A Cost-Benefit Analysis of Foot and Mouth Disease Control Program for Smallholder Cattle Farmers in Cambodia

Running head: Cost-benefit of Foot and mouth disease control

S. Sieng[1], I. W. Patrick[2,3], S.W. Walkden-Brown[4], C. Sar[5]

[1] General Directorate of Animal Health and Production, Ministry of Agriculture, Forestry and Fisheries, Phnom Penh, Cambodia

[2] University of Liverpool, UK

[3] ARECS P/L, Armidale, NSW, Australia

[4]Animal Science, School of Environmental and Rural Science, University of New England, Armidale, NSW, Australia

[5]Ministry of Agriculture, Forestry and Fisheries, Phnom Penh, Cambodia

Correspondence:

S. Sieng, General Directorate of Animal Health and Production, Phnom Penh, Cambodia.

Tel: +855 89908917 or +61 401512627; s.socheat2010@gmail.com

Summary

The Cambodian government is attempting to mobilise government, donor and private sector funding to implement a coordinated FMD vaccination program (FMDVP). A necessary first step is to convince the farmers of the benefits of participating in and potentially financially supporting this program. Information was collected from 300 farmers in order to estimate the on-farm benefits and costs of their participation in an FMDVP. Implementing a successful vaccination program is difficult, and farmers understand from previous experience that there may be institutional, social, technical and financial constraints which limit its success. A benefit-cost analysis needs to take into account that outbreaks do not occur every year, not all cattle will be successfully vaccinated, not all sick animals successfully treated and sometimes sick animals simply sold. This study sensitises these variables in order to give a realistic estimation of the farmer participation benefits in an FMDVP. A general result is that it is worthwhile for farmers to participate in the FMDVP if

there are average annual outbreaks, or at least two major outbreaks, in the ensuing five years. However, the results are influenced by the interaction of vaccination success and treatment success and coverage. Ineffective coverage and poor treatment of sick animals reduce the benefits of an FMDVP. It is also important that farmers do not sell sick stock and, if they do, that they are able to breed replacements rather than purchase replacements. There are many factors in the smallholder cattle farming system that will influence the success of an FMDVP; farmers will only choose to participate if they can be convinced of the short and long-term economic benefits.

Key Words: Foot and mouth disease; smallholder farmer; cattle; benefit-cost analysis; FMD vaccination

1 Introduction

1.1 FMD and FMD control in Cambodia

Foot-and-Mouth Disease (FMD) is a highly contagious disease (OIE-FAO, 2013) of wild and domestic cloven-hoofed animals as well as domestic animals such as cattle, buffalo, sheep, pigs, and goats (Alexandersen & Mowat, 2005; Eblé et al., 2004). It also affects 70 species of wild animals within 20 families of mammals (Hedger, 1981). The FMD virus (FMDV) causes acute symptoms such as fever, intense salivation, lameness and vesicular lesions of the feet, tongue, snout and teats (Arzt, Juleff, Zhang, & Rodriguez, 2011; Grubman & Baxt, 2004; Pinto, 2004). Pinto (2004) states that the severity of the disease varies between animal species, and it depends on the dose and strain of virus and susceptibility and the general health of the host. Doel (1994) has stated that it is not the most contagious disease known. The seven immunological types of the virus are the A, C, O, Asia 1, and South African Territories types SAT-1, SAT-2, and SAT-3 (Bachrach, 1968).

Davies (2002) identified several factors contributing to the rapid spread of FMD. These included the short incubation period, long infectious period and quantity of virus particles expelled, the spread of the virus by aerosol, the survival of the virus in fomites, persistence of the virus in carcasses, existence of carriers and density of the host population.

Alexandersen et al. (2003b) identified that the incubation period of FMD can be as short as one day, depending on the degree of contact. A study by Garland & Donaldson (1990) found that the incubation period from infection to clinical signs can be as short as two days or as long as 14 days while under experimental conditions.

Due to the longer virus survival rates in the temperate areas, indirect transmission through fomites may be as important as direct contact between infected and susceptible animals. Under tropical conditions, the movement of potentially infected animals and livestock trading patterns are the main factors influencing the spread of FMD (Geering & Lubroth, 2002; Gleeson & Ozawa, 2002; Hueston, Travis, & van Klink, 2011).

