, all agents receive a collective benefit of $\theta > 0$. For simplicity, I assume that $\theta = 1$[1].

$P(.)$ can take many different shapes, but for any given game, the shape of the production function is common knowledge. I look at cases where $P(.)$ is concave, convex and a step-function (as an extension I will also discuss a case where $P(.)$ is s-shape). If $P(.)$ is a concave function, the marginal increase in $P(.)$ decreases as the number of participants increases. An example of this is the creation of a social group, the first few units of participation in most important because they are what start the social group itself, any additional participation can help sustain the social group, but it is unlikely to be as crucial as the first units. If $P(.)$ is convex, the marginal increase in $P(.)$ increases as the number of participants increases. An example of this is maintaining peace among nomadic pastoralists as mentioned above. A few tribes committing to

[1] In Section 4, I relax this assumption and investigate how it influences the final outcome of the model.

peaceful co-existence with other tribes does not contribute much to peace if the other tribes do not do the same. If even a single tribe continues to be aggressive, it is difficult for the other tribes to continue their peaceful way of life even if they can commit to that among themselves. Any tribe that does not trust that other tribes can commit to being peaceful will believe that taking a more aggressive stance is crucial for their survival. If $P(.)$ is a step-function, the marginal increase in $P(.)$ is typically zero except at the "step(s)", where an additional agent participating in the public good production would give a sharp increase in $P(.)$. Examples of these are all threshold public goods.

Another underlying assumption made is that the value of the benefit of the public good is common knowledge and known to all agents. This assumption is applicable in many developmental settings for a few reasons. Firstly, beneficiaries of a public good tend to know very well how they and and their whole community can benefit from the public good. For instance, villagers in an agricultural community know very well how the construction and maintenance of an irrigation system benefit them as a group (Bardhan, 2000). Secondly, for some public goods, additional interventions such as from the local authorities and other organisations tend to raise awareness of the public good prior to it being produced. Therefore, by the time community members need to decide whether they should participate in the public good production or not, they can be quite well informed about the benefit of the public good already.

Given all these assumptions, the expected utility function of an agent i can be written as follows:

$$EU_i(a_i, r_{-i}, c_i) = P(r_{-i}, a_i) - c_i a_i \tag{3.1}$$

The timeline of the model is as follows:

- At time $t = 1$, Nature draws the agents' private participation cost c_i's
- At time $t = 2$, each agent observes only his/her own private cost of partici-

pating and choose whether to participate in the public good production

-At time $t = 3$, the public good is produced with probability $P(r)$ and all agents receive the benefit of the public good if it is produced, or not if it is not produced.

3.3 Equilibrium Analysis

In this incomplete information game, I define an agent's strategy as a function of his/her private cost of participation. I assume that agents who are indifferent between participating and not participating will always choose to participate.

Suppose now that a fraction r_{-i} of other agents choose to participate, i's expected pay-off from participating can be written as:

$$EU_i(a_i = 1) = P\Big(r_{-i} + \frac{1}{n}\Big) - c_i$$

His expected pay-off from not participating can be written as:

$$EU_i(a_i = 0) = P(r_{-i})$$

Agent i would participate in the public good production only if his expected pay-off from doing so exceeds that of not participating. Therefore, we can obtain the condition for i's participation:

$$P\Big(r_{-i} + \frac{1}{n}\Big) - P(r_{-i}) \geq c_i \tag{3.2}$$

Since we assume that $P(.)$ is increasing, the left-hand side of (3.2) is always positive. The right-hand side of (3.2) is non-negative by assumption. Condition (3.2) suggests that for i to participate, the efficacy of his participation or the probability that he is pivotal in the public good production has to exceed his cost of participation. If c_i is zero, then i would always participate. If c_i is one, then i would never participate unless $P(.)$ is a step-function and i is pivotal (in other words, the left-hand side of (3.2) is equal to one). It is unclear what action i would take if c_i is between zero and one, but a natural strategy one may consider is a threshold strategy around some value c in which i chooses to participate for $c_i \leq c$ and not participate otherwise.

Suppose now that all agents except i adopt the threshold strategy around some cost c and i's participation cost is c_i. Denote $p_j(c)$ as the probability that exactly j other agents apart from i have participation cost of c or less. Since it is assumed that c_i is independently and uniformly drawn from $[0, 1]$, the probability that an agent has a participation cost of c or less is simply c. We can then write $p_j(c)$ as:

$$p_j(c) = \binom{n-1}{j} c^j (1-c)^{n-1-j}$$

We can then write i's expected utility from participating as:

$$EU_i(a_i = 1) = \sum_{j=0}^{n-1} p_j(c) P\Big(\frac{j+1}{n}\Big) - c_i$$

Similarly, i's expected utility from not participating can be written as:

$$EU_i(a_i = 0) = \sum_{j=0}^{n-1} p_j(c) P\Big(\frac{j}{n}\Big)$$

We can then derive i's condition for participating as:

$$\sum_{j=0}^{n-1} p_j(c) \delta_j \geq c_i \qquad (3.3)$$

where $\delta_j = P\big(\frac{j+1}{n}\big) - P\big(\frac{j}{n}\big)$. Condition (3.3) suggests that agent i would participate if the expected efficacy of his participation or the expected probability that he is pivotal given other agents adopt the threshold strategy around c exceeds his private cost of participation. Treating both sides of the inequality (3.3) as functions of c and c_i respectively, we can find the set of equilibria geometrically by finding the range of c and c_i over which condition (3.3) is satisfied.

The right-hand side of (3.3) is clearly a 45 degree line within the domain $[0, 1]$.

Note that $\sum_{j=0}^{n-1} p_j(c) = 1$, for all $c \in [0,1]$ which means that the left-hand side of (3.3) is a convex combination of the numbers $\delta_0, ..., \delta_{n-1}$, with $p_j(c)$ as their respective weights. We also know that $\delta_j \in [0,1]$ for all j, therefore the range of the left-hand side of (3.3) must be a proper subset of $[0,1]$. This suggests that there is at least one intersection point between the left-hand side and the right-hand side of (3.3). This leads to the following proposition:

Proposition 3.1: In the game described above, there always exist at least one symmetric threshold equilibrium.

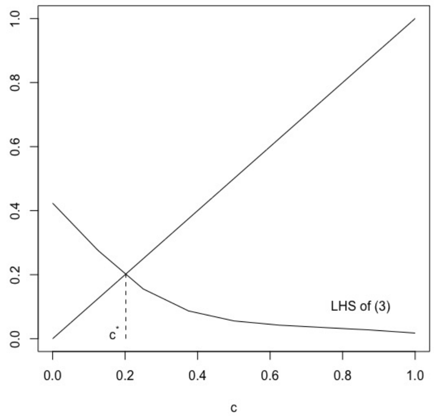
Proof: This is immediate from the preceding argument.

Concave $P(.)$

When $P(.)$ is concave, $0 < \delta_j < 1$ and $\delta_{j-1} > \delta_j$ for all $j \in \{1, ..., n-1\}$. These suggest that within the domain $c \in [0,1]$, the range of the left-hand side of (3.3) has to be $[\delta_{n-1}, \delta_0]$, which is a strict subset of $[0,1]$. It can also be shown that as c increases from 0 to 1, the convex combination shifts its weight gradually from being completely on δ_0 to δ_{n-1} (see Appendix for proof). This suggests that the left-hand side of (3.3) is a decreasing function in c. Given that the left-hand side of (3.3) is continuous, decreasing in c and its range is a proper subset of $[0,1]$ and the right-hand side of (3.3) is an increasing 45 degree line, the curves representing both sides of (3.3) must intersect exactly once at some c^*. Given that the agents are also symmetric, there must be only one symmetric threshold equilibrium around some c^*, in which agents whose private cost is less than or equal to c^* will participate and those whose private cost is higher will choose not to participate. This result is illustrated in Figure 3.1 and it leads to the following proposition.

Proposition 3.1A: If $P(.)$ is a concave function, then there always exists exactly one symmetric threshold equilibrium.

Proof: This result is immediate from the preceding argument.



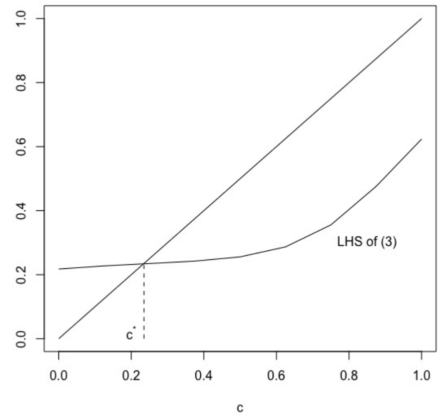


Figure 3.1: Equilibrium for concave $P(.)$Figure 3.2: Equilibrium for convex $P(.)$

Convex $P(.)$

When $P(.)$ is convex, $0 < \delta_j < 1$ and $\delta_{j-1} < \delta_j$ for all $j \in \{1, ..., n-1\}$. Following the same argument as the case of concave $P(.)$, we know that the left-hand side of condition (3.3) has a range of $[\delta_0, \delta_{n-1}]$ and is an increasing function of c. Therefore there must exist at least one intersection point between the curve representing the left-hand side of (3.3) and the 45 degree line representing the right-hand side of (3.3). It can be proven that there must be exactly one intersection point (see Appendix). Therefore, when $P(.)$ is convex, there is exactly one symmetric threshold equilibrium around c^*. Note, however, that this result is true only because it has been assumed that the benefit of the public good θ is equal to 1[2]. This result is illustrated in Figure 3.2 and it leads to the following proposition:

Proposition 3.1B: If $P(.)$ is a convex function and $\theta = 1$, then there always exists exactly one symmetric threshold equilibrium.

Proof: See Appendix.

[2]The next section discusses what happens when we relax this assumption and allow θ to be greater than 1

Step-function $P(.)$

When $P(.)$ is a step-function, δ_j must be zero for all j, except at some $\tilde{j}$ at which $\delta_{\tilde{j}}$ must be positive. Therefore, condition (3.3) is reduced to:

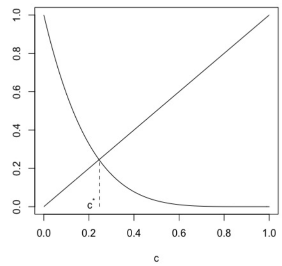
$$p_{\tilde{j}}(c)\delta_{\tilde{j}} \geq c_i \tag{3.4}$$

It can be shown that for any $\tilde{j}$, $p_{\tilde{j}}(c)$ is a single peak function in c, which peaks at $c = \frac{n-1}{\tilde{j}}$. Since $\delta_{\tilde{j}}$ is a positive number, the left-hand side of (3.4) must also be a single peak function. It can take many different geometric shapes depending on the values of $\delta_{\tilde{j}}$ and $\tilde{j}$ itself. Figure (3.3) provides illustrations of all possible cases.

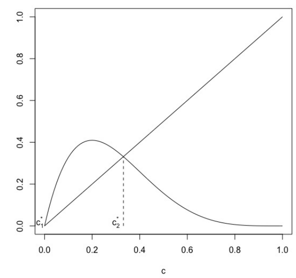
Figure (3.3a) illustrates what happens when $\tilde{j} = 0$ or when only one agent is needed to produce the public good. In this case, there is only one intersection between the left-hand side of (3.4) and the 45-degree line at $c = c^* > 0$. This suggests that there is a unique symmetric threshold equilibrium around $c^* > 0$.

Figure (3.3b) illustrates what happens when $\tilde{j} = 1$ or when only two agents are needed to produce the public good. In this case, there are two symmetric threshold equilibria, one where no one with positive participation cost participates and one where only those with costs c_2^* or lower participate. However, only the latter equilibrium is the stable equilibrium.

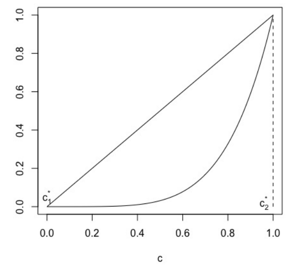
Figure 3.3: Equilibria when $P(.)$ is a step-function



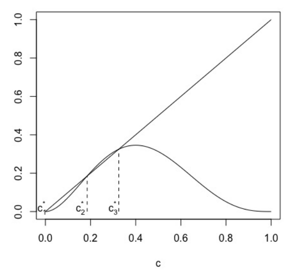
(a) $\tilde{j} = 0$



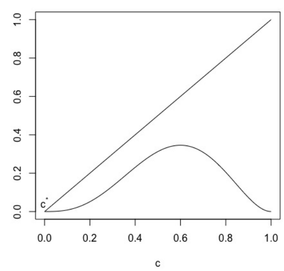
(b) $\tilde{j} = 1$



(c) $\tilde{j} = n - 1$



(d) $\tilde{j}$ small



(e) $\tilde{j}$ large

Figure (3.3c) illustrates what happens when $\tilde{j} = n - 1$. In this case, there are also two symmetric threshold equilibria, one around $c_1^* = 0$ and the other around $c_2^* = 1$. The first equilibrium suggests that virtually no one will participate in the public good production and the other suggests that everyone will participate. However, the latter equilibrium is unstable and likely diverges to the former equilibrium.

Figure (3.3d) illustrates what happens when $\tilde{j}$ is small but greater than one. In this case, there are three symmetric threshold equilibria, around c_1^*, c_2^* and c_3^*. However, the equilibrium around c_2^* is an unstable equilibrium which likely diverges to one of the other two equilibria.

Figure (3.3e) illustrates what happens when $\tilde{j}$ is large by less than $n - 1$. In this case there is only one equilibrium around $c = c^* = 0$. This suggests that when the participation threshold for the public good to be produced is high, it is most likely that no agent will participate because the only equilibrium is one where agents participate only if their private cost of participation is zero. These results lead to the following proposition:

Proposition 3.1C: If $P(.)$ is a step-function with some $\tilde{j}$ as the only point where $\delta_{\tilde{j}}$ is strictly positive, then the set of equilibria depends on the where $\tilde{j}$ is:

- If $\tilde{j} = 0$, then there exists exactly one symmetric threshold equilibrium.
- If $\tilde{j} = 1$, then there exists two symmetric threshold equilibria, at $c_1^* = 0$ and $0 < c_2^* < 1$, with the latter being the stable equilibrium.
- If $\tilde{j} = n - 1$, then there exists two symmetric threshold equilibrium, one around $c_1^* = 0$ and the other around $c_2^* = 1$, with the latter being an unstable equilibrium.
- If $\tilde{j}$ is small but greater than one, then there exists three symmetric threshold equilibria around some values c_1^*, c_2^* and c_3^*, where $c_1^* = 0$ and $c_1^* < c_2^* < c^*3$. In addition, the equilibrium around c_2^* is an unstable equilibrium which likely diverges to one of the other two equilibria.
- If $\tilde{j}$ is large but less than $n - 1$, then there exists exactly one symmetric threshold equilibrium around $c^* = 0$.

Proof: The existence of equilibria in all these cases have been proven by examples shown in Figure 3.3. For formal proof, see Appendix.

3.4 Extensions

3.4.1 Comparative Statics

The results above were reached under the assumption that $c_i \in [0, 1]$ and that the benefit of the public good θ is equal to 1 (the maximum possible value of c_i). One may be interested in understanding what would happen if these assumptions are relaxed. It is, however, unnecessary to relax both assumptions as they are both relative terms. In this subsection, I analyse what happens to the equilibrium set in each case if θ is allowed to be less than or greater than one.

For $\theta \neq 1$, condition (3.3) can be rewritten as:

$$\theta \sum_{j=0}^{n-1} p_j(c)\delta_j \geq c_i \tag{3.5}$$

Geometrically, the left-hand side of (3.5) is a vertical compression (for $0 < \theta < 1$) or a vertical stretch (for $\theta > 1$) of the left-hand side of (3.3). It is obvious that for $0 < \theta < 1$, the left-hand side of (3.5) is a vertical compression of the left-hand side of (3.3) and its range is still a strict subset of $[0, 1]$, therefore it has no effect on the equilibrium set of the game for any shape of $P(.)$, except for changes in the locations of the symmetric threshold equilibria.

For $\theta > 1$, the left-hand side of (3.5) is a vertical stretch of the left-hand side of (3.3). This suggests that for θ large enough, the range of the left-hand side of (3.5) will no longer be a strict subset of $[0, 1]$. This has no effect on the equilibrium set when $P(.)$ is concave except for the change in the locations of the threshold equilibria.

However, when $P(.)$ is a convex function, for θ large enough the left-hand side of (3.5) is increasing in c and its range may no longer be a strict subset of $[0, 1]$. This can lead to two cases, one where there is no intersection between the left-hand side of (3.5) and one where there are two intersections. These cases are illustrated in Figure 3.4.

Figure 3.4 plots the left-hand side of (3.5) for three different values of θ, $\theta_1 < \theta_2 < \theta_3$. At θ_1 which is greater than 1 but not large enough so that the range of the left-hand side of (3.5) is still a proper subset of $[0, 1]$, the result is the same as illustrated in Figure 3.2 and there is only one threshold equilibrium. At θ_2 there are two intersections between the left-hand side of (3.5) and the 45 degree line, at c^*_{21} and c^*_{22}. In this case, there are three threshold equilibria at c^*_{21}, c^*_{22} and at $c^*_{23} = 1$. However, the equilibrium around c^*_{22} is unstable and diverges downwards towards the equilibrium around c^*_{21} or upwards towards $c^*_{23} = 1$. The latter equilibrium means that all agents will participate in the public good production. When θ is very large, then there is only one symmetric threshold equilibrium where everyone participate. These lead to the following proposition:

Proposition 3.1B': If we allow $\theta > 1$ and $P(.)$ is convex, then the equilibrium set of the game is as follows:

- If θ is greater than one, but small enough that the left-hand side of (3.5) is a strict subset of $[0, 1]$, then there exists a unique threshold equilibrium around c^*_{11}.

