Chapter 2

Theory and Literature Review

A review of existing literature was conducted to identify the critical points of current knowledge including findings as well as theoretical and methodological contributions concerning the investigation of economic decisions and the assessment of zoonoses risk associated with livestock production. It focuses on four main themes: (1) introduction of animal health economics, (2) main contributions of veterinary economists to animal health economics development, (3) understanding zoonoses emergence through EcoHealth-One Health approach, (4) understanding risk assessment and probabilistic risk assessment, and (5) novel application of Bayesian Belief Network Analysis.

2.1 Introduction of Animal Health Economics

2.1.1 What is Economics?

Economic thinking was first used in the context of agriculture efficiency management between 394 and 365 BC (Backhouse, 2002 cited in Rushton 2009). Lionel Robbins defines economics as “the science which studies human behavior as a relationship between ends and scarce means which have alternative uses” (Backhouse, 2002: 3 cited in Rushton, 2009). Likewise, Black and others mentioned that economics is concerned with decisions about how to allocate and use scarce resources, particularly the production, distribution and consumption of commodities (Perry and Randolph, 1999 cited in Black, 2006).

2.1.2 What is Animal Health Economics?

“Animal health economics is a discipline, which does not belong to the core of veterinary science” (Otte and Chilonda, 2000 cited in Ruston, 2009) and is relatively young in relation to other economic disciplines (Rushton, 2009). However, it is becoming more and more important as the assistance for decision making on animal health intervention at all levels (Otte and Chilonda, 2000 cited in Sudan, 2009) attempting to optimize animal health management (Marsh, 1999 cited in Sudan, 2009).

In this field economics is not mainly dealing with money but rather with making rational choices in the allocation of scarce resources for achieving competing goals. With the hypothesis that people make decisions in order to optimize their satisfaction, utility or pleasure, some of these decisions have led to unintended consequences such as zoonoses emergence (Black, 2006). When outbreaks occur, scarce resources are used to care for both animals and humans that are sick and to prevent or control the transmission of infection. Productive capacity is constrained and trading relationships are disrupted by infection. Besides, there are likely to be missing markets for infection control caused by many reasons such as externalities, public goods, uncertainty and equity (Roberts, 2006, Ch.1: 12). As a consequence, infection poses a huge economic problem that needs to be addressed. The characteristics of zoonotic infectious diseases raise issues for economists seeking to apply their tools in this area.

2.1.3 How is Economics Useful in Controlling Zoonoses Associated with Livestock Production?

Evaluating interventions or controls is a central task for economists to contribute to the adoption of efficient policies to control infection (Roberts, 2006, Ch. 1: 8). Furthermore, economic instruments are becoming more and more important as the aids to understand behavior and decision-making processes, especially of small-scale farmers in animal health management (Chilonda and Huylenbroeck, 2001).

Economic analysis of the optimal control of zoonoses associated with livestock production is complex as it depends on the nature of occurrence, transmission, and circulation of the diseases. It takes account of the benefits and costs of controlling diseases in monetary terms. Consequently, information from both economists and non-economists is important for this economic analysis (Tisdell, 2006).

Economic approaches to infectious disease are embedded in many areas of work nowadays and cannot be ignored. The National Institute for Clinical Excellence in the United Kingdom, for instance now requires economic assessments included in guidelines for interventions. Specifications for grants to assess interventions used to prevent or control infections now often include economic assessments (Roberts, Ch. 2006, Ch.13: 237-240). Even though this was unpopular with the pure economist it is an innovative way of utilizing economics in explaining a complex, real-world problem.