FMD is endemic in Cambodia, with regular outbreaks causing significant losses to smallholder farmers. FMD control in Cambodia relies on ring vaccination around outbreaks. The approach taken is varied to suit local circumstances, such as the availability of funds and vaccines for the implementation of a vaccination program regardless of the time of vaccination. The results from a study by Sieng & Kerr (2013) in one Cambodian province indicated that more than half of cattle vaccinated with donated FMD vaccines subsequently became infected with FMD virus and showed clinical signs of FMD indicating possible vaccine failure. Poor planning and execution of the vaccination program, vaccine cold chain breakdown and poor vaccination technique could be important reasons for such results.

1.2 Estimating the economic loss of FMD

Direct losses are incurred through increased mortality rates in young animals, the poor performance of infected animals such as low milk yield and live weight gain, lower fertility and poor feed conversion (James & Rushton, 2002; Morris, Sanson, Stern, Stevenson, & Wilesmith, 2002; Otte & Chilonda, 2000; Rushton & Knight-Jones, 2013). The imposition of animal and animal product trade restrictions, reductions in tourism-related activities and the cost of eradication and control programs are some of the indirect losses due to FMD (Garner, Baldock, Gleeson, & Cannon, 1997; Otte & Chilonda, 2000; Rweyemamu & Astudillo, 2002). Studies in Cambodia have estimated that during FMD outbreaks, reductions in livestock value of between 54% and 92% have led to reductions in smallholder farmer household annual income of 4% to 12% (Shankar, Morzaria, Fiorucci, & Hak, 2012; Young, Suon, Andrews, Henry, & Windsor, 2012). Young et al. (2012) estimated that the impact per affected animal varied from US$216, caused by weight loss and paying for treatment, to US$371 if the animal was treated but still died. Studies in Lao PDR estimated financial losses due to FMD per household of between US$381 and US$1,124, or 16% to 60% of the annual household income. This loss was mainly due to reductions of 32% to 37% (Nampanya et al., 2013) and 22% to 30% (Rast, Windsor, & Khounsy, 2010) in sale price. Annual losses of US$25 per cow per year due to FMD were identified in South Sudan (Barasa et al., 2008), while a study in Turkey reported that the direct costs ranged from US$152 per affected dairy heifer to US$294 per an affected lactating dairy cow (Senturk & Yalcin, 2008). The milk production losses over 60 days due to an FMD outbreak in Pakistan were valued at US$100 per lactating cow (Ferrari, Tasciotti, Khan, & Kiani, 2014). The economic loss due to FMD ranged between US$76 (US$9.8 per head) to US$174 (US$5.3 per head) in a crop-livestock mix and a pastoral system in Ethiopia, respectively (Jemberu, Mourits, Woldehanna, & Hogeveen, 2014). Rast et al. (2010) found in Lao PDR that the losses due to FMD ranged between US$52-US$60 per animal if a sick animal is sold and US$62-US$71 per animal if retained and fed in a village where cattle are not vaccinated. The losses were much lower in a village where all cattle were vaccinated. In Southern Cambodia, a study estimated average benefits of US$31.50 per animal to smallholder farmers if they invested in biannual FMD vaccination (Young et al., 2012). A benefit-cost analysis (BCA) of a 5-year biannual FMDVP calculated a benefit-cost ratio (BCR) of 1.4:1 based on 2014 livestock prices and an expected annual incidence of 0.2 (Young et al., 2014). Nampanya et al. (2015) estimated the BCR of the FMD vaccination in northern Lao PDR at 5.3:1. Another study in Lao PDR highlighted the average net benefit to large ruminant smallholder farmers of US$22 for cattle and US$33 for buffalo, based on a biannual FMD vaccination (Nampanya et al., 2013). A study in South Sudan reported that the BCR of the FMD vaccination was 11.5:1, this compared to 2.9:1 when the prevalence and mortality of FMD were reduced by 75% (Barasa et al., 2008).

Throughout South East Asia, infections with gastrointestinal nematodes and trematodes are very common in cattle due to the appropriate climatic conditions for the development and transmission of the infective stages. Dorny et al. (2011) studied the prevalence and seasonal variations of helminth infections and their association with morbidity parameters in traditionally cattle husbandry in Cambodia. They found that all types and ages of cattle tested positive for gastrointestinal nematodes. A low body condition score was found to be associated with gastrointestinal nematode and liver fluke infections, and soft faecal consistency with Paramphistomum infections. In this present study, the assumption was made that de-worming and smallholder farmer training on animal husbandry and disease prevention would help to improve the condition of cattle compared to smallholder farmers who did not. As the Cambodian government routinely includes cattle de-worming and farmer cattle management training in their FMDVP, these costs and benefits were also included in this study.