- If θ is greater than one and the left-hand side of (3.5) is not a strict subset of $[0, 1]$, then there may exist three threshold equilibria at c^*_{21}, c^*_{22} and at $c^*_{23} = 1$, where $0 < c^*_{21} < c^*_{22} < c^*_{23}$ and $c^*_{23} = 1$. The equilibrium around c^*_{22} is unstable and diverges to one of the other two equilibria.

- If θ is very large, so that the left-hand side exceeds the right-hand side of (3.5) for all c, then there exist a unique threshold equilibrium around 1. This suggests that all agents will participate in the public good production.

When $P(.)$ is a step-function, the left-hand side of (3.3) is a bell-shape curve except when $\tilde{j} = 0$ and when $\tilde{j} = n-1$. Therefore, a vertical stretch of the left-hand side of (3.3), or increasing θ is likely to have little effect on the equilibrium set of the game, apart from that it raises the threshold equilibria marginally and it allows for positive threshold equilibria (where the threshold is strictly positive) for larger $\tilde{j}$. However, when $\tilde{j} = n - 1$, the key affect of an increased θ is that it turns the equilibrium where everyone participates from being an unstable equilibrium to being a stable equilibrium. In addition, there exists an additional threshold equilibrium, however this is unstable and likely diverges to one of the other two equilibria. These are illustrated in Figure 3.5.

Proposition 3.1C': If $P(.)$ is a step-function with $\tilde{j} = n - 1$ and $\theta > 1$, then there exists three symmetric threshold equilibria, $c_1^* = 0$, $0 < c_2^* < 1$ and $c_3^* = 1$. The interior equilibrium is unstable and likely diverges to one of the other two equilibria.

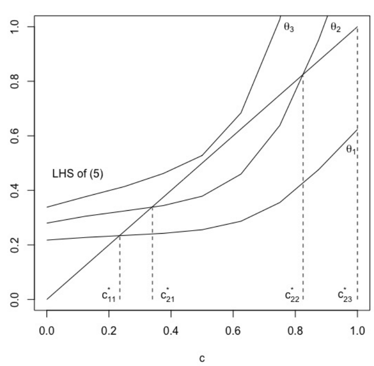


Figure 3.4: Threshold Equilibria for convex $P(.)$ and $\theta_3 > \theta_2 > \theta_1 > 1$

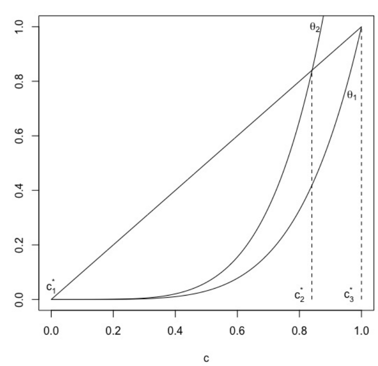


Figure 3.5: Threshold Equilibria for step $P(.)$, $\tilde{j} = n-1$, $\theta_1 = 1$ and $\theta_2 > 1$

3.4.2 S-shape Production Function

The production function of a public good can often take a more general form of an s-shape function. In an s-shape function, the efficacy of an agents' participation increases as the number of other participants increases, but after a certain threshold, the efficacy of the agent's participation starts to fall. An example of this is in disease elimination through mass vaccination. When there are few people vaccinating themselves against a disease, an additional person vaccinating himself does little to the elimination of the disease. However, as the number of people vaccinated reaches closer and closer to the threshold for herd immunity, the likelihood of the disease being eliminated increases much quicker. Once herd immunity is achieved, disease elimination is certain and the next person getting vaccinated makes little to no difference to this outcome.

Drawing a general theoretical conclusion on what the outcome of the game is like when $P(.)$ is s-shape is complex and near impossible because of the many different variations of an s-shape function. Specifically, a detailed analysis of this case needs to take into account many factors such as where the steepest part of the function is, how steep is the steepest part and what is the general dynamic of the function.

However, we can draw some insight from two extreme cases of an s-shape function. One extreme version of an s-shape function is a step-function, which has been discussed above. The other extreme is a linear function, in which $\delta_j = \delta_{j+1} = \delta$ for all $j \in \{1, ..., n-1\}$, where $\delta > 0$. Therefore, for a linear $P(.)$ condition (3.3) is reduced to:

$$\delta > c_i$$

Clearly, the left-hand side of (3.3) or (3.5) becomes a horizontal line when $P(.)$ is linear. Therefore, there can only be one threshold equilibrium when $P(.)$ is a linear function.

Comparing these two extreme cases we can draw the following conclusions. When $P(.)$ is a mild s-shape function (or almost linear), there tend to be only one threshold equilibrium. However, as $P(.)$ becomes closer and closer to the shape of a step-function, the characteristics of its equilibria are more likely to follow those of a step-function.

3.5 Implications and Discussion

3.5.1 Policy Implications

After obtaining the earlier results, one may question what their policy implications are or how this can contribute to guiding a policy-maker in making a more effective policy. The first general practical implication from the earlier analyses is that potential participants in public good production collectively respond differently to different production functions and also to different policies. The next question would be what kind of policy should be implemented in each of those cases.

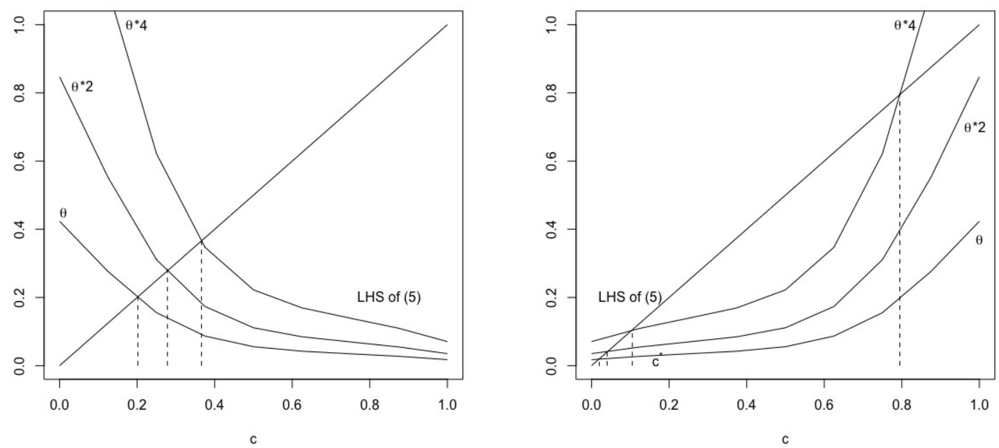
One obvious policy that can be very effective in all cases is the reduction of participation cost. It can be seen very clearly from the conditions (3.3) and (3.5) and the characterisation of all equilibria that cost reduction can be very effective in increasing participation. However, different production function shapes also have different characteristics that may respond well to policies other than cost reduction. I will discuss the policy implications case by case.

When $P(.)$ is concave, it has been shown that there is a unique threshold equilibrium. In this theoretical framework, a policy-maker can increase participation by raising a (stable) symmetric threshold equilibrium to a higher point. A typical policy to do that is to raise awareness and the perceived benefit of the public good. Such policy is unlikely to be effective in maximising participation when $P(.)$ is concave. To see this, suppose that such policy raises the perceived benefit of the public good to some θ. As argued in the previous section, raising θ only creates a vertical stretch of the left-hand side of (3.3). This suggests that when $P(.)$ is concave, any intervention designed to raise the perceived benefit of a public good is likely to only marginally raise the number of participants. To raise a significant number of participants, the improved perception may have to be impossibly large. A more effective policy would be to reduce the cost of participation so that it is within the threshold of as many agents as possible.

When $P(.)$ is convex, a completely different policy should be implemented. As shown in the previous section, an increase in θ or the perceived benefit of the public good can easily create a new stable symmetric threshold equilibrium around 1, at which point, everyone participates. This means that it creates a range of c_i such that as long as sufficient number of participants are willing to commit to participating at a cost within this range, the outcome naturally converges to the equilibrium where everyone participate. This suggests that a good policy, when $P(.)$ is convex, is to raise the perceived benefit of the public good and to encourage potential participants to commit to participating at a higher participation cost or to create an environment where individuals believe that others are willing to participate in the public good production. Such policy is completely achievable especially when the benefit of the public good exceeds the cost of participation. A policy that lacks the ability to get people to commit to participating is just as likely to fail as in the case of concave $P(.)$.

Figure 3.6 provides a comparison between the case of a concave production function (Figure 3.6a) and that of its inverse (Figure 3.6b), which is a convex production function. When the production function is concave, increasing θ by two times or four times also raises the symmetric threshold equilibrium which increases the expected number of participants, however this is marginal. On the other hand, when the production function is convex, doubling θ raises the symmetric threshold equilibrium by an even smaller margin than in the case of concave $P(.)$. However, when θ is quadrupled, two new equilibria exist, including one where everyone participates and the other which can diverge to it. This suggests that a policy that increases awareness and perceived benefit of a public good may be less effect for public goods with convex production func-

Figure 3.6: Change in equilibria in relation to θ for concave and convex $P(.)$



(a) Concave $P(.)$ (b) Convex $P(.)$

tions at the beginning. However, there exists a threshold of perceived benefit, above which, we can achieve full participation if only just enough participants can commit to participating.

If $P(.)$ is a step-function, as discussed in the previous section, the most significant change is when $\tilde{j} = n - 1$ or when everyone is required to participate for the public good to be produced. In this case, I showed that the equilibrium where everyone participates becomes a stable equilibrium and there exists a range of c_i over which, if enough agents can commit to participating within those range, the outcome will converge to the equilibrium where everyone participates. This suggests that when $P(.)$ is a step-function, a good policy needs to do three things. Firstly, it needs to convince participants that the benefit of the public good is high enough. Secondly, it needs to convince potential participants to commit to participating at a higher participation cost. Thirdly, it should encourage full participation and make salient the importance of full participation, rather than just high enough for the public good to be produced. Finally, an alternative to encouraging full participation may be to lower the required participation for the public good production $\tilde{j}$ (this may be through tools such as subsidies or matching funds) or to lower participation cost.

It should also be noted that just because some production functions may induce similar outcome in terms of equilibrium outcome and characteristics, their equilibrium outcomes do not necessarily respond to the same policy in the same way. For example, in both cases when $P(.)$ is concave or linear, there always exists exactly one threshold equilibrium. However, the location of the equilibrium will be affected differently by a policy that increases the perceived benefit of the public good. A vertical stretch to the left-hand side of (3.3) or (3.5) when $P(.)$ is linear is equivalent to a vertical shift, because then the left-hand side of (3.3) and (3.5) are horizontal lines. Therefore, an equivalent policy that increases θ is much more effective in raising participation when $P(.)$ is linear than when it is concave. This example provides another argument to highlight the importance of understanding the shape of public good production function in policy design.

Another case that I briefly discussed was what happens when $P(.)$ is an s-shape function. I argued that the characteristics of the equilibrium set depends on the exact shape of the function. If it is a mild s-shape with no extremely steep slope, then its equilibrium outcome is closer to the case of when $P(.)$ is linear. In this case, a good policy should be in line with what is suitable for a linear $P(.)$. This may include raising the perceived benefit of the public good and reducing participation cost. If it is closer to an s-shape function, then its equilibrium outcome is closer to the case of when $P(.)$ is an s-shape function. In this case, a policy should cover what was discussed earlier when $P(.)$ is a step-function.

3.5.2 Welfare and Policy Discussion

The previous subsection discussed what targets a good policy should try to achieve in each case. The next natural step is to discuss whether a particular policy is worth pursuing. Many different policies can be used to achieve the targets discussed earlier, however the cost and benefit differ between policies and contexts within which they are implemented. Therefore, it is difficult to pin-point which policy is the best policy to achieve each target. However, in this subsection I will discuss some of the policies that have been shown to be successful tackling the issues discussed.

The policy that has been recommended in all cases is the reduction of participation cost. Clearly, this can be very costly for a policy-maker, especially when it comes to directly cutting down cost, as this involves compensating each individual participant for their effort. In this sense, sometimes one may question whether such policy is worth pursuing. However, evidence have shown that even a small reduction in participation cost can significantly increase participation. For example, this can be done by using selective incentives and strategies to ease participation. Minyoo et al., (2015) showed that giving simple incentives such as wrist bands and dog collars can increase participation in canine rabies vaccination campaigns.

Another target discussed was to get participants to commit to participating at a higher cost. It should be noted that this policy is reasonable only when the benefit of the public good is high enough, so that committing to a higher cost is acceptable to participants if they know that the benefit of the public good outweighs their participation cost. Several policies can be used to get participants to commit. An example of this is guaranteed refunds to participants if a public good fails to be produced. Cartwright and Stepanova (2015) showed in an experiment that such policy can increase the likelihood of public goods being produced. This policy is not costly when participants' resources used for participation are refundable, but it can be very costly if otherwise and if the public good needs a lot of participation to succeed. Another possible policy is through behavioural factors such as leadership and altruism. Meinzen-Dick et al., (2002) provided an empirical example of how leadership and trust in leadership led to cooperation in the management of canal irrigation systems in India. Smith (2010) provided a detailed discussion of how not only altruism, but other behavioural factors such as mutualism, reciprocity and language can combine to increase cooperation in collective action. These tools do not require a lot of financial resources as it does not always require direct cost-related interventions, but it requires skills and the ability of policy-makers to convince and to build trust with potential participants.

Another policy mentioned was to encourage full participation. This policy recommendation was unique for the case of when the public good production function is a step-function only, as it allows an equilibrium where everyone participate to become a stable equilibrium. There is no known research that looks at this kind of policy specifically for public goods with a step-function as its production function. However, an example of such policy may be to provide rewards, which can be financial or psychological, to everyone only if there is full participation, pairing these rewards with the public good itself. Another type of intervention can be through behavioural factors as discussed in the last paragraph.

3.5.3 Application

So far, I have argued that to encourage the production of a public good, it is crucial to take into account the shape of its production function. In practice, the shape of the production function as perceived by participants may not always match with its actual shape. In this case, a policy that is designed to suit the actual shape of the production function may not be effective because participants are more likely to respond according to their perception than according to the actual situation. Therefore, as a policy-maker, it is necessary to understand a community's perception so that policies can be designed around it or to try to change the community's perception if needed.

There has been no known empirical study that tries to find the shape of a public good's production function as perceived by a community. A simple way to do this is to conduct a survey among community members on their perception of their marginal contribution to a public good given different levels of contribution from other community members. This survey can then be consolidated to obtain the shape of the production function as perceived by the community. The appendix (sub-subsection 3.7.4) below is a simple example of a production function survey that was conducted after the field experiment that will be discussed in Chapter 4.

3.6 Conclusion

In this chapter, I show that the shape of a public good's production function is an important structural factor determining the outcome of the public good production. This in turn means that different public goods with different production functions may demand different policies to get an effective response. Therefore, in designing a policy, a policy-maker needs to study clearly what the shape of the production function looks like, in order to design a suitable and effective policy.

As discussed briefly in the introduction, there are many structural factors that could have influenced participation in public good production. The shape of production functions is just one of them. There are large gaps in the understanding of some of those structural factors. To understand collective action and voluntary participation in public good production fully, it is important that all structural factors are identified and carefully studied.

3.7 Appendix

3.7.1 Dynamic of the Left-hand Side of (3.3)

Here I show that as c increases from 0 to 1, the left-hand side of (3.3) gradually shifts its weight from δ_0 to δ_{n-1}. To do this, I compute $p_j(c) - p_{j-1}(c)$:

$$\binom{n-1}{j} c^j (1-c)^{n-1-j} - \binom{n-1}{j-1} c^{j-1} (1-c)^{n-j}$$

$$= c^j (1-c)^{n-j} \Big[\binom{n-1}{j} (1-c)^{-1} - \binom{n-1}{j-1} c^{-1} \Big]$$

$$= c^j (1-c)^{n-j} \Big[\frac{(n-1)!}{j!(n-1-j)!} (1-c)^{-1} - \frac{(n-1)!}{(j-1)!(n-j)!} c^{-1} \Big]$$

$$c^j (1-c)^{n-j} \frac{(n-1)!}{(j-1)!(n-1-j)!} \Big[\frac{(1-c)^{-1}}{j} - \frac{c^{-1}}{n-j} \Big]$$

This value is positive only if $\Big[\frac{(1-c)^{-1}}{j} - \frac{c^{-1}}{n-j} \Big]$ is positive or $j < nc$. This suggests that as c increases from 0 to 1, the convex combination shifts its weight from left to right. In fact, at $c = 0$, the weight is completely on the first term δ_0 and at $c = 1$, the weight is completely on the last term δ_{n-1}, where $\delta_{n-1} < \delta_0$. This proves that the left-hand side of (3.3) is decreasing in c.