2.2 Main Contributions of Veterinary Economists to Animal Health Economics Development (Rushton, 2009)

Recent studies show that the emphasis of most of veterinary economists is usually on the economics of production disease (diseases induced by management practices) and in the evaluation of zoonoses intervention and control efforts. Peter Ellis is considered one of the leading veterinary economists (Dijkhuizen and Morris, 1997 cited in Rushton, 2009). In 1970, he was the first to apply cost-benefit analysis techniques to an animal disease, specifically for the analysis of classical swine fever (CSF) eradication in the UK. Furthermore, Roger Morris and Ellis had been working together on the various aspects of veterinary economics with particular emphasis on production disease and the evaluation of zoonoses control. In addition, in 1977, an interdisciplinary team designated as VEERU (Veterinary Epidemiology and Economics Research Unit) was established in the Department of Agriculture at the University of Reading in England. The early contributors to this group included economists, veterinarians, farm management experts, statisticians, and animal production experts. Their major contributions were in the early use in scientific studies of cost-benefit analysis techniques, herd models (CLIPPER and LPEC), herd monitoring systems (DAISY, EVA, MONTY, INTERHERD), promoting the use of economic techniques in planning processes, and examining economic impact across different levels of society.

VEERU aimed at developing teams through collaborative projects in various countries and building training schemes for management of veterinary and livestock services. These initiatives have been supported by Office of Development

Assistance of OECD, German Aid, Danish Aid, the British Council, FAO, World Organization of Animal Health (OIE) The World Bank and many other agencies (Rushton, 2009).

Likewise, Tisdell (1995) and Harrison (1996) also investigated the application of cost-benefit analysis for evaluating animal disease programs. These economists examined how animal health programs can aid sustainable development (Harrison and Tisdell, 1997 cited in Rushton, 2009) in Thailand.

Furthermore, Perry at the International livestock Research Institute (ILRI) is one of the world's most noticeable epidemiologists specialized in a range of diseases. She concentrates on a number of important themes in animal health economics, including farm-level economic evaluations, trade implications of sanitary requirements and veterinary service delivery (Perry, 1999 cited in Rushton, 2009).

Additionally, many of veterinary economists such as Ramsay, Tisdell and Harrison (1997) have concentrated on how better information communication for animal health could enhance decision-making. Their findings demonstrate that for endemic diseases there are two options: do nothing or eradication (Harrison et al., 1999; Tisdell, et al., 1999 cited in Rushton, 2009). Another pioneer in the field Richard Bennett initially worked on the advantages of information communication on animal health decisions (Bennett, 1991 cited in Rushton, 2009) and on decision-making for leptospirosis control in cattle (Bennett, 1993 cited in Rushton, 2009). This and other work by him and his colleagues is specifically in the field of animal welfare economics (Bennett, 1995, 1998; Bennett and Larson, 1996; Blaney and Bennett, 1997; Anderson et al., 1999 cited in Rushton, 2009).

Some veterinary economists have been working on the development of economic analysis techniques in the study of diseases and their control. Tim Carpenter was the first to examine the use of various economic analysis techniques such as decision tree analysis (Carpenter and Norman, 1983; Carpenter et al., 1987; Ruegg and Carpenter, 1989; Rodrigues et al., 1990 cited in Rushton, 2009), microeconomics analysis of disease (Carpenter, 1983 cited in Rushton, 2009), simulation models to assess animal disease (Carpenter and Thieme, 1980 cited in Rushton, 2009), dynamic programming (Carpenter and Howitt, 1988 cited in Rushton, 2009), dual estimation approach to derive shadow prices for diseases (Vagsholm et al., 1991 cited in Rushton, 2009), estimation of consumer surplus (Mohammed et al., 1987 cited in Rushton, 2009), willingness to pay for vaccination (Thorburn et al., 1987 cited in Rushton, 2009), linear programming (Carpenter, 1978; Carpenter and Howitt, 1980; Chirstiansen and Carpenter, 1983 cited in Rushton, 2009), use of economic analysis to review subsidies to veterinary support institutions (Carpenter and Howitt, 1982 cited in Rushton, 2009), and the use of the cost-benefit analysis approach for selecting veterinary services (Zessin an Carpenter, 1985 cited in Rushton, 2009)

He also has been involved in economic assessment using more conventional economic instruments such as financial and cost-benefit analysis (Carpenter et al., 1981,1988; Davidson et al., 1981; Kimsey et al., 1985; Miusing et al., 1988; Vagsholm et al., 1988; Sischo et al., 1990 cited in Rushton, 2009). His work has been based on the very detailed knowledge of a production system and the epidemiology of the disease concerned.