1.3 Study Objective

It is difficult to estimate the economic impact of FMD on smallholders due to the lack of sufficient economic data maintained by smallholders (Perry et al., 1999). The losses to smallholder farmers due to FMD in Cambodia have not yet been adequately defined, and it is not clear whether or not FMDVP, which includes infrastructure development, farmer training, and de-worming, provides net benefits to the smallholder farmers using current animal husbandry and marketing systems. Therefore, estimating the benefits and costs of a FMDVP may assist smallholder farmers, and those who provide services and advice to the livestock sector, make more informed decisions regarding FMD prevention. This analysis uses and builds on the information collected through a smallholder farmer survey (SFS) and is a first attempt at identifying and varying the key variables that influence the economic success of a FMDVP. These variables include the expected success rate of the FMD vaccination, the proportion of the sick animals treated, and the proportion of treated animals that are still sold sick. This study assesses whether or not implementing an FMDVP is beneficial to smallholder cattle producers.

2 Methodology

2.1 Study areas and sampling of respondents

A smallholder farmer survey was conducted in the Cambodian provinces of Kampong Cham (KC) and Pursat (PS). There was one district in KC and two districts in PS selected by the staff of the ACIAR project AH/2010/046 and partners from the Provincial Office of Animal Health and Production (POAHP). In each province, there were five villages selected to participate in the survey. Thirty smallholders in each study village were selected based on the number of cattle owned and their willingness to participate in the study.

2.2 Data collection

Trained enumerators used semi-structured questionnaires to collect qualitative and quantitative data. The questionnaires collected data on the general background of the farm and smallholder farmer, livestock information (e.g. the number of animals, husbandry and feeding practices), household incomes, knowledge and experience with FMD (vaccination, morbidity, and mortality), and financial information including the perceived and actual losses caused by FMD infection in the last three years. Each household head was interviewed individually in the local language (Khmer). Government officials from the DAHP, POAHP, and District Office of Animal Health and Production (DOAHP) were excluded from these interviews to ensure confidentiality and encourage honest responses. All respondents who had experienced FMD during the previous three years (2011-2013) were asked additional questions related to their experience of the disease. The additional questions elicited information regarding the morbidity and mortality rate of cattle, estimated costs of treatment, labour required to nurse infected animals, the cost of draught replacement, percentage of farmers who sold infected cattle, and the cost of the FMDVP.

2.3 Data management and analysis

The financial data were collected in Khmer Riel (KHR) converted to US Dollars and entered into a spreadsheet (Microsoft office 2010). The data were used to construct gross margins (GMs) for cattle herds that have participated in the FMDVP and compare them with GMs from cattle that did not participate. Using Benefit-Cost Analysis (BCA), the study estimated the benefits and costs of a vaccination program over five years and reported these results using Net Present Value (NPV), Benefit Cost Ratio (BCR), and Internal Rate of Return (IRR). The variables that are important in influencing the results were identified, and detailed sensitivity analysis undertaken. Further modelling which varied the most critical factors influencing the GMs, provided further information about the sensitivity of the results. Table 1 shows all key input values used to construct GMs, BCA, NPV, BCR, and IRR.

>Insert Table 1<

3 Results

3.1 Gross margins

GMs have been constructed to represent the realistic choices that farmers can make under the threat of an FMD outbreak. Farmers can either participate in the FMDVP or not, and there can be either an outbreak (FMDYes) or not (FMDNo). Under the basic assumptions of the analysis, the GMs for the VaccYes are the same whether or not there is an outbreak as the starting assumption is that vaccination is 100% effective; hence only one GM needs to be presented for the VaccYes option (Table 2). The results show that the higher GM (US$127) is for the no vaccination and no FMD outbreak (VaccNo FMDNo) scenario as there is no loss of income from disease and no FMDVP costs. This scenario also assumes that sale cattle obtain the same price as vaccinated cattle as they are free of FMD. If regular outbreaks of FMD occur during the five years causing average production impacts, the average annual GM will decrease from US$127/cow to US$95/cow if cattle are not vaccinated. This loss is made up of reductions in value and quantity of sale stock, as well as the nursing and treatment costs required for the cattle to regain the pre-FMD live weights. On the other hand, VaccYes would expect an average annual GM of US$144 irrespective of if there is an outbreak or not during the five years. Even though the farmer incurs vaccination program participation costs, this GM is higher than the other GMs as participation in the program also includes participating in cattle management training and a livestock deworming program that will improve productivity (Table 2). This initial analysis indicates that with or without FMD outbreaks and a vaccination program that is 100% effective, it is worthwhile for farmers to participate in the FMDVP. If a farmer is not involved in an FMDVP and suffers average losses, the farmer will lose US$32/head per year. There are, of course, other variables that may influence the economic viability of the program.