3.7.2 Proof of Unique Equilibrium when $P(.)$ is Convex

Here I prove that there can only be one threshold equilibrium when $P(.)$ is convex provided θ remains at one. To do so, I only need to prove that the left-hand side of (3.4) is convex in c. The left-hand side of (3.3) is the expected efficacy of i's participation given all other agents adopt some threshold strategy around c. As c increases, i's expectation of the number of agents participating must increase, because an increase in threshold c means that the probability of each of the other agents participate must be higher. As $P(.)$ is convex, it means that i's expected efficacy should be even higher as c increases. Therefore, the left-hand side of (3.3) must be convex. Since it is convex and increasing and its range is a proper subset of $[0, 1]$, there can only be one intersection between the left-hand side of (3.3) and the 45 degree line.

3.7.3 Set of Equilibria when $P(.)$ is a Step Function

Here, I prove that the set of equilibria of the game when $P(.)$ is a step function is as discussed above. I begin by discussing the shape of the left-hand side of (3.4). First I find its derivative with respect to c:

$$\frac{\partial p_{\tilde{j}}(c)}{\partial c} = \binom{n-1}{\tilde{j}} c^{\tilde{j}-1}(1-c)^{(n-2-\tilde{j})}(\tilde{j} - c(n-1))$$

The partial derivative has only three roots within the domain $[0, 1]$, 0, 1, $\frac{n-1}{\tilde{j}}$.[3] The first two roots are at the boundary of the domain of c and the partial derivative is positive for $0 < c < \frac{n-1}{\tilde{j}}$ and negative for $\frac{n-1}{\tilde{j}} < c < 1$. This means the left-hand side of (3.4) has a single peak at $c = \frac{n-1}{\tilde{j}}$.

I now show that at $\tilde{j} = 1$ the slope of the left-hand side of (3.4) is greater than one at and around $c = 0$. To show this I simply substitute $\tilde{j} = 1$ and $c = 0$ into the partial derivative, which is then equal to $n - 1$, which is greater than 1 for $n > 2$. Since both the left-hand side of (3.4) and its partial derivative are also well defined on c, its curve must be higher than the 45 degree line at c close to zero. And since it is single-peaked and decreases to zero as c increases to 1, it must cross the 45 degree line again exactly once. This proves that when $\tilde{j} = 1$, there is a second crossing point between the left and right-hand side of (3.4).

I now show that when $\tilde{j} > 1$, the slope of the left-hand side of (3.4) is less than one around $c = 0$. Again, I substitute $c = 0$ into the partial derivative, which is then equal to zero. This suggests that if $\tilde{j} > 1$, the left-hand side of (3.4) must be less than c for c very close to zero. It can be seen from the partial derivative that the slope of the left-hand side of (3.4) can be very steep and positive at lower ranges of c when $\tilde{j}$ is very small relative to n. In this case, if $\tilde{j}$ is small enough, but greater than 1, the left-hand side of (3.4) can intersect the 45 degree line as c increases. If it does, it will do so again as it decreases to

[3] 0 is not a root when $\tilde{j} = 1$, however this does not affect the main result.

zero when c increases to 1. However, if $\tilde{j}$ is large relative to n, then the slope of the left-hand side of (3.4) is not steep enough to intersect the 45 degree line as c increases to 1. In this case, there is only one crossing point at $c = 0$.

3.7.4 Production Function Survey

Approximately one year after the field experiment studied in Chapter 4 of this thesis, a production function survey was conducted. This survey was conducted with the same group of villages and villagers that participated in our experiment. However, 2 of the 56 villages were discarded because they were no longer accessible. In addition, not all households that participated in the household questionnaire and the cash experiment could be located. Taking this into account and the number of invalid data, the average number of participants per village that participated in the production function survey was just over 17 participants and the total number of participants were 932.

During the production function survey, participants were given three sets of questionnaires. The first set was a priming questionnaire, which asked them questions designed to ensure that participants were able to understand and use percentage terms. The second set of questionnaire was designed to test their knowledge about the externality of dog vaccination. The third set of questionnaire was the production function survey itself.

To determine the shape of the production function, each participant was asked to respond to a graphical/visual questionnaire. Each participant was presented with a sheet with a grid containing 20 cells. Each cell contained 10 dog-logos representing the total number of dogs in the participants' village. Each dog was either highlighted black, meaning that the dog had not been vaccinated, or green, meaning that the dog had been vaccinated. Each cell represented scenarios in which 0%, 10%, 20%,... or 100% of the dogs were vaccinated. Each scenario was represented by two different cells with differing distribution of vaccinated dogs. We call these, sub-scenarios. For clarification, see the sample survey questionnaire in the Appendix. For each cell, participants were then asked to give a percentage rating of the chance that rabies would be eliminated in their villages given the specified percentage of dogs vaccinated.

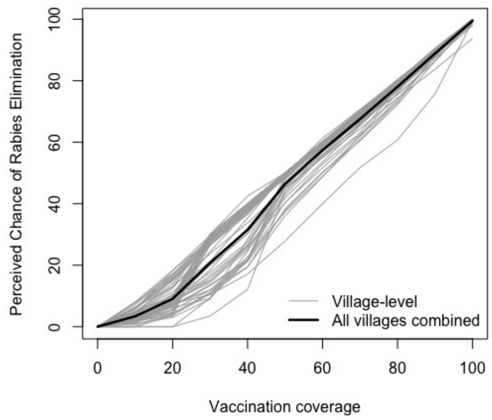
In order to construct production functions from this data, the data had to be consolidated in some way. Firstly, the data was consolidated at village-level using three methods: mean, mode and median. This allowed us to construct three different production functions for each village, each derived using different consolidation methods. Secondly, the whole data was consolidated into just one data point using the three consolidation methods again. This allowed us to construct three production functions, each with different consolidation methods, that represent all the data collected.

Before analysing the result of the production function survey, we had to check the priming questionnaires to ensure that all participants were able to use percentage terms reliably when they answered the questions related to the production function survey. One set of questions that was asked to participants was what is the percentage that one of their children would improve or worsen his/her ranking in school. If their responses to both questions sum up to greater than 100, then we presume that the participants may not have been able to use percentage terms reliably. In this case, we drop their responses from our analysis. Because of this, we dropped 27 participants from the analysis and we had 905 remaining participants in our dataset.

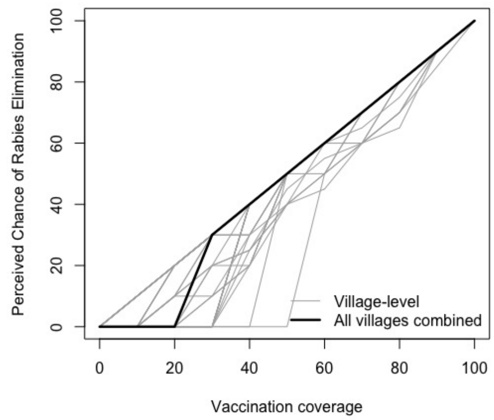
We also checked if participants understood the externality of rabies vaccination, by asking them several related questions. Based on their responses, we saw they generally understood that their risks of being infected with rabies were influenced not only by their own behaviour but by the behaviour of others too. The only unexpected response is that many seem to think that even if many of their neighbours vaccinate their dogs against rabies, but they do not, they are still at high risk from rabies. This may be explained by the fact that many people in that area were farmers who tend to have to make long commutes which means that they may be exposed to many dogs, not just their neighbours'. See Appendix for a summary of the responses that we received to this set of questionnaire.

Figure 3.7 shows the perceived shapes of the production function of rabies elimination based on three different methods of data consolidation. Each grey line in the graphs represent the perceived production function of a single village. The dark line in each graph represents the production function when all data from each participant was consolidated. Figure 3.7 shows that when combining all data together, the shape of the production function is s-shape, but very close to linearity, especially at the upper-end. At village-level the shape of the production function is also generally s-shape but very close to a linear function. The only exception is when Mode was used as a consolidation method, that we see some stronger cases of s-shape production functions at village-level.

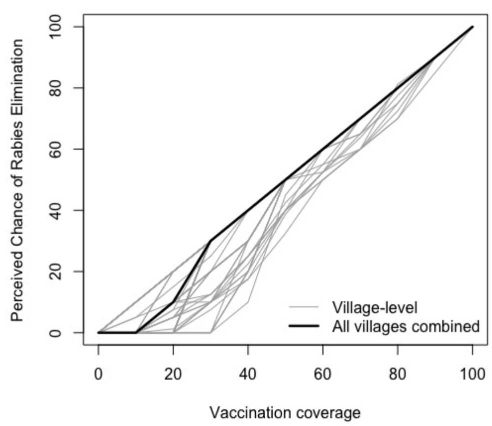
Figure 3.7: Shape of Rabies Elimination Production Function Based on Different Consolidation Methods



(a) Consolidation method: Mean



(b) Consolidation method: Mode



(c) Consolidation method: Median

Data Collection Tools

The following are the set of questions used during the survey:

Priming questionnaires:

Answer the following questions using percentage terms.

1. At what percentage, do you think it will rain tomorrow?

2. At what percentage, do you think the oldest child in school in your household would improve his rank over last year?

3. At what percentage, do you think the same child would worsen his rank compared to last year?

4. At what percentage, do you think at least one of your household members will get malaria in the next 6 months?

5. At what percentage, do you think at least one of your dogs will get infected with rabies in the next 6 months?

Rabies vaccination externality questionnaires:

Answer the following questions using percentage terms.

1. If all your neighbours vaccinate their dogs against rabies, but you do not, what is the chance that at least one of your family members get bitten by a rabid dog?

2. If you are the only person vaccinating your dogs in your village, what is the chance that your neighbour get bitten by a rabid dog?

3. If you are the only person vaccinating your dogs in your village, what is the chance that at least one of your family members get bitten by a rabid dog?

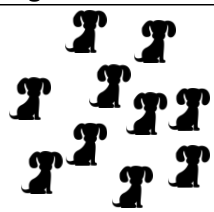
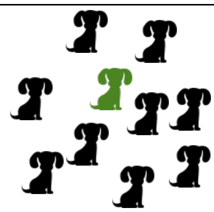
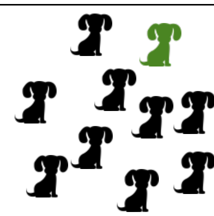
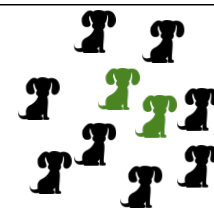
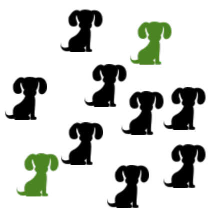
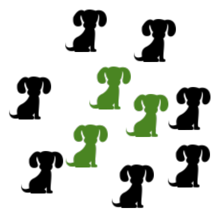
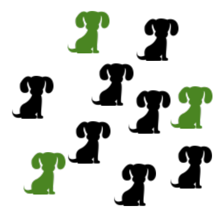
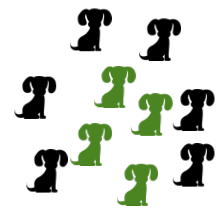
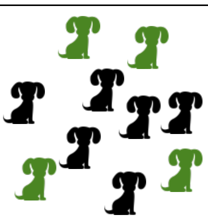
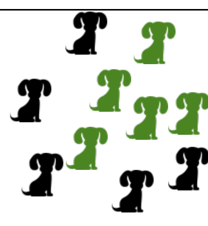
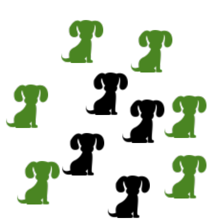
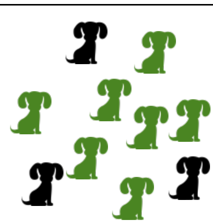
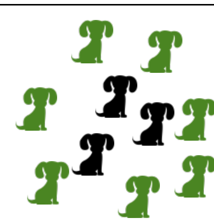
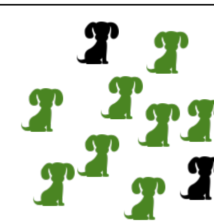
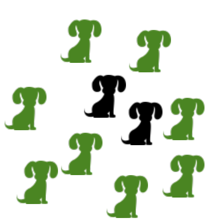
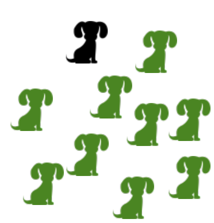
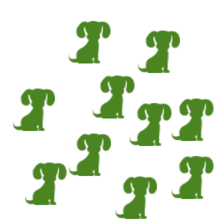
4. If everyone in your village vaccinates their dogs, what is the chance that at least one of your family members get bitten by a rabid dog?

5. If no one in your village vaccinates their dogs, what is the chance that at least one of your family members get bitten by a rabid dog?

Production Function survey

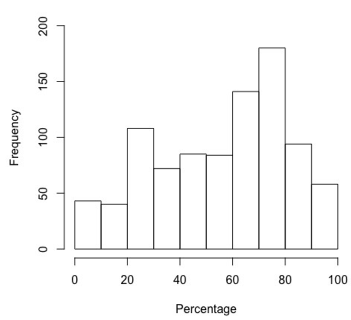
Determining the shape of the production function

Suppose 10 dogs represent all dogs in your village.  represent those vaccinated against rabies and  represent those not vaccinated. In each case, in percentage terms, describe the chance that rabies is eliminated from your village. Also, suppose that you have to pay a fixed cost of 1000 TZS to vaccinate your dogs, indicate whether you would vaccinate your dogs.

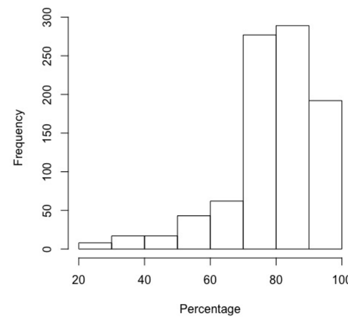
			
1	**2**	**3**	**4**
			
5	**6**	**7**	**8**
			
9	**10**	**11**	**12**
			
13	**14**	**15**	**16**
			
17	**18**	**19**	**20**

Summary of Responses to Rabies Vaccination Externality Questionnaire

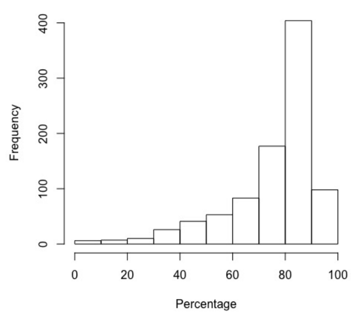
Note that all histograms presented blow show the frequency or the number of participants use a particular percentage term as their response to the respective questions in the externality questionnaires.



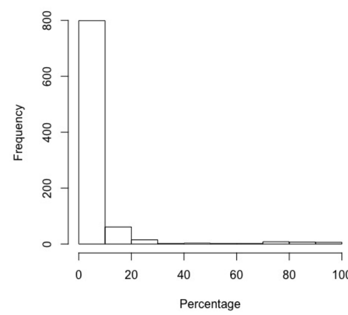
(a) Responses to Question 1



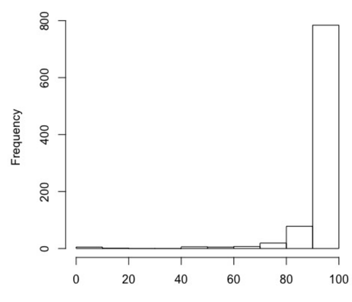
(b) Responses to Question 2



(c) Responses to Question 3



(d) Responses to Question 4



(e) Responses to Question 5

Chapter 4

Raising Participation in Rabies Vaccination Campaigns: Evidence from Tanzania

4.1 Introduction

The production of public goods is crucial in many developmental contexts. Many times, it requires collective action. Community members need to work together to build infrastructures, protect forests and fishes and improve overall livelihoods of the whole community (for examples, see Bardhan (2000), Gautam (2006), Jentoft and Finstad (2018), Siegal et al., (2009)). In some cases, governments or local authorities take the initiative to produce some of the public goods. But in many cases, it still requires collective action from community members. In his seminal work, Olson (1965) argued that self-interested individuals would fail to work together to produce a collective good. Experimental work do not always show such extreme result, but in many cases there are clear underproduction of public goods.

In the context of public health, the elimination of infectious diseases can be a priceless asset to many communities. If a disease is completely eliminated, community members do not have to spend time and resources dealing with the disease, they do not have to fear getting infected. Infectious diseases can easily be eliminated if a large enough proportion of the community is protected against it, so that herd immunity is achieved (Fine et al., 1993). This means that vaccine-preventable diseases can be easily eliminated as long as enough members of the community is vaccinated. Clearly, this involves collective effort from community members and a lack of participation from community members results in the persistence of the disease.

In this experiment, we examine the elimination of rabies. Rabies is a viral disease that causes around 59,000 human deaths per year (Hampson et al., 2015). The global annual cost of the disease is estimated to be around \$530 million dollars (Schwiff et al., 2013). Most human deaths from rabies occur in marginalised communities, especially in Asia and Africa (Knobel et al., 2005). Hence eliminating rabies can bring a significant economic benefit to developing countries.