Meanwhile Aalt Dijkhuizen at Wageningen Agricultural Univesrity of The Netherlands began researching the use of economic evaluation techniques for animal disease. Dijkhuizen and his team worked on problems including the economics of pig fertility and culling management, cattle problems and diseases, and the economics of Foot and Mouth Disease at a time when Europe was considering changing from a policy of annual vaccination to no vaccination. They also working the problems of a “stamping out policy,” exotic disease risk and the inclusion of risk analysis into economic analysis. Other research conducted by them was on the use of insurance against the outbreak of contagious diseases, and on animal welfare, food safety and animal health economics.

Dijkhuizen utilized animal recording systems such as PORKCHOP and decision support systems such as CHESS in his work. His modeling inputs have assisted decision makers at the farm, national and region levels. His experience has \ benefited from examining a wide range of techniques for the economic evaluation of diseases. His contributions to the field of animal health economic analysis have been significant in directing animal health policies in his own country.

On the theoretical side some veterinary economists such as McInerney and Howe began researching the economics of livestock disease through the development of conceptual models of farmer behavior towards disease (Howe, 1985; McInerney et al., 1992; Howe and Christiansen, 2004 cited in Rushton, 2009). This group is credited as being the first to apply a conceptual framework for economic analysis of disease and its control. However, their influence on the thinking of animal health economics has largely been limited to concepts and theory.

All the above approaches are in the practical field of the economic evaluation of animal disease based on a detailed knowledge of the production system. This research is relatively limited in scope and focused on existing or endemic diseases of interest to the agricultural industry. It is true that they have demonstrated its value in understanding the problem of production disease or the way to maximize utility in this context. However, the field had not yet begun to address the more complex and real-world problem emerging diseases. Here, a more holistic approach such as that advocated by EcoHealth-One Health approaches is required.

2.3 Understanding Zoonoses Emergence through Ecohealth-One Health Approach

Source: Department of Environmental and Global Health, University of Florida, 2012

Figure 2-1: Concept of Ecohealth-One Health Approach

Veterinary medicine appears to have been a distinct discipline during the Zhou Dynasty in China (11-13th century). This period had one of the earliest organizations of a holistic public health system including human and animal health (Driesch and

Peters, 2003 cited in Zinsstag et al., 2010). Later on in the 19th century, based on the discovery of similar disease processes in humans and animals, Rudolf Virchow as a scientist had a strong interest in an interconnection of human and veterinary medicine (Saunders, 2000 cited in Zinsstag et al., 2010). In the 20th century, Calvin Schwabe originated the concept of ‘one medicine’ suggesting that human and veterinary medicine are interconnected and can contribute to the development of each other (Zinsstag et al., 2010). Later on, a broader approach to health and well-being of societies was introduced as ‘one health’. In these years, given the global health thinking, ecosystem approaches to health have emerged. Based on multifaceted thinking that goes beyond humans and animals, these approaches consider as inseparable the interconnection between ecosystems and health.

The idea of ecohealth, a term used as a contraction for “ecology and health” and “ecosystem and human health,” was first popularized internationally by the Canadian government’s International Development Research Centre (IDRC) drawing on Lebel’s (2003) “ecosystem approaches to human health”. As described by Wilcox and colleagues (Wilcox et al., 2012), who are among the founders of ecohealth as an academic field, “the ecosystem approach” in general means applying an understanding of the properties of a whole entity of relevance to the health problem of concern, an infectious disease or otherwise. According to these researchers this includes “contextualizing a problem by situating it geographically and identifying the biophysical as well as socio-cultural and economic conditions and forces contributing to a human or veterinary public health issues.” They point out that the objective is to identify the proximal as well as the distal causative factors and how they interact to, for example, understand a zoonoses outbreak. Thus, they point out that in addition to conducting a routine epidemiological investigation, an ecohealth study would consider all the potentially relevant underlying factors as well as the source or origin of the agent(s) responsible, with the aim of targeting the critical variables that will limit the likelihood of emergence events involving existing disease-causing agents or "new" agents, for example, Highly Pathogenic Avian Influenza (H5N1).