>Insert Table 2<

Additional gross margins have been constructed to represent different disease scenarios. Instead of assuming average annual outbreaks, it may be useful to consider the scenarios of either 1 or 2 major FMD outbreaks with morbidity rates of either 50% or 75% over the 5 years. The mortality rate remained the same. As with the initial analysis, when herds are vaccinated, the nature of the disease outbreak is irrelevant; the baseline GM remains the same. Likewise, without participation in the FMDVP, the nature of the disease outbreak is also irrelevant if there was no disease outbreak. However, if there are one or two major FMD outbreaks, the average annual GM of herds who had not been vaccinated would be significantly reduced (Table 3). With a morbidity rate of 50%, the GM would be reduced to US$78/cow, and with a higher morbidity rate (75%), the GM would be further reduced to US$55/cow. This loss is made up of reductions in the value and quantity of cattle sold as well as the nursing and treatment costs of infected stock. Compared to herds that vaccinate, these are 46% and 62% reductions in GM.

>Insert Table 3<

3.2 Benefit-cost analysis

The BCA builds on the results and discussion provided in the GM section above. BCA is required as GM only includes the annual variable costs of particular activities. GM analysis does not include the extra overhead costs that may be required to change from one management system to another. In implementing an FMDVP, some additional costs must be included to maximise the chance of success. These costs are for farmer training and the construction of better cattle yards. Training is required to educate farmers on the process of disease transmission and control. An analysis that includes a time factor, in this study 5 years, also allows for analysis of more realistic scenarios. Rather than assuming an average outbreak, this analysis can evaluate the effect of larger outbreaks at different intervals in the upcoming years. The timing of outbreaks may also influence the economic viability of being involved in the FMDVP.

In this initial BCA analysis, it is assumed that vaccinated cattle were 100% protected from FMD. It is estimated that the NPV of the FMDVP with average outbreaks per year was US$109 with a BCR 1:1.16 (Table 4). This indicates that there is a potential economic benefit of US$0.16 per vaccinated cattle for every dollar invested in the FMDVP if average annual FMD outbreaks occurred every year during the 5 years. The estimated IRR (49%) was higher than the discount rate (12%), which indicated that farmers could invest their money in an FMDVP and receive a positive return on their investment. It is not, however, a significant benefit, if farmers are required to pay for their training, they will not breakeven until Year 3.

>Insert Table 4<

The results indicated that if FMD did not occur during the following 5 years, it would not have been beneficial to be involved in the program. The farmer would have accrued increased costs of participating and investing in the program and would have received no extra benefits. The next step was to evaluate the benefits of being in the program under different outbreak scenarios. What if the disease occurred only once in the 5 year time frame or maybe twice? What would happen if outbreaks did not occur in the first few years of the program but did in the later years? The results showed that one significant outbreak (morbidity of 75%) early in the program (year 2) would be close to a breakeven result for the farmer (NPV=US$-2). If there were 2 or more outbreaks with morbidity rates of above 50%, it would be worthwhile for the farmer to participate in the program (Table 4).

3.3 Sensitivity analysis

The sensitivity analysis is undertaken in three parts. The first identifies and discusses the essential variables that will be varied. The second considers the effects of changing the essential variables in isolation of others, and it shows the relative importance of each but does not take into account the fact that the variables may interact with each other. It is also useful to take the third step and consider the effect of a combination of variable changes on the benefits and costs of the FMDVP. The analysis is undertaken concerning the scenarios of the baseline model and major outbreaks with higher morbidity rates during years 1 and 3 of the study period. The baseline analysis assumes that the vaccination program was 100% successful in minimising the effects of an FMD outbreak, all treated cattle recover and return to full production capacity in the ensuing year, and 100% of the cattle that get sick with FMD are treated. In many countries and particularly developing countries, including Cambodia, these are unrealistic assumptions. In order to get a more accurate understanding of the economics of on-farm FMD control, it is necessary to identify the variables that have the most influence on the effectiveness of the FMDVP and then include these in the sensitivity analysis. Five variables that are likely to have influences on the GMs were evaluated.