Humans can contract rabies through bites from infected animals. Once symptoms of rabies occur, it is invariably fatal. In most cases, transmissions of rabies to humans result from domestic dog bites (WHO, 2013). Infection and deaths can be prevented in bite victims through timely administration of post-exposure prophylaxis (PEP). However, for those in marginalised communities, access to PEP is still an issue. Even if accessible, PEP may still be unaffordable to those who need it (Hampson et al., 2008). Canine rabies vaccination has been proven to be a cost-effective method to reduce human deaths from rabies. Successful canine rabies vaccination campaigns have been shown to reduce bites by suspected rabid dogs and the demand for PEP (Cleaveland et al., 2003) and even to eliminate rabies completely.

Rabies can be eliminated from a dog population if at least 70% of the population is vaccinated (Coleman and Dye, 1996). Once elimination is achieved, the main source of infection to humans is also removed and hence the risk of rabies. Canine rabies vaccination campaigns carried out in many parts of the world have been shown to successfully control rabies (Cleaveland et al., 2003, Schneider et al., 2007, Vigilato et al., 2013). However, the 70% vaccination threshold is not always achieved, even in communities most at risk from rabies, leading to disease persistence. Reasons for the failure to achieve this target may pertain to the supply side (failure to supply and administer vaccines or do so effectively) or the demand side (failure by community members to participate in vaccination campaigns) or both. This research focuses on dealing with the latter issue by investigating some advertising interventions to raise demand for rabies vaccines. However, during this research, we also found some suggestive evidence that some operational changes that ease access to vaccination campaigns could increase participation significantly. This evidence will also be discussed in detail along with that related to the advertising interventions.

Many policies have been used to motivate participation in rabies vaccination campaigns, but not all were successful. Minyoo et al., (2015) provided incentives (dog collars and owner wristbands) to participants of vaccination campaigns in northern Tanzania. They showed that these incentives were effective in increasing participation, although the increase was not enough to reach the 70% threshold. Cleaton et al., (2018) used mobile phone text messaging to alert community members about vaccination campaigns in two communities in Haiti. They showed that those who received the alert were twice more likely to participate in the vaccination campaigns than those who did not.

Our research tests the effectiveness of two advertising interventions in increasing participation in vaccination campaigns: text messaging (similar to that used in Cleaton et al., (2018)), and religious and tribal leaders[1]. We hypoth-

[1]Tribal leaders refer to leaders of Maasai communities

esise that these interventions work in the following ways. Text messaging can be used to provide community members with all relevant information about the vaccination campaigns, is a more personal approach of communication and additional information to make the risk and danger of rabies more salient to them and attract their attention to the problem of rabies elimination. Text messaging may also have the potential to reach more people than other routine advertisement methods such as posters or loudspeakers. The use of religious and tribal leaders can similarly spread information about the vaccination campaigns, but they can be uniquely effective due to the authority and leadership that they hold in communities. Several literatures, such as by Vedeld (2000) and Glowacki and von Rueden (2015) have proven the potential effectiveness of leadership in dealing with collective action problem. We hypothesise that the use of religious/tribal leaders can increase participation through a similar mechanism.

The study by Cleaton et al., (2018) is the only known study in the literature to have used mobile phone text messaging to advertise rabies vaccination campaigns and that demonstrably increased participation in Haiti. We do not know of any study that looks at the use of religious and tribal leaders (or other leadership type) in advertising rabies vaccination campaigns. However, the role of leaders in planning vaccination campaigns has been shown to be important in achieving high vaccination coverage (Léchenne et al., (2016)) and uptake of vaccines in general (Nasiru et al., (2012) and Goldstein et al., (2015)).

We found no evidence that either of the advertising interventions alone were effective in increasing participation in our vaccination campaigns, which is contrary to what was found by Cleaton et al., (2018). However, we found evidence that both interventions were effective in increasing participation when they were used in conjunction with each other. We argue further that contextual and environmental factors could have influenced this outcome. We also found strong evidence that operational changes to how vaccination campaigns were delivered could have a significant impact on participation in vaccination campaigns and they could also influence the effectiveness or at least the observable effectiveness of the advertising interventions.

This study can also form a contribution to the literature on public good experiments. In the existing literature, public good experiments tend to take place in controlled laboratory conditions. Chaudhuri (2011) provided a survey of a wide range of literature that identified key factors that influence participation in public good games. Ledyard (1995) identified communication and marginal per capita contribution as some of the influencing factors. Andreoni and Petrie (2004) and showed that revelation of identities could have a positive effect on participation. Bochet et al. (2006) showed that face-to-face communication is about just as effective as anonymous verbal communication, and the use of punishments can increase participation but it has little effect on efficiency due to its cost. These laboratory experiments rely on controlled conditions to identify factors influencing participation. There have been little literature that are based on field experiments. Many of the empirical studies that take place in the field similarly try to identify influencing factors instead of looking at effective interventions (for example, Bardhan (2000)). Our study differ from these studies by looking at interventions instead of influencing factors. In addition, the fact that it takes place in a less controlled environment means that it can provide a more general understanding to how the interventions influence participation in real world settings.

The organisation of this chapter is as follows. The next section discusses the methodology and all activities performed during the experiment. Section 3 gives a brief description of key data. Section 4 discusses the results. Section 5 discusses the implication of the results and concludes.

4.2 Methodology

4.2.1 Study Area

To decide on the size of our sample, we conducted a simulation-based power analysis. In the power analysis, we started by generating a normal random variable of size n with mean 50% and a standard deviation of 5%, where n represents the sample size or number of villages and each entry in the variable represents the vaccination coverage of each village. We assumed that, on average, each intervention increases the vaccination coverage of each village by 10 percentage point. We also assumed that the vaccination coverage is subjected to a noise term with mean zero and a standard deviation of 12 percentage points. We also set a threshold for the p-value of the coefficient of the interventions at 0.05 or less. Based on these assumptions, we ran 1000 simulations and found that we need a sample size of 56 villages to obtain a power of just over 0.8.

The 56 villages were selected from the Morogoro Rural district of Tanzania (based on the 2012 population census, the district had a population of 286,248 and the sampled villages had a combined population of 122,945 or just under 43% of the district's population). The Morogoro Rural District was selected as it had existing infrastructure that can support canine rabies vaccination campaigns and there had been no known study on policy interventions, which could contaminate our data. The villages were selected randomly from a larger set of 93 villages in the district with confirmed permanent mobile phone network. Figure 4.1 provides a mapping of the study area, with each villages colour coded by their experimental group. Coloured grey in the primary map in Figure 4.1 is part of the Mikumi national park which is an uninhabited area. The experiment took place between November 2017 and February 2018.

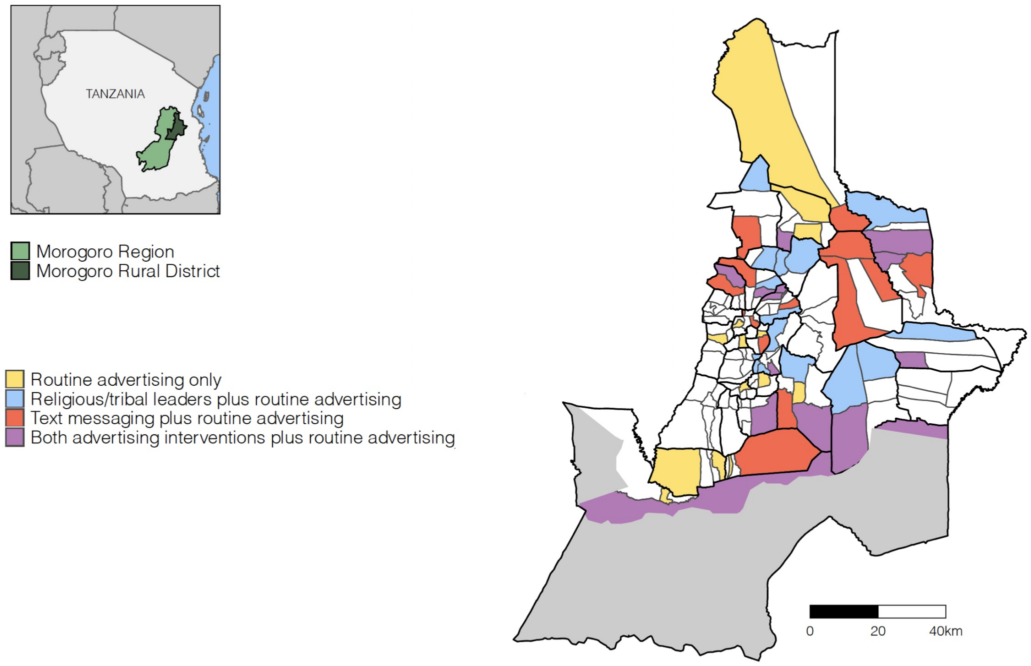


Figure 4.1: Mapping of Study Area

4.2.2 Experimental Design

The primary objective of the study was to determine the effectiveness of two advertising interventions, namely text messaging and religious/tribal leaders, on participation in vaccination campaign. To do this, we had a factorial experimental design. We divided the sampled villages randomly into four equal groups receiving different combinations of the interventions (plus routine advertising): routine advertising only, religious/tribal leaders plus routine advertising, text messaging plus routine advertising and both advertising interventions plus routine advertising. We then analyse for the effect of the interventions between the four experimental groups. We also explored the potential effect of operational changes on vaccination coverage.

Our unit of analysis in this experiment is the villages instead of individuals. The main reason for this is that analysis at individual level is prone to contamination as individuals can inform each other about the interventions that they are exposed to. Setting the unit of analysis at village level minimises this as the likelihood of contamination across village is smaller due to the distances between village. In addition, analysis at village level provides more insight for collective behaviour, which is the topic of our interest.

4.2.3 Pre-Intervention Activities

Prior to implementing the advertising interventions, workshops were conducted with participants from 43 of the 56 villages[2]. From each village, a village leader, a veterinary officer (if there was one stationed in the village) and a health official (nurse or medical attendant) were invited. The purpose of the workshops were to identify any potential issue that might impede the implementation of the advertising interventions, and to seek local advice on potential improvements to the study design and the vaccination campaigns more generally. Workshop participants were first asked about their experience with past rabies vaccination campaigns, including challenges encountered. After detailing the plan related to the advertising interventions to be tested, they were encouraged to provide feedback on the design and any potential impediment they envisaged.

Those workshops identified issues encountered in the previous vaccination campaigns and resulted in a few operational changes to the delivery of the vaccination campaigns (to be discussed below). Participants in the workshops were also helpful in designing the overall design of the intervention. Specifically, they helped design the structure and appearance of the content of the text messages, the timing for when the texts should be sent and they also identified potential problems related to the intervention.

[2]The remaining 13 villages were not able to participate in the workshops because of accessibility problems. However, district veterinary officers who were familiar with those villages were present during the workshops and were able to provide all necessary information needed during the workshop.

Focus group discussions were conducted in 5 of the selected villages comprising a total of 47 villagers. Participants were mostly ordinary community members. The ultimate objective of these discussions was to produce a locally-relevant message to be tested in the advertising interventions, although the overall design of the study was also addressed. The focus group discussions started with a general discussion on rabies. Participants experience with the disease was assessed. Feedback on the anticipated design of the study was sought. Specifically, participants were asked how to ensure that text messages would attract attention and make the risk of rabies salient to the recipients. The design of the text messaging intervention was a result of these discussions and is described in the next subsection.

Phone numbers of villagers in villages assigned to receive the text messages were collected manually. They were first collected from village leaders in the first set of workshops. Afterwards, a team of officials were asked to go to each of the villages and collect as many phone numbers as they could. The phone numbers were then recorded and sorted by village name in Excel files and imported into a mass text messaging platform Rasello[3].

A specific workshop was also conducted with a group of 8 community leaders (two village leaders, one Muslim leader, three Christian leaders from different denominations (Pentecost, Tanzania Assembly of God and Lutheran) and two Maasai tribal leaders). All leaders were from villages outside the sampled villages to avoid them taking their own initiatives to advertise the vaccination campaigns without our invitation, which could affect the outcome of the experiment if their villages were included in the sample. This workshop started with a general discussion on rabies and rabies vaccination campaigns to familiarise the participants with the problem. This was then followed by a discussion on the roles that they could play in advertising rabies vaccination campaigns and

[3]Rasello was a mass text messaging platform run by a private company in Tanzania.

we were assured that their participation in our experiment did not contradict their beliefs or tradition in anyway. The design of the religious/tribal leaders intervention is described in the next subsection.

4.2.4 Advertising Interventions and Other Advertisement

The design of the text messaging intervention was as follows. All phone numbers collected earlier were sent the following text messages according to their villages (in Swahili):

> "***VILLAGE NAME:*** *Recently, in a neighbouring village to yours, a child died a painful death after being bitten by a rabid dog. You and your neighbours can protect your children by vaccinating your dogs. Dog vaccines in* ***VILLAGE NAME*** *will be provided for free at* ***LOCATION(S)*** *on Saturday 20/01/2018 between 8am to 4pm.*"

The choice to start the texts with the respective villages' names was to make the recipients of the texts feel that the text message was regarding some issue relevant to their respective villages. The brief account on the recent human death from rabies was to make the risk of rabies salient to the text recipients[4]. The final sentence in the text was simply to inform text recipients about the timing and location of the vaccination campaigns and to ensure that they know that the vaccines were provided for free.

This message was sent to those phone numbers five days, three days and one day before the vaccination campaign day. This was to ensure that villagers had enough time to consider and get prepared to bring their dogs to the vaccination points. The text messages were sent at around 4pm on the days they were due to be sent. This was because 4pm was the time when villagers would have completed their daily work and meet and interact with one another. The design

[4] The account was based on a real event.

of this intervention, including the content of the text messages and timing for when the texts were sent, was the result of the workshops and the focus group discussions discussed above. The mass text messaging platform (Rasello) indicated that 88% of the texts were successfully delivered.

The design of the religious/tribal leaders intervention was the result of the workshop with the community leaders and was as follows. The identities of religious and tribal leaders in each of the sampled villages assigned to receive the religious/tribal leaders intervention were collected by the district veterinary officer. Each of the religious and tribal leaders were then sent a letter inviting them to advertising the vaccination campaigns one week before vaccination day. The letter provided all details related to the vaccination campaigns including the location and opening time of the vaccination station(s) in their respective villages. Included in the letter also was a guided message that the religious and tribal leaders could use to inform their community members:

> "*To eliminate rabies from our village and to protect our family and friends from rabies, it is important that we all bring our dogs to be vaccinated in the upcoming vaccination campaign. If all dogs in our village are protected against rabies, then we won't be at risk of contracting the deadly disease. Vaccinating your dogs against rabies is the right thing to do. The next rabies vaccination campaign will take place in our village on Saturday the 20/01/2018 at* ***LOCATION(S)*** *between 8am to 4pm*".

It was made clear to them that the message above was a guided example only and that they had the freedom to use any other message that they think is appropriate. It was only important that they informed their community members of the timing and location of the vaccination campaigns and that the vaccines would be provided for free. All religious and tribal leaders were also sent text messages reminding them to advertise the vaccination campaigns. We know that the religious leaders tend to meet with their congregation more regularly than normal. Based on the workshop with the religious leaders, we know that all religious groups meet at least once during the weekdays and there tend to be regular interactions between religious leaders and their community outside religious activities. Evidence from data collected after the vaccination campaigns showed sufficient evidence that the religious and tribal leaders of villages assigned to receive the intervention advertised as we expected.

In addition to the advertising interventions, routine advertising were also used in all 56 villages. These included posters, loudspeakers and the use of local village/sub-village administrative leaders. All advertising methods provided information on the location and timing of the vaccination campaigns and that the vaccines were provided for free. Posters were placed in prominent places of each village such as schools, markets and town halls around one week before the vaccination date and left there until at least the day after the vaccination day. Local village and sub-village chiefs or chairpersons were also asked to be involved in the advertising of the vaccination campaigns. Prior to this, vaccinators and other officials involved were instructed on how to carry out these routine advertisements and the vaccination campaigns themselves. Note that the routine advertising was not part of the advertising interventions and they were used in all of the sampled villages as a baseline advertising method only.

4.2.5 Vaccination Campaigns and Post-Campaign Activities

Vaccination campaigns were conducted in all 56 villages after the interventions were implemented. The vaccination strategy that we used was central point strategy (as described in Kaare et al., (2009)). At least one vaccination point was placed in each village and villagers were asked to bring their dogs to one of these points. As a result of workshop discussions we also made several significant changes to how the vaccination campaigns were delivered compared to the campaigns in the years before. Those changes were as follows.

Firstly, we ensured that at least one vaccination station was placed in each sub-village. This was to maximise consistency and ensure that there was no bias between large and small villages in terms of the average distance that community members had to travel to reach the closest vaccination point. In the previous campaigns, there was no such policy of stationing a vaccination station at sub-village level. Secondly, the vaccination stations were open all day long. In the previous campaigns, stations were generally open for half a day only, so that vaccinators could move from one station to another to cover more geographical area. By opening the vaccination stations all day long, we ensured that there was no bias between villages that had vaccination stations opened in the morning or in the afternoon. Thirdly, as discussed above, advertisement started one week before the campaigns and continued throughout the week, instead of just for one day before. From now on, we refer to these three changes as operational changes. These changes were made for research purposes only, to ensure consistency but in the understanding that they could have had a major impact on participation. It has been shown in other studies that these changes could potentially have a large impact on participation (Castillo-Neyra et al., 2017, Castillo-Neyra et al., 2019). As expected, we found some suggestive evidence that these changes had a significant impact on participation and it could have affected the effectiveness of the advertising interventions (text messaging and religious/tribal leaders) as well. The effect of the operational changes will be discussed in detail in the next two sections.