3.4 Identifying the most important variables

FMDVP costs: The vaccination (US$2.47) and deworming (US$3) costs used in the baseline analysis were estimated by the local experts (POAHP). Previous studies reported lower vaccination costs of US$0.89, US$1.22, and US$2.10 per head (Nampanya et al., 2013; Rast et al., 2010; Young et al., 2012). While the cost of FMD vaccination is unlikely to be higher than the baseline values used in the study, potentially, they could be cheaper. Decreasing vaccination and deworming costs by 25% and 50% were tested and led to increases in GMs for cattle involved in the FMDVP of 4.2% and 9.0%, respectively.

Treatment and nursing costs: The treatment (US$15.10) and nursing (US$25.70) costs used in the baseline analysis were obtained from the SFS. As similar treatment costs were also reported by other studies (Rast et al., 2010; Young et al., 2012), the costs of treatment and nursing are unlikely to be higher than the baseline values used in the study. Reductions in treatment and nursing costs by 25% and 50% were tested, resulting in an increase in GMs for cattle not involved in the FMDVP of 8.4% and 15.7%, respectively.

Vaccination success rate: The initial analysis assumed that all cattle (100%) vaccinated achieved immunity. However, studies (Sieng & Kerr, 2013; Sieng, Walkden-Brown, & Kerr, 2016) have shown that half of FMD vaccinated cattle were still infected with FMD during an outbreak, and vaccines in most study areas had been exposed to temperatures outside the recommended range (2-8°C). Therefore, decreased vaccination success rates of 25%, 50%, and 75% were tested and led to reductions in GMs for vaccinated cattle of 12%, 23%, and 35%, respectively.

Treatment success: The assumption that there were no cattle treated but still sold sick was used in the baseline analysis, implying that all the treated cattle recovered. However, other studies reported that many farmers and livestock traders do sell FMD infected livestock (Kerr, Sieng, & Scoizec, 2012; Sieng, Hawkins, Madin, & Kerr, 2012) and, therefore, increasing the percentage of cattle treated but still sold sick was tested in this study. The results showed that increasing the number of cattle treated but still sold sick by 25%, 50%, and 75% decreased GMs for non-vaccinated cattle by 17%, 32%, and 51%, respectively.

Treatment coverage: In the baseline analysis, the assumption was that 100% of infected cattle were treated by farmers. Similar proportions of sick cattle treated were found during the SFS. However, in some cases, farmers might sell their infected cattle if they believed that the infected cattle were too sick and had little hope of a quick recovery. Therefore, the assumption was relaxed, allowing farmers to sell some or all of their infected cattle. The results showed decreased treatment rates of 25%, 50%, and 75% produced reductions in the GMs of non-vaccinated cattle by 9%, 18%, and 27%, respectively.

3.5 Relaxing the assumptions of the key variables

To get a better understanding of the potential variability of the results to changing conditions and to elicit more realistic results that farmers can relate to, sensitivity analysis was performed. According to the above discussion, the three variables that most influenced the BCA results were; the success of vaccination, treatment success and treatment coverage. When evaluating these 3 variables, 3 alternate disease outbreak scenarios were considered. These were:

1. Average disease outbreaks every year for 5 years (morbidity for calves=32.8%; adults=30.2%)
2. One disease outbreak in year 2 (morbidity for all age group of cattle=50%), no outbreaks in the remaining 4 years
3. Two disease outbreaks in year 1 and 3 (morbidity for all age group of cattle =75%), no outbreaks in the remaining 3 years

3.6 Vaccination success

Figure 1 shows the economic viability of the FMDVP if the success of vaccination is reduced. While the program costs are the same, the reduction in success will reduce the calving rate, live-weight, and price of affected cattle. This still assumes that all sick cattle are treated and will return to full health.

In an average disease outbreak year, without successful vaccination, the GM/cow will be reduced from US$144 to US$77. In this average year scenario, it is worthwhile for a farmer to participate in an FMDVP if there is, at least, an expectation that the vaccination will be successful in 77% of the cattle (Fig. 1). If the vaccine fails to protect any cattle, farmers will suffer a significant loss (NPV=-US$364). Not only would they still need to bear the FMDVP costs, but they would also bear the nursing costs and the costs incurred through productivity losses. When considering other disease scenarios, different results emerge. If there is only one outbreak in Year 2 with a morbidity rate of 50%, participation in the FMDVP would not be viable, even though the vaccination success rate is perfect (NPV=-39). However, with a higher morbidity rate and two significant outbreaks in years 1 and 3, it is only worthwhile for a farmer to be involved in the FMDVP if they can maintain vaccination's success rate above 91%.

>Insert Figure 1<

3.7 Treatment success

Figure 2 shows the effect on economic viability if infected cattle are treated but do not recover and are sold sick. The base assumption is that if cattle are vaccinated, there will be no need for treatment, irrespective of the success of the treatment program. If they choose to treat all infected cattle, the expectation would be that they all recover, this is the base assumption. By relaxing this assumption, farmers are then faced with the option of selling those cattle that have been treated but do not recover at a reduced price. If there are average outbreaks every year and treatment fails completely (NPV=US$969), the farmer not only incurs all the productivity losses and a reduced price for the sale of sick stock but has also incurred significant nursing and treatment costs. Any reductions from complete success (100%) in the treatment program will lead to significant on-farm losses. In this scenario, it is always beneficial for a farmer to participate in the program. However, this is not the case if there is only one significant outbreak during the 5 years. Under this scenario, the FMDVP would be worth doing if at least 84% of the cattle treated recovered (Fig. 2). If treatments were more successful than this, it would be more efficient for the farmer to treat well rather than vaccinate. However, if the farmer could not be sure of a successful treatment program (less than 84% successful), he should be involved in the FMDVP. With higher morbidity rates and 2 significant outbreaks in year 1 and 3, the farmer will always benefit from being in the FMDVP.

>Insert Figure 2<

3.8 Treatment coverage

The decision to treat or sell also has implications for being able to breed replacements or purchase replacements. The current analysis assumes all replacement cows are bred, and it is only when there are not enough replacements available that heifers are purchased. If a farmer sells all the sick cattle at the reduced price and breeds or purchases replacements at the regular cattle market price, the GM will be only US$10 per head compared to US$95 if all sick cattle are treated 100% successfully. When all sick cattle are sold without treatment, there will be a significant loss to the farmer. Participation in the FMDVP, assuming average outbreaks per year, will provide significant benefit (NPV=US$756) to the farmer (Fig.3). This scenario has indicated that the farmer would always benefit by participating in the FMDVP. Under this scenario, it would be worth participating in the FMDVP if less than 73% of the cattle were treated. If coverage was better than this and the treatment program was successful, it would be better for farmers to treat all sick cattle rather than vaccinate. However, with a higher morbidity rate (75%) and two significant outbreaks in years 1 and 3, farmers who vaccinated their cattle would always benefit from the FMDVP (Fig.3).

>Insert Figure 3<

3.9 Varying multiple variables

This section broadens the sensitivity analysis to include the interactions of two variables on the viability of the FMDVP. It uses the same scenarios as in the previous section but examines the relationships between two variables. In reality, it cannot be assumed that vaccination success, treatment success and treatment coverage will be 100%. The following discussion outlines the combined effects of these factors on economic viability.

Varying multiple variables (average annual FMD outbreak):

Combining the effects of vaccination and treatment success (Fig. 4A) and vaccination and treatment coverage (Fig. 4B) assuming average outbreaks for 5 years indicates that participation in the FMDVP will always benefit farmers if the treatment of sick cattle success dropped below 25% (NPV=US$3) and the proportion of sick cattle treated was below 36% (NPV=US$2). This is because of the other non-FMD benefits that were included in the program (e.g., de-worming and training). If the vaccination program fails completely, participating farmers will suffer a significant loss (NPV=-US$364) if all the sick cattle can be successfully treated. Participating farmers would always benefit from the FMDVP irrespective of treatment success or coverage if farmers believed that vaccination would protect at least 77% of their herd during an outbreak.

The fact that the lines in these graphs are not linear is due to the change in cattle replacement requirements in the different scenarios. It is more financially viable for farmers to breed their own replacements. However, when the death or sale of sick breeding cows becomes too high, farmers are then required to purchase replacements, this swing the balance back towards favourable farmer participation in the FMDVP.

>Insert Figure 4A and 4B<

Varying multiple variables (a major FMD outbreak in year 2):

The results of the combined effects of vaccination success with treatment success and treatment coverage with only one outbreak (morbidity rate of 50%) in 5 years indicated that participation would benefit the farmers if they believed that at least 20% of the sick and treated cattle would still be sold sick, or they believed that they would not be able to treat at least 73% of the sick cattle. With only 1 outbreak during the 5 year time frame, there would need to be a good expectation of vaccination success and a lower expectation of treatment success and treatment coverage (Fig. 5A and 5B).

Figure 5B noted that there are benefits to participating in the FMDVP if the vaccination success rate is better than 82% and lower than 50% if there are no sick cattle treated. The reason for this is related to the herd dynamics. While cattle can be sold and replaced from the herd, the benefit from participating declines. However, when more than 50% of the herd is vaccinated without success and sold sick, the farmer must purchase very expensive replacements. Thus, the lower the vaccination success, the more valuable the vaccination program. This result clearly shows the importance of a successful FMDVP and the need for an effective treatment program for sick cattle.