At selected vaccination points, those who brought their dogs for vaccination were asked to complete a short survey questionnaire. The survey was to collect data on how the attendants learned about the vaccination campaigns or what advertisement methods they were exposed to. For more information, see Table 4.5 in the Appendix.

To estimate vaccination coverage, the vaccinators were asked to conduct transects in their respective villages or sub-villages in the evening after the vaccination campaigns (as described by Kaare et al., (2009) and Sambo et al., (2017)). Dogs that were vaccinated at the vaccination stations were marked with a coloured collar. In the same evening of the vaccination day, after the vaccination points were closed, vaccinators travelled through their respective villages or sub-villages and counted the number of dogs with and without collars. The estimated vaccination coverage was calculated by dividing the number of dogs observed with collars by the total number of dogs seen during the transect.

The week after the vaccination campaigns, village-level questionnaires were administered to village leaders (either village chairperson or executive) in the sampled villages to collect village-level socio-economic data and other variables that could have influenced vaccination coverage. The questionnaire included information on access to basic needs and facilities and experiences and attitudes towards rabies and previous vaccination campaigns. The interviews also allowed us to check whether the advertisements and the interventions were implemented as intended. These questionnaires were needed since official village-level data was limited, however it also means that a lot of the data relied on the village leaders' knowledge of the variables of interest. See Appendix for the questionnaire administered to village leaders.

Household questionnaires were administered and completed within five weeks of the vaccination campaigns. In each village, a target of 20 households were randomly selected to answer the questionnaires. A total of 1,114 households' data were retained after data processing. The questionnaires were administered to the head of each household or, if the head was not present, the most senior adult (at least 18 years old). If no adult was present, the household was unselected and another household was selected to replace it. The questionnaire collected data on the household socio-economic status (based on the United Nation Development Programme's multidimensional poverty index (Kovacevic and Calderon, (2014))), general and health locus of control, participation in the most rabies vaccination campaigns, and attitudes towards and knowledge about rabies in general. Note however, that even though data on the geographic location of each household was collected, which meant that we could have calculated the distance between each household to their nearest vaccination station, the data could not be used as we later discovered that there were technical errors in the collection of the data. See Appendix for the questionnaire.

Since we believe that rabies elimination is a public good, we believe that participation in rabies vaccination campaigns can be associated with a village's underlying ability to coordinate and participate in collective action. Therefore, we decided to create an indicator for collective action at village-level. To create the indicator, the same households which participated in the household-level questionnaires were asked to engage in a small experiment. We call this a cash experiment. All participants were given 5,000 Tanzanian Shillings (TZS) (equivalent to 1.68 GBP) and they could choose to either return the cash (participate in "collective action") or keep the cash (refuse to participate in the "collective action"). If at least 14 out of 20 participants in the village returned the cash, then all participants within the same village were rewarded with 20,000 TZS (equivalent to 6.72 USD). Otherwise, there was no reward and those who returned the 5,000 TZS, would lose the cash. The index for a village's willingness to participate in collective action was the proportion of participants who returned the cash. The index would be used in the regression analyses as control for village-level propensity to participate in collective action only. Our hypothesis was that there would be some correlation between the indicator and participation in the vaccination campaigns. Villages with higher propensity to participate in collective action would be more likely to have higher vaccination coverage rate, provided villagers understand that rabies elimination requires them to collectively vaccinate their dogs.

Follow-up in-depth interviews were conducted with 16 interviewees selected from the group of participants who were interviewed in the household questionnaire. To ensure that we could obtain some insights from different groups of people, the interviewees were chosen based on the interventions they were exposed to and their decision to participate or not. Specifically, interviewees who received any of the interventions were asked if the interventions affected their decision to participate in the vaccination campaigns. Interviewees, who did not participate in the vaccination campaigns and were not exposed to the interventions, were asked whether the interventions could have affected their decision had they been exposed to the advertising interventions, and whether other factors prohibited them from participating. The effects of the operational changes were also explored as well as further modifications to the field protocols that could have facilitated these processes further. The interviewees were specifically asked if any of those operational changes made it easier for them to participate in the vaccination campaigns and if there were other changes that could have been made to improve the campaigns further. See Appendix for the key questions asked during the interviews.

4.2.6 Data Analysis

To identify the effect of the interventions on participation in the vaccination campaigns, we used Generalised Linear Mixed Models (GLMM) with logit link function. The use of GLMM regression models is considered appropriate for our data as it addresses several issues. Firstly, the dependent variable (estimated vaccination coverage) is bounded between 0 and 1. Secondly, the estimation of vaccination coverage using transect is likely to be very noisy, especially for those villages with low dog counts. GLMM address this issue in two ways: it allows us to use weighted regressions which put relatively more weight on villages with high dog counts during transects and relatively less weight on those with low dog counts. This then allows us to use all 56 villages in our sample, instead of discarding villages with low dog counts. In addition, we could include village-level random effects in the model which can cushion the effects of noise in the transect estimates of vaccination coverage and the lack of reliable village-level data, which could affect the regression analyses.

In the GLMM models, we used estimated vaccination coverage of each village as proxy for its participation rate in the vaccination campaigns. We used a variable called text messaging coverage as proxy for the text messaging intervention. Specifically, text messaging coverage of a village is the number of phone numbers collected in that village divided by its estimated number of households. The estimated number of households of a village is the population size of the village divided by the average household size. Therefore the text messaging coverage is a number between 0 and 1. It is a better proxy than a dummy variable because it also captures the varying extent to which the text messaging intervention was implemented in each village. As proxy for the religious/tribal leaders intervention, I used a dummy variable which takes the value 1 if a village received the intervention. A lot of the variables obtained from the village-level data were used in constructing GLMM regression models, but a lot of them were discarded because they made no improvement to the models, in terms of the AIC criterion and they provided little additional insight into how they could influence participation in the vaccination campaigns.

This research was not designed to identify the effect of the operational changes to the vaccination campaigns (discussed above) on participation in the campaigns. However, during the experiment we found some suggestive evidence that strongly suggested that the operational changes had a significant impact on participation. To identify the effect of the operational changes, we first used paired t-tests to compare the vaccination coverage of our vaccination campaigns with those of 2014 and 2016. This could reliably be done because vaccination coverage estimation of those years were also done using transect. Note, however, that the 2014 transect data was available for only 29 of the 56 sampled villages and 2016 transect data was available for only 33 villages. We then collated the vaccination coverage data that we have from those years with those of the year 2018 to create a larger dataset of 118 observations and used GLMM regression (as described above) to identify the effect of the operational changes and the advertising interventions on participation in the vaccination campaigns. The only difference in this case is that we included random effects at both village-level and observational level. The only known village level differences between the three years were the implementation of the advertising interventions and the operational changes. Therefore we acknowledge that the results of these analysis need to be interpreted with caution as it lacks data on other village-level variables that could have affected participation and could have changed between 2014, 2016 and 2018.

All qualitative data was recorded, transcribed and translated into English for analysis. To analyse the qualitative data, we used thematic analysis method to identify all the key patterns and themes within the data.

4.3 Data Description

In this section, I provide descriptive statistics of key variables that could have had an impact on vaccination coverage. All data used in this study was collected by our research team, with only the exception of the data on village population size which was taken from the 2012 population census.

The different experimental groups are comparable because most of the sampled villages shared many socio-economic traits and for traits with larger variation across the sample, there is sufficient representation across all experimental groups. Firstly, almost all villages relied on crops as their primary source of income, with only one village whose village leader described livestock as their primary source of income. For secondary income source, they were about equally divided between livestock and commercial activities. Most of the sampled villages had an issue with access to basic needs. All villages had basic health facilities at dispensary level, but only 3 villages had health centres within their village. 48 out of 53 remaining villages had health centres within a 2-hour walk, while the other 5 villages within a 4-hour walk. All villages had difficulty accessing clean water, most villagers in all villages had to collect water manually. 50 of the 56 villages had livestock field officers[5] assigned to their villages. The only socio-economic factor that differed significantly between villages was their population sizes. Using data from 2012, the population size of the villages ranged from just over 450 to almost 6000, they average at about 2200. However, there was sufficient representation of villages from varying sizes in each experimental group. The mean population size of each experimental group was no more than half a standard deviation away from the sample mean. Another socio-economic indicator was created using the cash experiment described in the previous section. Results of the experiment showed that only 3 villages succeeded in the "collective action" and on average, approximately 39% of the participants chose to participate in the "collective action".

The sampled villages also shared similar experience and attitudes towards dog ownership, rabies and rabies vaccination campaigns. Dogs were generally treated in similar ways. The primary reason for owning dogs were for them to guard houses, crops or livestock. Our household questionnaire showed that more than 90% of respondents kept dogs for these reasons. In case of a dog biting humans, most of the villagers described killing the dogs and getting the owner to compensate the victim for post-exposure prophylaxis as the most

[5]Livestock field officers are government officials given the task of advising villagers on how to keep their domestic animals and livestock safe.

typical response. All villages had experience with canine rabies vaccination campaigns before our campaigns. During our campaigns, vaccination stations were placed in relatively similar locations, such as schools, markets and town halls. When asked about the locations of our vaccination stations, all village leaders, except one, said that the locations could not have been improved. Hence, we believe that the placing of our vaccination stations were optimised.

One key variable that affected the effectiveness of the first intervention was the text messaging coverage of each village. There was considerable variation in the text messaging coverage, with the minimum and the maximum coverage at 18% and 97%, respectively, and the mean of almost 50%[6]. Villages with larger population size tended to have lower text messaging coverage than those with smaller population size. This was because it was harder to collect a large number of phone numbers in larger villages. Text messaging coverage will be used as an index for the extent to which this intervention was implemented in each village.

To quantify how well these advertising methods reached their intended audience, we conducted questionnaires at vaccination stations and with household heads on information sources about the dog vaccination campaign (see Tables 4.4 and 4.5, respectively, in Appendix). There were in total 935 attendants interviewed at selected vaccination stations. However only data from 887 of the attendants were usable, the others had to be discarded as invalid as they did not specify how they learned about the vaccination campaigns. There were in total 1,114 respondents to the household questionnaires.

There are some key similar patterns in both set of data. Firstly, neither of the advertising interventions were primary source of information for the respondents. Only about 11% of respondents in the vaccination station surveys

[6] These figures exclude the villages that did not receive the first intervention.

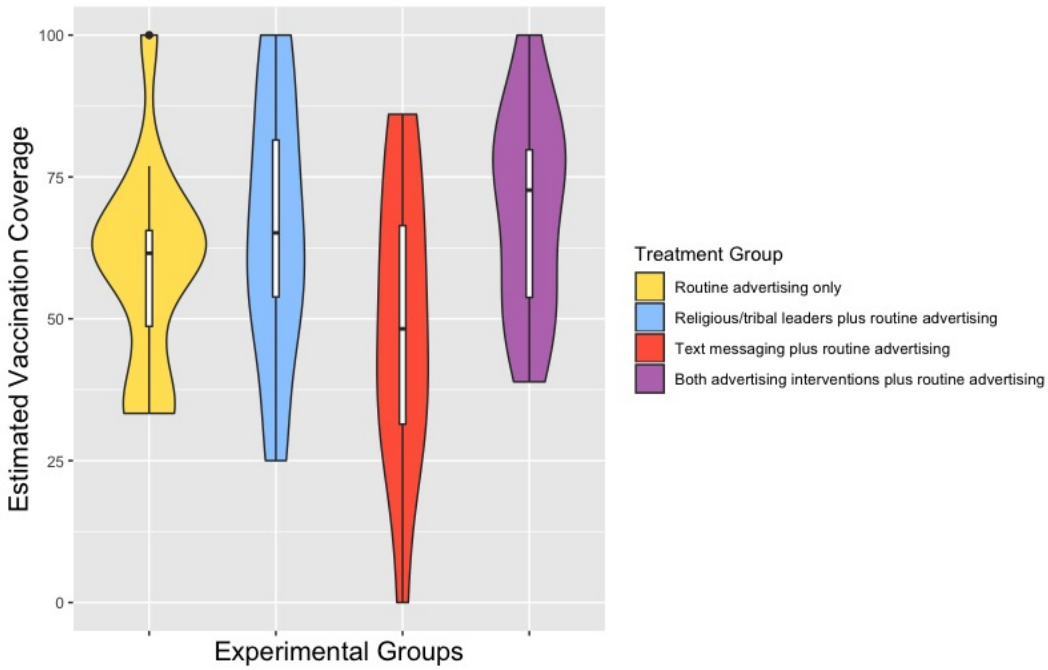


Figure 4.2: Estimated Vaccination Coverage by Experimental Group

said at least one of the advertising interventions were their only sources of information. The corresponding figure is much lower at less than 2% in the household questionnaires. Secondly, routine advertising and word-of-mouth were still the most important source of information for most villagers. More than 88% of the respondents to vaccination station survey said that they were made aware of the campaigns through routine advertising or other villagers. The corresponding figure is much higher in household questionnaires, at 98%.

4.4 Result

4.4.1 The Effect of the Advertising Interventions

The vaccination campaigns took place on the 20th of January 2018. A total of 3,256 dogs within the sampled villages were vaccinated. Figure 4.2 presents a comparison of mean vaccination coverage of all experimental groups. Villages that received both the text messaging and the religious/tribal leaders advertising had the overall highest vaccination coverage, at approximately 70% (see Figure 4.2). Surprisingly, the group receiving the text messaging intervention plus routine advertising had the lowest average estimated vaccination coverage at around 50%. The group with only routine advertising and religious/tribal leaders plus routine advertising had average estimated vaccination coverage at 60% and 65% respectively. From these figures, the effect of each intervention remains unclear.

Table 4.1 provides a summary of our GLMM regression analyses with estimated vaccination coverage as the dependent variable and a list of independent variables on the far-left column. In Model 1, only the coefficient for Religious/Tribal Leaders was statistically significant and positive, which means that we only have evidence that religious and tribal leaders had a positive effect on participation in the vaccination campaigns. However, this result changed when the interaction term for the two advertising interventions (Text Messaging Coverage*Religious/Tribal Leaders) was included in the regression (Models 2 and 3), and the coefficient for Religious/Tribal Leaders lost statistical significance whilst the interaction term was statistically significant. This indicated that Model 1, which did not include the interaction term, incorrectly captured the effect of the interaction term as that of the religious and tribal leaders. The coefficient for Text Messaging Coverage also gained statistical significance at 10% level, and was negative. The positive coefficient of the interaction term outweighs the negative coefficient of mobile phone text messaging, which means that when used together, both interventions should generate an overall positive outcome.

Regarding other variables, the coefficient for the presence of livestock field officers is positive and statistically significant at 10% level in both Model 2 and Model 3. As expected, this indicates that livestock field officers had a role to play in increasing vaccination coverage. The coefficient for the presence of

Table 4.1: Village-Level Regression Results

Independent Variables	Model 1	Model 2	Model 3
Text Messaging (TM) Coverage	-0.1023	-1.0439*	-1.0391*
	(0.4162)	(0.6116)	(0.6067)
Religious/Tribal Leaders	0.4601**	0.0429	0.0518
	(0.2329)	(0.3011)	(0.2986)
Pastoralist Presence	-0.2594	-0.3191	-0.2778
	(0.2454)	(0.2404)	(0.2421)
Livestock Field Officer Presence	0.4803	0.6931*	0.7376*
	(0.3995)	(0.4020)	(0.4015)
Collective Action Indicator			-0.6769
			(0.7152)
TM Coverage*Religious/Tribal Leaders		1.7399**	1.6772**
		(0.8405)	(0.8353)
AIC	283.9	281.7	282.8
BIC	296.0	295.8	299.0
Number of Observations	56	56	56

*Significant at 10% level, **Significant at 5% level

Numbers in brackets are the standard errors of the coefficient.

The dependent variable is the estimated vaccination coverage.

pastoralist communities is negative as expected, but it is not statistically significant. Model 3 includes a variable called Collective Action Indicator, which is an index for a village's collective ability to overcome collective action problem, as generated from the cash experiment. Its coefficient is not statistically significant, which indicates that either the result of the cash experiment was not a good indicator for collective action or, if it was, that the villagers did not consider participating in the vaccination campaigns as participating in a collective action, or that the indicator was a wrong measure of people's tendency to contribute to a health-related public good. Several other variables based on data collected from village leaders were also used to estimate the models, but were not retained in the models because they did not improve the models in any way.

These results suggest that there was no evidence that either of the interventions on their own had a positive effect on vaccination coverage, but there was evidence that, when used in conjunction with each other, they had a positive impact. Follow-up in-depth interviews conducted with local villagers provided some explanation for this. In interviews conducted with 16 randomly selected villagers, 9 received the text messaging intervention. Of these, 5 interviewees mentioned that they needed some kind of confirmation through other information sources before they believed the authenticity of the text messages. To quote one of the interviewees:

> *"(When) the text came before the campaign, I didn't think anything of it, but after two or three days, some people came advertising on loudspeakers about the campaign,..., realising the text was also related to this, I said to myself I must vaccinate my dogs".*

Local village/sub-village leaders and officials as well as other advertisement methods were mentioned amongst the other sources of confirmation. This is consistent with the findings of the analysis whereby text messaging and religious/tribal leader interventions combined to produce a positive effect. Other factors that was mentioned by the interviewees to may have impeded the effect of text messaging included illiteracy and weak phone signal.