>Insert Figure 5A and 5B<

Varying multiple variables (two major FMD outbreaks in year 1 and 3):

The results of this scenario where there are 2 outbreaks (years 1 and 3 with a morbidity of 75%) during the 5 year period are in between the results of the previous 2 scenarios. Participants would benefit from the FMDVP irrespective of the treatment success program if vaccination protected more than 90% of the cattle. However, if vaccination success decreased to approximately 50%, participation would only be beneficial if treatment was only expected to be successful on 40% of the sick animals. Likewise, if treatment coverage were expected to be 60% or better, at least 70% of the cattle would need to be successfully vaccinated (Fig. 6A and 6B). If vaccination failed to protect any vaccinated cattle, and all sick cattle are treated, and all of them make a full recovery, participants would suffer a significant loss (NPV=-US$990). Alternatively, if the treatment program completely failed or all sick cattle were sold without treatment at a reduced price, farmers would receive a significant benefit (NPV=US$1326 and NPV=1100 respectively), if vaccination did protect all vaccinated cattle.

>Insert Figure 6A and 6B<

4 Discussion

Foot and mouth disease is endemic in Cambodia, with outbreaks nearly every year in the study areas causing significant losses to smallholder farmers. The primary control strategy for FMD is vaccination, and all FMDVPs are provided as subsidised government programs using a limited annual budget and dependent on the continued support of international organisations. Due to the high cost of FMD vaccines, lack of coordination between government and private sectors, and lack of disease knowledge by smallholder farmers, private FMD vaccination services have not existed in the study areas. Mass FMD vaccination programs are not routinely practised and widely adopted. Many farmers in the study areas think FMD is unlikely to occur every year and is not a fatal disease. Therefore, they do not realise the negative financial impacts of FMD and hence do not intend to participate in FMDVPs. The economic analysis described in this study is a significant attempt to determine practical benefits and costs at the household level that assist all stakeholders, including smallholder farmers, to rethink and make more informed decisions regarding their willingness to participate in both FMDVP supported by the veterinary authorities and provided by the private sector.

The results suggest that the control of FMD through farmer participation in FMDVPs in the study areas can be justified if adequately planned and implemented. Previous studies have demonstrated that private vaccination programs provide benefits to livestock owners as well as national economies (Nampanya et al., 2015; Nampanya et al., 2013; Young et al., 2012; Young et al., 2014). GMs identified that a successful FMDVP, average annual FMD outbreaks (baseline model), could provide economic benefits to the smallholder farmers. The baseline GM for vaccinated cattle, whether or not there is a disease outbreak, is higher (US$144) than the GM for non-vaccinated cattle if there is no outbreak (US$127); this is due to the other benefits of the program, e.g. de-worming and management training. Initial GMs indicated that for every dollar invested in the FMDVP, the smallholder farmer would earn a return of US$0.16 per cow. This result is supported by other studies that showed the biannual FMD vaccination is cost-effective (Barasa et al., 2008; Nampanya et al., 2015; Nampanya et al., 2013; Young et al., 2012). It also indicated that if there were average annual FMD outbreaks, participation in the FMDVP would incur 3% higher costs but receive benefits that were increased by 15%. If there were no outbreaks, it would be cost-effective for farmers not to participate in the FMDVP. The practice of selling infected (or even dead) stock is common as poor smallholder farmers often cannot afford the treatment and nursing costs (US$41 per head) required to restore their cattle to full health.

A significant reason for vaccinating may be the high cost of treatment and the on-going risk that stock may not recover and, therefore, will still be sold sick. The reductions in sale price during and post-outbreak indicated that farmers could lose a significant proportion of their income as well as an important household asset. The price of an infected cow could drop to below half that of healthy cattle (USD735). The weight loss due to FMD identified in the farmer survey was approximately 30-40%, and similar weight losses were reported by other studies (Rast et al., 2010; Shankar et al., 2012). Under the assumptions outlined in the earlier sections of this study (e.g. complete vaccination success, and all sick cattle being successfully nursed back to health), if there is no outbreak or only one major outbreak in the 5 years then, it is not worthwhile for smallholder farmers to participate in the FMDVP. If there are average annual outbreaks or at least 2 major outbreaks in the 5 years, then it is worthwhile for smallholder farmers to participate in the FMDVP.