Despite these results, the qualitative data also provided some positive feedbacks related to text messaging. Specifically, we found some evidence that the anecdote about the recent case of human death from rabies was especially effective when text recipients could relate the case to themselves or to their family. Two interviewees explicitly mentioned that the content of the text message made them feel differently about the risk of rabies. One said:

> *"... when you receive a text like this and when you look back at home, you realize you have dogs and kids, you will definitely take your dog for vaccination".*

Another interviewee said:

> *"the reported kid who died from rabies was my grandson*[7]*... people were referring to the case in their conversations. ... very few people didn't vaccinate their dogs, the majority of them were sensitised by the texts."*

These excerpts showed that the content of text messaging could indeed make the risk of rabies salient to the text recipients and attract their attention.

While qualitative data provided some insight into why the text messaging intervention needed religious/tribal leaders to produce a positive effect, it did not explain why the latter were ineffective on their own, nor did it explain the mechanism through which religious/tribal leaders motivated community members to participate in the vaccination campaigns. We obtained evidence that community members support the use of religious/tribal leaders. Several studies such as by Nasiru et al., (2013) and Goldstein et al., (2015) similarly showed that leaders, including religious leaders, were effective in reducing vaccine hesitancy and increasing vaccination uptake. Therefore, we are confident that the use of religious/tribal leaders had a positive effect in some way. However, community members did not seem to take special interest in the fact that information regarding vaccination campaigns came from religious/tribal leaders. We found no evidence that religious/tribal leaders were able to raise participation through the mechanism hypothesised in the introduction, namely through overcoming collective action problem.

[7] This was not necessarily true. The case in the text refers to a specific case that happened in another village that was not included in our sample.

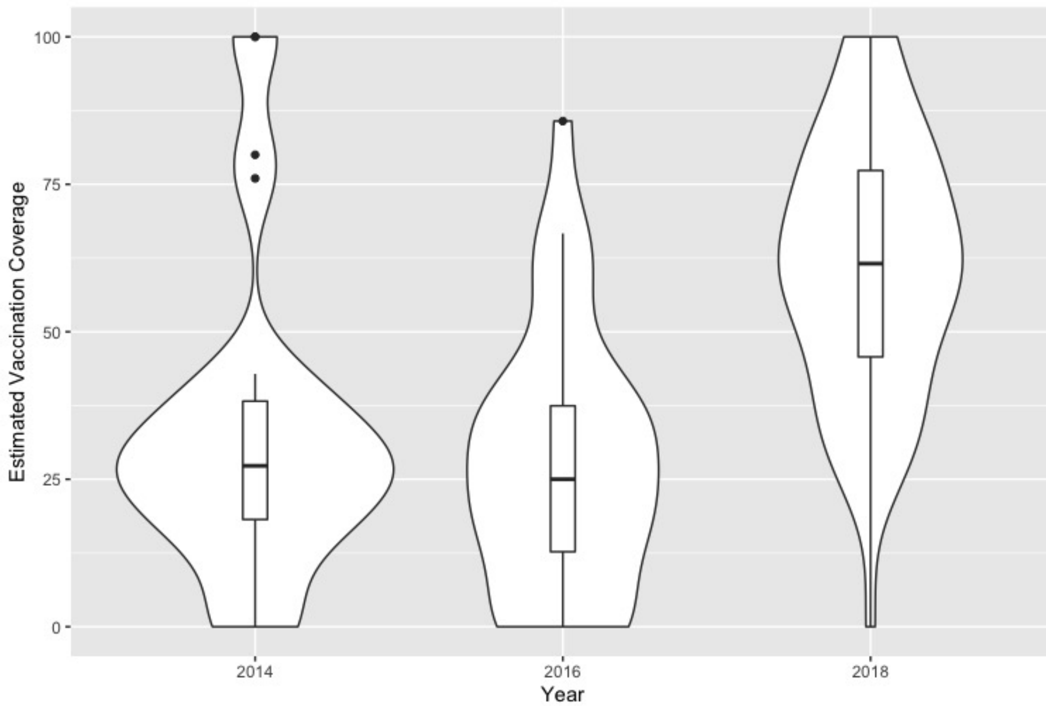


Figure 4.3: Estimated Mean Vaccination Coverage Across Years

4.4.2 The Effect of the Operational Changes

As far as we know, the operational changes to the campaigns (described in section 2) were implemented in the 2018 vaccination campaigns, but not in the previous years (2014 and 2016). We are not aware of other village-level changes, apart from the advertising interventions, that could have had a significant impact on participation in rabies vaccination campaigns. We know that awareness about recent rabies cases can have an impact on participation, but we also know that human deaths have occurred in the district every year. Figure 4.3 illustrates how mean estimated coverage in 2018 was considerably higher in 2018 than in 2014 and 2016.

To check if there was any significant and positive difference in vaccination coverage between 2018 and 2014, we first conducted simple one-tail paired t-tests. Mean vaccination coverage of the 2018 campaign was significantly higher than the campaigns in 2014 and 2016 (Table 4.2), including among the villages

Table 4.2: One-tail paired t-tests

Coverage difference (2018-2016)	Mean Difference	Standard Error	Sample Size	T-value	Significance
All sampled villages	0.3069	0.0543	33	5.6531	Yes
Villages with no intervention	0.3050	0.1119	10	2.7248	Yes
Coverage difference (2018-2014)					
All sampled villages	0.3282	0.0651	29	5.0376	Yes
Villages with no intervention	0.3413	0.1056	8	3.2318	Yes

that did not receive any of the two advertising interventions.

In addition to the paired t-tests, we collated all vaccination coverage data for all three years to create a larger dataset of 118 observations (29 observations in 2014, 33 in 2016 and 56 in 2018) and used GLMM regression with estimated vaccination coverage as the dependent variable and the independent variables are listed on the left column of Table 4.3. In Model 1, the coefficient for Operational Changes was positive and statistically significant at 1% level. Model 2 uses Year as an independent variable instead of Operational Changes. It provides a similar result in which the coefficient of Year 2018 takes a similar value to the coefficient of Operational Changes in Model 1.

As far as we know and according to the district veterinary officer, the operational changes had not been implemented in the previous campaigns, therefore this is suggestive that the operational changes could have an impact on participation. The interpretation of these results still have to proceed cautiously as

Table 4.3: Regression Results Across Different Years

Independent Variables	Model 1	Model 2
TM Coverage	-0.8244	-0.8250
	(0.6136)	(0.6144)
Religious/Tribal Leaders	0.1773	0.1772
	(0.3000)	(0.3003)
Operational Changes	1.2757***	
	(0.2403)	
Year 2016		-0.0458
		(0.2362)
Year 2018		1.2516***
		(0.2706)
TM Coverage*Religious/Tribal Leaders	1.3663^{+}	1.3671^{+}
	(0.8372)	(0.8383)
AIC	558.8	560.8
BIC	578.3	583.0
Number of Observations	119	119

$^{+}$Significant at 10.3% level, ***Significant at 1% level

Numbers in brackets are the standard errors of the coefficients.

The dependent variable is the estimate vaccination coverage.

we do not have sufficient quantitative data to claim this result as a concrete evidence. However, qualitative data which will be discussed below supports the positive effect of the operational changes.

In our in-depth interviews, we also took the opportunity to ask interviewees on their views on each of the operational changes that were made to the vaccination campaigns. There was general support for the operational changes, however, other issues were also brought up during the interviews.

One of the operational changes was stationing at least one vaccination point in each sub-village. More than half of the interviewees mentioned that distance from vaccination points and difficulty restraining dogs or losing control of dogs while travelling to a vaccination station as one of the general reasons for failures to participate in vaccination campaigns. Shortening the distances to the vaccination points at least partially helped tackle this issue by minimising the time that dog owners had to travel and restrain their dogs. In addition, stationing vaccination points in sub-villages also made sub-village leaders get involved in the advertisement of the campaigns and there is evidence that sub-village leaders can have an influence on villagers' decision to vaccinate their dogs. One interviewee mentioned that sub-village leaders tend to have information about dog-owners in their respective sub-villages and the presence of sub-village leaders can also encourage other villagers to participate in the vaccination campaigns. Despite this, around a third of the interviewees still recommend house-to-house vaccination as a better strategy.

Another operational change was to ensure that vaccination stations were open all day long. According to more than a third of the interviewees, having vaccination stations opened for a whole day was certainly an improvement over the previous campaigns, as it gave villagers more time and flexibility to vaccinate their dogs. However, 9 of the interviewees believed that the vaccination campaign should have been held for at least two days. It should also be noted that longer vaccination campaigns can be costly so any additional effort in prolonging the campaign should be balanced with sufficient increase in participation from the community members.

Another change that could have affected participation was that advertisements about the vaccination campaigns started one week before and continued until the campaign day instead of only one day before the campaign day. According to 11 of the interviewees, this change helped them to prepare for the vaccination campaigns by giving them time to restrain their dogs and make other necessary preparation to bring their dogs to the vaccination point. Dogs in many of the villages tend to be left to freely roam the villages, which in many cases make it difficult for the owners to find and restrain them on time for vaccination if the period of notice is too short. In addition, this new advertising strategy also allowed information to travel within the villages and ensured that more dog owners were informed than if advertising were to happen only one day before the campaign. According to the interviews and some quantitative data (see Appendix, Tables 4.4 and 4.5), there was evidence that villagers tend to inform each other about the vaccination campaigns and word-of-mouth played an important role in the transmission of information. Therefore, extending the advertising period means not only that there were more villagers likely to be exposed to the advertisements, but it also gave time for those not exposed to the advertisements to be informed by other villagers.

4.5 Discussion and Conclusion

The results of our analyses are as follows. Firstly, there was no statistical evidence that each of the advertising intervention was effective in raising participation on its own, but there was evidence that when used together, they were effective in raising participation. However, qualitative data showed at least a degree of support for both interventions. Secondly, we found strong suggestive evidence, both quantitative and qualitative, that the operational changes that were made to the vaccination campaigns had a significant impact on participation.

The first set of results may raise the question of whether the absence of any positive statistical evidence suggest that the advertising interventions were ineffective on their own. This may not necessarily be the case due to many contextual factors. To see how these contextual factors could have affected our result, we compare our study to another related study by Cleaton et al., (2018).

In contrast to our results, Cleaton et al., (2018) found evidence of a positive effect of mobile phone text messaging in Haiti. A number of contextual factors may explain this difference. Firstly, compared to the communes studied in Haiti (Gonaives and Saint-Marc), Morogoro rural district in Tanzania is more sparsely populated. The need to travel long distances to reach vaccination stations meant that participants in our study area were more limited by higher participation costs. Secondly, cultural factors or social norms may have played a role. In both studies, routine advertising methods such as posters and loudspeakers began one week before the vaccination day. Information had therefore the same amount of time to reach community members. However, Cleaton et al., (2018) reported that only about 15% of survey interviewees had heard about the campaign from others. In our study, the corresponding figures are much higher (more than 63% from household questionnaires and 50% from vaccination station questionnaire, see Appendix, Tables 4.4 and 4.5). This suggests that communication mechanisms and information sharing likely differ between the two study areas. It is possible that our text recipients in our study area could have easily been made aware of the vaccination campaigns through other villagers or sources, making text messaging redundant rather than the primary source of information like in Haiti. Based on these arguments, the effect of text messaging was likely limited by some external impediment to participation in the campaign itself or made redundant or hidden by the effect of other information sources. In addition, it should be noted that routine advertising and word-of-mouth played a much more important role in spreading information than the advertising interventions (based on vaccination station surveys, more than 88% of the attendants had been made aware of the campaigns through routine advertising and other villagers, the corresponding figure from household questionnaires was more than 98% (not considering those who were not aware of the campaigns)). This does not suggest that the text messaging was ineffective in raising awareness, but rather that its effect was largely made redundant by routine advertising and word-of-mouth.

The effect of religious/tribal leaders, on the other hand, could have easily been affected by the same contextual factors, which could also limit its observed effect. There is no known study that looked at the effect of religious or tribal leaders specifically in raising participation in rabies vaccination campaigns. However, Léchenne et al., (2016) showed evidence of a positive effect that community leaders in general had on participation. Studies related to solving vaccine hesitancy in other diseases (for example, Nasiru (2012) and Goldstein (2015)) showed that religious and other political leaders could have a major influence in raising vaccination uptake. Our qualitative data also showed support for religious/tribal leaders as a trusted source for communication. We therefore argue that even though we do not observe any positive effect of religious/tribal leaders on their own, it does not necessarily mean that it is ineffective, but rather its affect was limited or made redundant by contextual factors.

Another possible reason why we observed no evidence for a positive effect of each advertising intervention on its own might be because there was already sufficient information and motivation prior to the interventions being implemented. Villagers could have been well-informed about the campaigns even without being exposed to the advertising interventions. Rabies risk could have already been sufficiently salient. Therefore, participation in vaccination campaigns was likely limited by other factors rather than the effect of the advertising interventions. This may explain why we saw a much larger effect of the operational changes than the advertising interventions because the key reason behind low participation previously was due to difficulties accessing vaccination points, which was addressed with the operational changes.

Our second set of results showed that operational changes to how the campaigns were run could have a major impact on participation. Note however that there was no known data on other village-level changes that could have affected participation and the only known changes were the advertising interventions and the operational changes. Therefore, the interpretation of those results had to be done cautiously.

However, these results are intuitive and there are many arguments and studies to support them. The first change, stationing vaccination points at sub-village level, lowered the direct participation cost incurred by the villagers, making the vaccination point more accessible. Villagers did not have to walk too long or spend too much time restraining their dogs. Beyenne et al., (2018) showed distance to a dog rabies vaccination point has a significant impact on participation in Malawi. In a study by Bardosh et al., (2014), 16% of respondents to their survey gave distance from vaccination point as the main reason for not participating. This, combined with those who listed lack of awareness as main reason for not participating, made up 39% of the respondents. We partially addressed the problem of lack of awareness by starting to advertising the vaccination campaigns one week in advance so that more villagers had the time to learn and inform each other about the campaigns. The other operational change was opening the vaccination station all day long. This gave the villagers more flexibility and more windows of opportunities to vaccinate their dogs. A comprehensive study by Castillo-Neyra (2017) showed that similar changes, that include similar small changes in the implementation of the vaccination campaigns and timely advertising could have a positive effect on participation.

These results may also have a broader implication not only in terms of disease elimination, but also public good production in general, especially those that require voluntary participation from community members. Our research argued that although our advertising interventions could have been effective, their effect were limited or made redundant or both at least to some extent by contextual factors. In addition, our operational changes which significantly eased access for villagers seemed to have a major impact on participation. These suggest that to design a cost-effective policy that deals with any collective action problem a policy-maker needs to understand the context the problem is in. In our case, our advertising interventions inform and make the problem salient to community members, so that community members are informed about the risk of rabies and the benefit of vaccination and rabies elimination, and the operational changes eased access to the community members so that their cost of participation in the collective action is sufficiently low.

One of the shortcomings in our research is that we were not able to isolate the effect of advertising in general. This is because we bundled advance advertising with the other two operational changes. This means that we were not able to identify exactly what caused low participation in those villages prior to our campaigns, whether it was because of lack of information and knowledge or ineffective delivery of the vaccination campaign or both. Being able to isolate and identify each problem could have helped significantly in designing a cost-effective policy which can target each specific problem individually.

4.6 Appendix

4.6.1 Workshop Discussions:

List of topics discussed during workshop:

1. Discuss local experience with rabies and rabies vaccination campaigns.
2. Are there barriers to community members participating in rabies vaccination campaigns? How can the vaccination campaigns be improved to increase participation?

3. We are planning to use mobile phone text messaging to advertise the vaccination campaigns. Do you think it will be useful? What do you think should be in the content of the text messages? (Ask participants for their general opinion on the intervention and for any potential impediment to the intervention.)

4. Do community members participate in collective action in different activities? (Discussant of the workshop should explain what collective action is and provide examples and ensure that all participants understand what collective action is before proceeding into detailed discussion).

4.6.2 Topic Guide for Focus Group Discussions

List of discussion topics discussed in Focus Group Discussions:

1. Are you familiar with rabies? Have there been cases of rabies in human or dogs in the village recently? Do you think your village is at risk of a rabies outbreak?

2. Do you think your participation in the vaccination campaigns can protect you and your family from rabies?

3. Do you think your participation in the vaccination campaigns can help eliminate rabies from your village?

4. Have there been dog vaccination campaigns in the village before? 1=Yes, 2=No

5. If yes, did many people in the village participate in the most recent vaccination campaign?

6. What do you think stopped you or anyone else from participating in the most recent vaccination campaign?

7. What do you think would have encouraged you or anyone else who did not participate to participate in the vaccination campaigns?

8. What do you think about the use of text messages to remind everyone and encourage them to participate in the vaccination campaigns?