In Cambodia, however, it is unlikely that the assumptions of vaccination success and cattle treatment and recovery will hold. Therefore, this analysis relaxes these assumptions to give a more realistic picture of the economic viability of smallholder farmer participation in the FMDVP. Relaxing individual assumptions under the condition of an average outbreak every year in the 5 years indicated that when vaccination protects less than 77% of the vaccinated cattle and farmers who did not vaccinate adequately treated their sick cattle, it was not worthwhile to be involved in the FMDVP. However, if participating farmers believed that vaccinating would protect all their cattle, farmers would profit from being involved in the program (NPV=US$109) irrespective of the success of the treatment program. The lower the success of treatment for FMD, the more significant the benefits of FMDVP participation. If treatment is not expected to be successful, it would be better for those who do not vaccinate to sell their infected stock rather than retain and feed them and take the loss rather than investing valuable resources in an activity with a limited chance of success and then having to sell them at a reduced price.

The study demonstrated that farmers would not benefit from participating in the FMDVP (NPV=-US$39) if there were only one outbreak in the 5 years with a 50% morbidity rate. In this case, if farmers were confident that their sick cattle treatment and nursing program was going to be effective, then participation in the FMDVP is unlikely to be the best option for them. However, if there were two major FMD outbreaks in the 5 years with a morbidity rate of 75%, smallholder farmers would benefit from a successful FMDVP irrespective of the treatment success and coverage. The economic benefits and losses due to FMDVP participation are influenced not only by the success of the vaccination program but also by the farmers' decision to treat their sick cattle and the treatment and nursing program's success.

In endemic countries, including vaccines during the early stage of the FMD control program should be regarded as a basic first step (Sutmoller, Barteling, Olascoaga, & Sumption, 2003). There is evidence that if FMD vaccination were adequately organised and implemented, the number of infected cattle would be reduced, and there would be financial benefits to smallholder farmers. It suggests that the FMDVP is worth doing in Cambodia as there are no other preventive options that could be better implemented to control the outbreak of FMD. However, there is concern as to whether or not the current FMDVP implemented by the DAHP and POAHP will provide sufficient protection for farmers' vaccinated cattle. If the FMDVP can be improved and veterinary authorities and farmers believe that FMDVP can be successfully implemented, then smallholder farmers should consider biannual FMD vaccination as an important measure to protect their cattle.

These findings must be interpreted with caution. This study does not provide a complete guide to the cost-effectiveness of the FMDVP to smallholder farmers in these two study provinces. However, it does provide some objective information that may assist smallholder farmers and animal health policy makers in their planning and implementation of future FMDVPs supported by the veterinary authorities and the private sector. The economic analysis provides relevant information and evidence that FMDVP could be a good investment for farmers in the study areas. It shows that simply looking at the costs of implementing a vaccination program and the expected improvements in disease control is not sufficient for farmers to realistically make an informed decision with regard to their participation in an FMDVP. Farmers also need to understand the chances of success and, if not successful, the treatment costs and coverage needs. A major reason for poor uptake in

Cambodia may be due to the fact that that farmers have experienced poor results in previous programs and therefore need more information regarding what will happen if vaccination is not completely successful. This study is an initial attempt to realistically consider vaccination and treatment related shortcomings and how these interact and affect a farmer's desire to participate in an FMDVP.

While farmers must decide whether or not they wish to participate in an FMDVP, the government must also consider whether there is sufficient public benefit for them to subsidise the program. Even though the results from this study indicate that an FMDVP can be cost-effective, vaccination alone is probably not enough to ensure FMD control in Cambodia. Vaccination needs to be implemented in association with other FMD control interventions, including restrictions on animal movement (Davies, 2002; Perez, Ward, & Carpenter, 2004; Sutmoller & Casas, 2002), strict zoo-sanitary measures (King, 2001; Laddomada, 2003; Thrusfield et al., 2005), proper surveillance (Bates et al., 2003b) and disease reporting and public awareness. However, many factors could influence the success of the FMDVP. Understanding the history of FMD is required before determining the financial and human resources needed to implement the FMDVP. Appropriate training on the simple preventive measures to mitigate the risks of spreading diseases and the economic costs and benefits of participating in FMDVPs would help improve future vaccination uptake by smallholder farmers and other stakeholders in the communities. .

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Ethics Statement

Statement of human rights: Approval to use the questionnaire was obtained from the University of New England Human Research Ethics Committees (Approval No. HE 13-242, November 19, 2013 – November 19, 2014). Informed consent was obtained from all individual participants included in the study. This article does not contain any studies with animals performed by any of the authors

Conflict of interest statement

The authors declare that they have no conflict of interest.

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