9. What type of content in the text message do you think would encourage people to vaccinate in the vaccination campaigns? (Participants should be given a list of messages (obtained from the workshops) and asked to rank those messages)

4.6.3 Discussion topic in Community Leaders workshop

List of topics discussed in community leaders workshop

1. Explain the importance of collective action in eliminating rabies from the local dog population. (Specifically, explain that for rabies to eliminated we need to consistently achieve at least 70% coverage for a few consecutive years. This requires collective action. Explain how in their position as religious leaders who lead groups of followers, we believe they can influence the decision of others to vaccinate their dogs. This can be helpful in overcoming collective action problem and eliminate rabies.)

2. Communication with their respective religious/tribal communities:

    - Do they have regular worship meetings?
    - Are most of their followers active? (ie. Regularly attending meetings and living by the standards prescribed by the religious leaders)
    - Do they often meet with their followers outside the regular worship meeting?
    - Have other members of their respective religious groups sought advice from them regarding non-religious issues?
    - Have you and your followers/congregation organised any collective activities?

- How hard is it for them to sensitise non-religious activities among their followers?

3. If we are to ask them to help convince dog-owners in their religious groups to participate in vaccination campaigns, how should this be done (from their perspective)?

    - When can this be done, during or outside religious meetings?
    - Should this be done in groups or one-to-one?
    - What kind of information would encourage their followers to participate in vaccination campaigns? Can the information be portrayed in the form of religious morality (conforming to their religious doctrines)?

4. Questions for tribal leaders:

    - Do you think members of your tribe are at risk from rabies?
    - Do pastoralist communities generally face difficulties attending canine rabies vaccination campaigns? If so, what are the difficulties and what can be done to overcome the difficulties?
    - If we are to send text messages to remind the pastoralist communities to vaccinate their dogs, would this be helpful? (also discuss literacy rate)
    - In your position, as a tribal leader, is there anything you can do to encourage your tribe members to vaccinate their dogs?

4.6.4 Village-Level Questionnaire

List of questions asked in village-level questionnaire (administered to village-leaders (chairman or executive)):

1. Is there a hospital or health centre in your village?

- Yes
- No

2. If not, how long does it take to reach the nearest hospital or health centre?
    - Less than 2 hours
    - 2 to 4 hours
    - 4 to 6 hours
    - More than 6 hours
3. If not, is there access to public transport from your village to the nearest hospital or health centre?
    - Yes
    - No
4. Are there qualified veterinarians in your village?
    - Yes
    - No
5. Is there regular presence of Livestock Field Officers in your village?
    - Yes
    - No
6. Please rank the following income-generating activities in order of importance to your village (1 - most important to 3 - least important):
    - ....Agriculture (crops)
    - ....Agriculture (Livestock)
    - ....Commercial activity (Including trading in agricultural products)

7. Is there any other income-generating activity that we should take note of?

8. Do most households in your village own mobile phones?

    - None
    - Less than half
    - Around half
    - More than half
    - All household

9. Is there permanent mobile phone signal coverage in your village?

    - Yes
    - No

10. Do most households have access to basic needs such as clean water and energy?

    - None
    - Less than half
    - Around half
    - More than half
    - All household

11. Do most villagers have to collect water for their daily usage?

    - Yes
    - No

12. If yes, how long does it take for most of them to collect water? (From time leaving to arriving back home)

    - Less than one hour

- Between one to two hours
- More than two hours

13. What is the proportion of the villagers that live 10 minutes' walk from the village center?
    - None
    - Less than half
    - Around half
    - More than half
    - All household
14. How many people in your village have completed standard 7? (Education)
    - None
    - Less than half
    - Around half
    - More than half
    - All household
15. What is the religious composition in your village?
    - There are more Christians than Muslims
    - There are more Muslims and Christians
    - They are equally divided
16. Are most of them active in their respective religious practices?
    - None
    - Less than half
    - Around half
    - More than half

- All household

17. Are there pastoralist communities in or nearby to your village?
    - Yes
    - No
18. If yes, how far do they typically live from the village centre?
    - Less than 10-minutes' walk away
    - Less than 1-hour's walk away
    - More than 1-hour's walk away
19. How many of the dogs in your village are owned by the pastoralist communities?
    - None
    - Less than half
    - Around half
    - More than half
    - All dogs
20. Is there easy road access to the residence of the pastoralist communities?
    - Yes
    - No
21. Are the pastoralist communities usually involved in village community activities?
    - Yes
    - No
22. Do pastoralists usually come into contact with the rest of the community in the village?

- Yes
- No

23. What is the population of dog-owning households in your village?
    - None
    - Less than half
    - Around half
    - More than half
    - All household
24. In your village, what do people usually do to a dog that bit someone? (select multiple if necessary)
    - Kill the dog
    - Restrain the dog
    - Chase the dog away
    - Other, specify ....
25. According to village custom, if a dog bites someone in your village, does the owner of the dog have to pay for post-exposure prophylaxis to the victims?
    - Yes
    - No
26. If yes, how often is it successfully enforced?
    - Never
    - Less than half the time
    - Around half the time
    - More than half the time

- Always

27. What is the dog population in your village?

    - Less than 20
    - 21 to 50
    - 51 to 100
    - 101 to 200
    - More than 200

28. How do dog-owners generally treat their dogs?

    - As family pet
    - As guard dogs (for home)
    - As guard dogs (for crops and livestock)
    - Left to free-roam

29. Have there been canine rabies vaccination campaigns in your village before?

    - Yes
    - No

30. If yes, please provide the month and year of the most recent vaccination campaign.

31. If yes, did many dog-owners participate in the most recent vaccination campaign?

    - None
    - Less than half
    - Around half
    - More than half

- All household

32. If yes, how were the vaccination campaigns advertised (select multiple if necessary):

    - Loudspeakers
    - Radio/television
    - Mobile phone text messaging
    - Posters
    - Other, specify.....

33. If yes, where did the vaccination campaign take place? (select multiple if necessary)

    - Local school
    - Local hospital
    - Town hall
    - Other, specify.....

34. Do you think there could have been a better location for the vaccination campaign?

    - Yes
    - No

35. If yes, where do you suggest the next vaccination campaign should take place?

    - Local school
    - Local hospital
    - Town hall
    - Other, specify.....

4.6.5 Household Questionnaire

Questions asked in household questionnaire:

Information about Interviewee:

Name:............................... Age:........ Gender:.......... Phone number:..........

Head of Household: Yes/No

If not, what is the name of the head of the household?......................................

If not, role in the household: ....

Head of household's occupation:

- Farmer (crops)
- Farmer (livestock)
- Businessperson
- Civil servant
- Other ....

Household Information

1. Are there children in your household?
    - Yes
    - No
2. If yes, how many children are in your household?
    - Aged 5 or less ....
    - Aged 6 to 12 ....
    - Aged 13 to 17 ....
3. How many adults (aged 18 or above) are in this household?..........
4. Do all children aged between 7 and 15 years old go to school?
    - None of them goes to school

- Only some go to school
- All of them go to school

5. Do those aged above 13 years old have at least completed standard 7?
    - None has completed
    - Only some have completed
    - All of them have completed
6. Has there been a child death in the household in the last 5 years?
    - Yes
    - No
    - There are no children in the household
7. Has there been a child death to a woman of age 35 or less?
    - Yes
    - No
    - There has been no child birth in the household
8. Does the household have access to electricity?
    - Yes
    - No
9. If yes, what is the main source of your electricity?
    - Battery
    - Solar
    - Publically provided electricity
    - Other,specify ....
10. What is the household's source of drinking water?

- Piped water, public tap
- Protected dug/tube well/spring or rainwater collection
- Unprotected well/spring or surface water (rivers, ponds, lakes, streams, dams)
- Water provided by carts or tanker trucks
- Other, specify ....

11. If safe drinking water must be collected, how long does it take to collect the water?
    - Less than 30 minutes' walk round-trip
    - At least 30 minutes' walk round-trip
12. What type of lavatory is used in the household?
    - Flush/pour flush toilets or latrines connected to a sewer, septic tank or pit
    - Pit latrines (Ventilated or with a slab or platform that covers the pit)
    - Composting toilets
    - Public or shared facilities (of any type)
    - Toilets which discharge directly into open sewer or ditch
    - Pit latrines without slab
    - Other, specify ....
13. What type of fuel does the household use for cooking?
    - Gas or Kerosene
    - Dung or wood
    - Charcoal
    - Other, specify ....

14. What is the flooring material of the dwelling?
    - Dirt, sand or dung
    - Wood or concrete
    - No finished flooring
    - Other, specify..................
15. Does the household own any device for access to external information? Choose all that apply:
    - Radio
    - Television
    - Telephone or Mobile phone
    - Other, specify ....
    - None
16. Does the household own any form of private transportation? Choose all that apply:
    - Bicycle/Animal Cart
    - Motorbike
    - Car/Truck
    - Motorboat
    - Other, specify ....
    - None
17. If you own automated vehicles, is any of them used as direct means of generating income? For example, as taxi or taxi motorbike, etc.
    - Yes
    - No

18. Does the household own a refrigerator?
    - Yes
    - No
19. Does the household own any agricultural land?
    - Yes
    - No
20. Does the household own any livestock? Choose all that apply:
    - At least 1 horse or cattle
    - At least 2 goats or sheep
    - At least 10 Chicken
    - Other, specify (include amount) ....
    - None
21. Please rank the following items in order of importance to you when choosing your daily activities (1 - Most important to 5 - Least important):
    - .....Meeting the basic short-term or current needs of the family members.
    - .....Keeping the family healthy.
    - .....Ensuring that the children meet their educational needs.
    - .....Saving up as protection against future difficulties (e.g. protection against future illness, job loss or natural disasters, etc.)
    - .....Saving up for future needs (e.g. save for children's education or wedding, for a big purchase, etc.)

About dogs within household

1. Do you own dogs?

- Yes
- No

2. Reasons for owning dogs, choose all that apply:
   - As pet
   - As guide dogs
   - As guard dogs for crops
   - As guard dogs for livestock
   - Other, specify:............
3. If own dogs, how many dogs do you own?
   - Less than 3 months old ....
   - More than 3 months old ....
4. How many of these dogs were vaccinated against rabies in the most recent vaccination campaign?
   - Less than 3 months old ....
   - More than 3 months old ....
5. If not all dogs were vaccinated, why not?
   - Those that were not vaccinated in the recent campaign have been vaccinated already
   - Unable to bring all of them to the vaccination point at once
   - Unable to find all of them on that day
6. If you participated in the most recent vaccination campaign, did you incur any costs?
   - Costs of transport...................
   - Cost of vaccination (per dog) ....

- Total ....

7. How did you become aware of the vaccination campaigns taking place?

    - Mobile phone text messaging
    - Religious or tribal leaders
    - Village or sub-village leaders
    - Other villagers
    - Posters or loudspeakers
    - Other, specify......................

8. If you participated in the previous vaccination campaign, how long did it take for the whole process to be completed? (From leaving home to arriving back home)

    - Less than 1 hour
    - 1 to 2 hours
    - 2 to 4 hours
    - More than 4 hours

9. If you did not participate in the most recent vaccination campaign, why not?

    - No knowledge of the campaign
    - Too Busy
    - Do not believe in the benefits of vaccination
    - Believe that the vaccine can harm the dogs
    - Other, specify ....

10. Please tell us who in your household look after the dogs, decide whether to vaccinate them, and would bring them to the vaccination point, by

giving us their position in the household (eg, household head, children, etc) and their age.

Knowledge, Attitudes and Practices towards Rabies

1. Do you know what rabies is?
   - Yes
   - No
2. If Yes, how did you first learn about rabies?
   - Personal experience with the disease
   - Media
   - By word of mouth
   - Previous vaccination campaigns in the village
   - Other, specify ....
3. Do you have family members or friends who have been bitten by rabid dogs before?
   - Yes
   - No
4. If yes, please tell us their relation to you, whether they received PEP, the cost of PEP, the number of trips it took to complete the PEP, travel cost and total cost.
5. Do you have family members or relatives who died from rabies?
   - Yes
   - No
6. If yes, tell us their relation to you, the name of the village they were from and the year in which they died.

7. Have you heard of other cases of rabies in human before?

    - Yes
    - No

8. If yes, tell us the name of the village and the year of the case.

9. Do you think that it is important to vaccinate your dogs against rabies?

10. If yes, why? (choose all that apply)

    - It protects my dogs from rabies
    - It protects my family from rabies
    - It contributes to the elimination of rabies in my village
    - Other, specify ....

11. If no, why not? (choose all that apply)

    - The vaccine is ineffective in protecting my dogs and it causes other problems for them
    - Even if I vaccinate my dogs, my family is still not completely protected from rabies
    - Vaccinating is useless because my neighbours are not vaccinating anyway
    - Other, specify ....

12. Do you think that vaccinating your dogs can protect your family from rabies?

    - 1. It will completely protect my family from rabies
    - It will protect my family from rabies to some extent only
    - It will not protect my family from rabies

13. How much do you think you or your family members are at risk from rabies?

    - No risk
    - Low risk
    - Medium risk
    - High risk
    - Very high risk

14. Do you think most of your neighbours (other dog owners) participated in the vaccination campaigns?

    - Yes
    - No
    - Only some

15. If not or only some, why do you think some of your neighbours did not participating in the recent vaccination campaign?

    - No knowledge of the campaign
    - Too Busy
    - Do not believe in the benefits of vaccination
    - Believe that the vaccination can harm the dogs
    - Other, specify ....

16. How many people in the village do you think participated in the recent vaccination campaign?

    - None
    - Less than half
    - Half

- More than half
- Everyone

17. How likely do you think that a child in your village will get bitten by a rabid dog in the next month?
    - Unlikely
    - Moderately likely
    - Very likely
18. How likely do you think that a child in your village will get bitten by a rabid dog in the next six months?
    - Unlikely
    - Moderately likely
    - Very likely
19. How likely do you think that a child in your village will get bitten by a rabid dog in the next year?
    - Unlikely
    - Moderately likely
    - Very likely
20. If you and all your neighbors participate in dog vaccination campaigns, how likely do you think that children in your village will be protected from being bitten by a rabid dog?
    - Unlikely
    - Moderately likely
    - Very likely
21. What proportion of your community is likely to participate in a dog vaccination campaign?

- Too few to make a difference to whether or not a child gets bitten by a rabid dog
- Enough to substantially lower the likelihood of a child getting bitten by a rabid dog

22. What difference would your participation in the dog vaccination campaigns make to whether or not a child gets bitten by a rabid dog?

    - Some difference but not enough to prevent a child from being bitten by a rabid dog
    - My participation is essential to prevent a child from being bitten by a rabid dog
    - So many other community members participate in dog vaccination campaigns that my participation isn't essential

General Collective Action-related questions

1. Please select the following activities that you think require collective participation from other villagers to be successful:

    - The construction of a new dispensary/school/village headquarter, etc.
    - Keeping our children healthy through collectively taking preventative measures
    - Keeping our source of drinking water clean
    - Eliminating infectious diseases

2. Suppose your village require a new village dispensary, would you be willing to participate in building the dispensary?

    - Yes
    - No

3. If yes, in what capacity?
    - Contributing cash
    - Contributing physical labour and other skills
    - Both
4. If not, why not?
    - I do not see why the village needs a new dispensary
    - Other people will not participate, so my contribution will be in vain
    - Many other people will be contributing already, the dispensary will be built regardless of whether I contribute or not.
5. What proportion of your community is likely to participate in such activity as building a dispensary?
    - Too few for it to be successful
    - Enough for it to be successful
    - Too many for my participation to be necessary
6. What proportion of your community would contribute through cash only?
    - None
    - Less than half
    - Around half
    - More than half
    - Everyone
7. What proportion of your community will contribute through physical labour and other skills only?
    - None
    - Less than half

- Around half
- More than half
- Everyone

8. What proportion of your community will contribute through both cash and physical labour and other skills?

    - None
    - Less than half
    - Around half
    - More than half
    - Everyone

9. How significant do you think your participation is to the success of such project?

    - My participation is not enough to ensure the success of the project
    - My participation is essential to the success of the project
    - Many other people are participating already that my participation is not so essential

10. Do you think you can rely on your fellow villagers to complete such project?

    - If I want such project completed, I need to actively participate myself
    - If I want such project completed, I need not only to actively participate, but also to mobilize other villagers
    - I can completely rely on them to complete the project, even without my participation

General Measure of Locus of Control (selection from Rotter, 1966)

Of the pairs of statements below, please select one statement you most agree with:

1. - Many of the unhappy things in people's lives are partly due to bad luck.
   - People's misfortunes result from the mistakes they make.
2. - I have often found that what is going to happen will happen.
   - Trusting in fate has never turned out as well for me as making a decision to take a definite course of action.
3. - Getting a good job depends mainly on being in the right place at the right time.
   - Becoming a success is a matter of hard work, luck has nothing or little to do with it.
4. - It is not always wise to plan too far ahead because many things turn out to be a matter of good or bad fortune anyhow.
   - When I make plans, I am almost certain that I can make them work.
5. - Many times, we might as well decide what to do by flipping a coin.
   - In my case, getting what I want has little or nothing to do with luck.
6. - Most people don't realize the extent to which their lives are controlled by accidental happenings
   - There really is no such thing as "luck".
7. - In the long run, the bad things that happen to us are balanced by the good ones.
   - Most misfortunes are the result of lack of ability, ignorance, laziness or all three.

8.
    - Many times I feel that I have little influence over the things that happen to me.
    - It is impossible for me to believe that chance or luck plays an important role in my life.

9.
    - Sometimes I feel that I don't have enough control over the direction my life is taking.
    - What happens to me is my own doing.

Health Measure Locus of Control

1. If I am going to be sick, I will get sick regardless of what I do.
    - Strongly disagree
    - Moderately disagree
    - Disagree
    - Agree
    - Moderately agree
    - Strongly agree

2. Taking preventative measures, such as vaccinating, can keep me and my family healthy.
    - Strongly disagree
    - Moderately disagree
    - Disagree
    - Agree
    - Moderately agree
    - Strongly agree

3. My good health is a largely a matter of good fortune.

- Strongly disagree
- Moderately disagree
- Disagree
- Agree
- Moderately agree
- Strongly agree

4. Even when I take care of myself, it's easy to get sick.
    - Strongly disagree
    - Moderately disagree
    - Disagree
    - Agree
    - Moderately agree
    - Strongly agree

5. Even if I try to protect my health, I still get sick if others around me do not protect themselves.
    - Strongly disagree
    - Moderately disagree
    - Disagree
    - Agree
    - Moderately agree
    - Strongly agree

6. When I don't feel well, health professionals can always help me.
    - Strongly disagree
    - Moderately disagree

- Disagree
- Agree
- Moderately agree
- Strongly agree

7. To improve my family's happiness, I need to prioritize the health of my family.
    - Strongly disagree
    - Moderately disagree
    - Disagree
    - Agree
    - Moderately agree
    - Strongly agree
8. There is nothing I can do to protect myself and my family from rabies.
    - Strongly disagree
    - Moderately disagree
    - Disagree
    - Agree
    - Moderately agree
    - Strongly agree
9. Vaccinating my dogs against rabies does not protect my family members from rabies.
    - Strongly disagree
    - Moderately disagree
    - Disagree

- Agree
- Moderately agree
- Strongly agree

10. My family is protected against rabies only if many people in the village vaccinate their dogs against rabies.
    - Strongly disagree
    - Moderately disagree
    - Disagree
    - Agree
    - Moderately agree
    - Strongly agree

Intervention-related questions

1. Does at least one member of the household own a mobile phone?
    - Yes
    - No
2. How often do you check your phone for text messages?
    - Texts are read as soon as notification is received
    - Daily
    - Weekly
    - Other..............................times/week
3. Have you ever received information about community-based activities through text messaging?
    - Yes
    - No

4. Have you ever received information about commercial deals through text messaging?
    - Yes
    - No
5. Do you normally pay attention to all information you receive through text messaging?
    - Yes
    - No
    - Only some
6. If only some, what type of information do you pay attention to? Choose all that apply:
    - Community-based activities
    - Commercial deals
    - Texts from mobile phone companies
    - Job opportunities
    - Other.............................
7. What do you use your mobile phone for? Choose all that apply:
    - Communication through phone calls and text messaging
    - Social media
    - Mobile banking
    - Other.......................
8. For the type of information that you pay attention to, on a scale from 1 to 10, how much do you trust the information you receive through text messages? .... (1 - I do not trust any information in the text messages,

10 - I trust that the information in the text messages are completely accurate).

9. What is the main religion of this household?

    - Christianity
    - Muslim
    - Traditional Religions
    - Other ....

10. Do you regularly attend religious meetings?

    - Yes
    - No

11. Do you usually seek advice from your religious leaders?

    - Yes
    - No

12. If Yes, what kind of advice do you seek from them? Choose all that apply:

    - Health advice
    - Financial advice
    - Spiritual advice
    - Children education
    - Other.....................

13. On a scale from 1 to 10, how much does the opinion or advice of your religious leader influence your action?..................................... (1 – their opinion/advice is not part of my consideration, 10 – I follow whatever they advise)

4.6.6 Tables Summarising the Number of Interviewees Exposed to Different Information Sources

Number *(percentage)* of interviewees by experimental group and awareness methods	Experimental Groups				Total
	Routine advertising only	Routine advertising plus religious/tribal leaders only	Routine advertising plus text messaging only	Routine advertising plus both interventions	
Awareness methods:					
Text messaging only	N/A	N/A	11	2	13 *(1.12%)*
Religious/Tribal leaders only	N/A	1	N/A	2	3 *(0.27%)*
Routine advertising only	68	52	42	52	214 *(19.21%)*
Other villagers only	131	127	119	118	495 *(44.43%)*
Text messaging plus religious/tribal leaders only	N/A	N/A	N/A	1	1 *(0.09%)*
Text messaging plus routine advertising only	N/A	N/A	21	18	39 *(3.50%)*
Text messaging plus other villagers only	N/A	N/A	41	16	57 *(5.12%)*
Religious/tribal leaders plus routine advertising only	N/A	4	N/A	0	4 *(0.36%)*
Religious/tribal leaders plus other villagers only	N/A	2	N/A	2	4 *(0.36%)*
Routine advertising plus other villagers only	35	41	27	31	134 *(12.03%)*
Text messaging plus routine advertising and other villagers only	N/A	N/A	2	7	9 *(0.81%)*
Religious/tribal leaders plus routine advertising and other villagers only	N/A	5	N/A	1	6 *(0.54%)*
Both advertising interventions plus routine advertising only	N/A	N/A	N/A	0	0 *(0%)*
Both advertising interventions plus other villagers only	N/A	N/A	N/A	0	0 *(0%)*
All methods only	N/A	N/A	N/A	1	1 *(0.09%)*
Not aware of the campaigns or not exposed to any advertising	46	44	15	29	134 *(12.03%)*
Total	280	276	278	280	1,114

Table 4.4: Number of interviewees exposed to different advertising methods based on household questionnaire

Number *(percentage)* of interviewees exposed to different advertising methods by experimental group	Experimental Groups				Total
	Routine advertising only	Routine advertising plus religious/tribal leaders only	Routine advertising plus text messaging only	Routine advertising plus both interventions	
Awareness methods:					
Text messaging only	N/A	N/A	66	21	87 *(9.81%)*
Religious/Tribal leaders only	N/A	12	N/A	1	13 *(1.47%)*
Routine advertising only	117	59	54	39	269 *(30.32%)*
Other villagers only	81	42	79	50	252 *(28.41%)*
Text messaging plus religious/tribal leaders only	N/A	N/A	N/A	3	3 *(0.34%)*
Text messaging plus routine advertising only	N/A	N/A	19	15	34 *(3.83%)*
Text messaging plus other villagers only	N/A	N/A	16	13	29 *(3.27%)*
Religious/tribal leaders plus routine advertising only	N/A	24	N/A	4	28 *(3.16%)*
Religious/tribal leaders plus other villagers only	N/A	7	N/A	5	12 *(1.35%)*
Routine advertising plus other villagers only	52	13	28	7	100 *(11.27%)*
Text messaging plus routine advertising and other villagers only	N/A	N/A	16	9	25 *(2.82%)*
Religious/tribal leaders plus routine advertising and other villagers only	N/A	11	N/A	12	23 *(2.59%)*
Both advertising interventions plus routine advertising only	N/A	N/A	N/A	7	7 *(0.79%)*
Both advertising interventions plus other villagers only	N/A	N/A	N/A	2	2 *(0.23%)*
All methods only	N/A	N/A	N/A	3	3 *(0.34%)*
Total	250	168	278	191	887

Table 4.5: Number of interviewees exposed to different advertising methods based on vaccination point questionnaire

4.6.7 Cash Experiment

The design of the cash experiment was as follows. 20 participants in each village were selected to represent their respective villages. Each participant was given 5,000 Tanzanian Shillings (TZS) (equivalent to approximately 1.68 GBP at the time of the experiment). They were then given the choice to either keep the 5,000 TZS (not participate in "collective action") or return it (participate in "collective action"). If at least 14 of the participants in the same village return the 5,000 TZS then all participants in that village receive 20,000 TZS, regardless of whether they returned the 5,000 TZS in the first place or not. Specifically, participants who returned the 5,000 TZS would end up with 20,000 TZS if at least 13 other participants in the village also return the 5,000 TZS cash, and those who did not return the cash would end up with 25,000 TZS. If less than 14 of the participants in the village returned the cash, then those who returned the cash would end up with nothing, while those who did not return the cash could keep the 5,000 TZS. Each village's measurement of its willingness to participate in collective action is the fraction of participants that returned the 5,000 TZS cash. A village is described as successful in the cash experiment if 14 participants return the cash, or fail otherwise. The amount of cash used was consulted with local researchers and was deemed appropriate and sufficient for the purpose of the experiment.

On the day of the administration of the household questionnaires and the cash experiment, a team of two interviewers were asked to administer the household questionnaires and the cash experiment in each village. Each interviewer visited 10 households individually accompanied by a village leader (or his/her representative) whose role was to observe the interviewing process and to introduce the research team to the households. Before administering the questionnaires, participants were given full information about the household questionnaire and the cash experiment. Only those who agreed to participate in both activities were allowed to participate. Those who did not agree to either of the two activities or both, were not allowed to participate. However, those who had agreed to participate, but then changed their mind, were allowed to withdraw if they wished to.

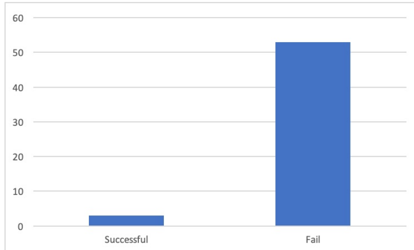


Figure 4.4: Number of villages succeeding or failing in the cash experiment

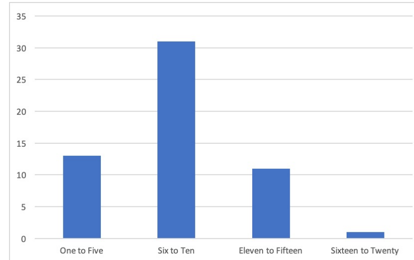


Figure 4.5: Number of villages by number of participants returning the 5,000 TZS cash

At the interviews, the order of the activities were as follows. After being briefed and agreeing to participate in the activities, the participants were given 5,000 TZS in cash. Following this, the participants completed the household questionnaires and were then given a few minutes to decide whether they wished to return the cash or not to the interviewer.

After each interview is completed, the interviewers moved to the next randomly selected households until they had collected data from 20 households in a village. The interviewers then summed up the number of participants who returned the cash. If at least 14 participants returned the cash, then the interviewers would revisit the respective households that they interviewed with the 20,000 TZS cash on the same day, immediately after the activities concluded. If less than 14 participants returned the cash, the interviewers would phone or text each household informing them that they would not be receiving the 20,000 TZS. Figure 4.4 shows that only three villages were successful in the cash experiment. Two of those villages had 15 participants returning the 5,000 TZS cash and the other village had 16. Figure 4.5 sorts the villages by the number of participants returning the cash. Most of the villages (31) had between six to ten participants returning the cash. The next smaller group (13 villages) is those with one to five participants returning the cash, followed by

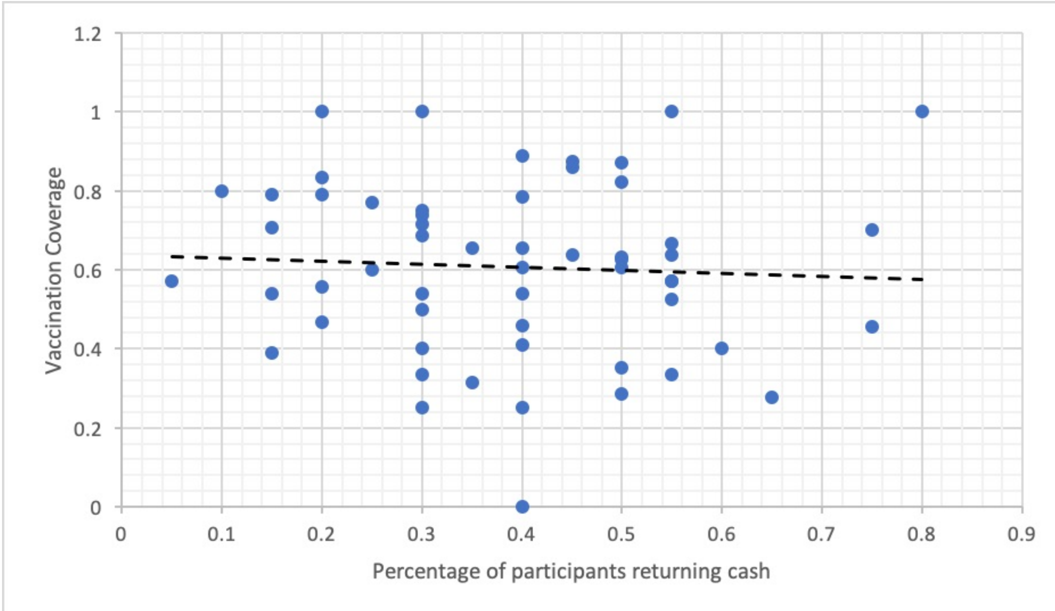


Figure 4.6: Scatter plot: Number of participants and vaccination coverage

the group with eleven to fifteen (11 villages, of which only two were successful). Only one village had 16 participants returning the cash.

Since we used the result of the cash experiment as a proxy for a village's underlying willingness to participate in rabies vaccination campaigns, we made a comparison between the result of the experiment and vaccination coverage, which is a proxy for participation. Figure 4.6 shows a scatter plot between the number of participants returning the cash and vaccination coverage. Each data point on the scatter plot represents a village. The fitted line shows a negative but insignificant relationship. This suggests that there is no noticeable correlation between the number of participants returning the cash in the cash experiment and vaccination coverage.

Chapter 5

Conclusion

In this thesis, the key objective was to design policies that can help increase participation in rabies vaccination campaigns. In trying to understand the cause for the lack of participation in rabies vaccination campaigns, I looked at this problem as a public good production problem. Therefore, I started by studying two different public good production games. Results from these models indicated that effective policies need to be able to overcome collective action problem and effective policies may vary between different public goods with different structural factors (in Chapter 3, I looked at the shape of the public good's production as a structural factor). I then discussed a field experiment which tested the effect of two advertising interventions, the use of mobile phone text messaging and religious/tribal leaders, in raising participation in rabies vaccination campaigns. There was no evidence that each of the interventions on their own were effective in raising participation in the vaccination campaigns, but there was evidence that the interventions had a positive effect when used together. There was also some suggestive evidence that measures that were used to ease participation in the vaccination campaigns could have a significant and positive impact.

There are several lessons to be learned in the context of rabies control in Tanzania and in the context of the general public good production problem. In the context of rabies control in Tanzania, we learned that the key impediment to participation in rabies vaccination campaigns in Tanzania is the cost of participation incurred by participants. This could be seen in the results of the field experiment which suggested that advertising interventions may have had a much smaller impact on participation than operational changes eased participation of the villagers. This suggests that an effective vaccination campaigns should make it less costly for villagers to participate. However, this recommendation may differ for other parts of the world, which face different reasons for low participation.

In the context of the general public good production, this study suggests that context matters in policy-design. There can be different underlying reasons for the failure to produce a public good. These include, for example, the lack of awareness, the inability of a community to coordinate in collective action or both. The first step that a policy-maker should take in policy-design is to identify all underlying reasons behind any low participation in public good production. The second step would be to design a set of policies which are tailored to address those problems and the structural factors of the public good.

There are several weaknesses that should be mentioned in this study. Firstly, although the theoretical models in both Chapter 2 and Chapter 3 provide some useful insights, they are quite simple and they did not capture some of the structural factors of public goods that are relevant in rabies control in Tanzania. Secondly, reliable village-level data was lacking in the field experiment. This meant that the identification of the effect of the interventions could have been improved if we had data on village-level variables that could be used as control variables. The lack of village-level data also meant that we could at most obtain a suggestive instead of a conclusive evidence of the effect of the operational changes. This leads to the third weakness, which was that the design of the experiment was not able to overcome problems associated with the lack of village-level variables. A difference-in-difference experimental design would have been a much better design that would not require access to the village-level variables, but the design would have required more time and other resources.

These weaknesses mean that the theoretical models and the field experiment should be explored even further. The theoretical models could be extended to take into account more structural factors (discussed in Chapter 3) that could impact participation in public good production. This can further help in the understanding of specific public goods and in the design of policies that can be tailored for each type of public goods. In terms of the field experiment, further improvements could be made to the design of the experiment to better isolate the effect of the interventions we were interested in. Firstly, a difference-in-difference experimental design could have improved the results of the experiment as discussed above. Otherwise, additional reliable dataset on key village-level variables are needed. The effect of the operational changes and other related measures should be studied under a clearer framework so that a more conclusive evidence could be obtained.

As discussed throughout this thesis, public good production is crucial in improving the livelihood of many, especially in marginalised communities. This thesis has tried to understand some underlying reasons behind why there is low voluntary participation in public good production and it has provided some useful insights in terms of policy-design. There are many more factors that influence the success of public good production and have not been explored by this thesis, nor by the larger literature. It is encouraged that more effort should be put into studying driving factors that influence the production of different types of public good so that there is a deeper understanding in what drives the success of public good production and how to design effective policies that are tailored for each types of public good.

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