Accordingly, to understand the complexities of causes behind zoonoses emergence, it is important to call for more holistic and comprehensive approaches to analyze and address this real-world problem (McDermott and Grace, 2011). In pointing this out, EcoHealth-One Health approach has emerged to capture the increasing potential risk of zoonoses at local, regional and global scales (AVMA, 2008).

2.4 Understanding Risk Assessment and Probabilistic Risk Assessment

2.4.1 Risk Assessment

Risk is fundamental to any decision making scheme. Risk can be defined as imperfect knowledge for stochastic events where the probabilities of the possible outcomes are known (Hardaker et al., 1997 cited in Kaan, 2000; Siegel and Alwang, 1999 cited in Devereux, 2001). To put it simply, stated in terms of economics, risk is uncertain consequences (Kaan, 2000) resulting in welfare losses (Devereux, 2001). Risk assessment models are important instruments in economic analysis of infectious disease. It has been described as the science of identifying and understanding unwanted events, of estimating the possibility of these events occurring and of the consequences if they do occur (Roberts, 2006: 237). Risk assessments will not be beneficial unless they provide guideline for management.

Managing risk is significant for livestock farming. In agriculture, the sources of risk are various such as a fluctuation of price in market for agricultural products, financial viability, or a diversity of hazards related to weather and diseases. Risk management strategies involve decisions on the farm and the household to find out the amount of outputs to be produced, the allocation of land, the use of inputs, etc. Farmers can manage risk through market tools including insurance. However, not all risks are insurable because of a market failure from information asymmetries. Government can empower farmers to take responsibility for risk management by providing a variety of instruments so that they can choose the best that fits their needs (OECD, 2009).

2.4.2 Probabilistic Risk Assessment

Probabilistic Risk Assessment (PRA) utilizes probability distributions to identify variability or uncertainty in estimations of risk (Mitchell et al., 2004: 1-10). The method has been proved useful in many fields, including animal health (Roberts, 2006: 246). It is excellent tool for estimating the probability of an unwanted event occurring, such as contamination of food with pathogens (Roberts et al., 1995 cited in Roberts, 2006: 246). The output of a PRA is a range or probability distribution of risks experienced by the receptors. The performance of a PRA is limited by the availability of distributional data that sufficiently describe one or more of the input parameters. PRA can provide a quantitative explanation of the degree of variability and uncertainty in risk estimates for unwanted events such as the outbreak of diseases. This can provide a more comprehensive identification of risk, additional information and potential flexibility that affords the risk manager (Mitchell et al., 2004: 1-10). Additionally, the beauty of PRA model is that it can illustrate the risk of trade-offs associated with various interventions. Once the risk trade-offs have been estimated, economic data can be added to estimate the benefits and costs of alternative options (Narrod et al., 1999 cited in Roberts, 2006: 251). Usually PRA models are tackled by a team composed of decision scientists, economists, modelers and subject matter experts such as veterinarians. The team attempts to capture the scenarios that can lead to significant levels of unwanted events such as contamination in model (Roberts, 2006: 246). However, PRA may not be suitable for every analysis since it generally requires more time, resources, and expertise (Mitchell et al., 2004: 1-10).

2.5 Bayesian Belief Network Analysis

2.5.1 Introduction

Bayesian Belief Network (BBN) was invented in the 1940's and 1950's for the purpose of incorporating the effects of uncertainty in management systems for decision making (Henrion et al., 1991 cited in Dambacher et al., 2007). It is a graphical conceptual model that captures the components of analyst's beliefs and probabilistic data in relation to the causal relationships of significant interrelated variables in the system of interest (Dambacher et al., 2007; Wongthanavasu, 2008; Carmona et al., 2011). Both quantitative and qualitative methods are employed in BBN to deliver advanced knowledge-based systems to solve real world problems (Harrison, 1997). The qualitative part represents causality, relevance and relationships between variables, while the quantitative part represents probability distributions that quantify these relationships. Once a complete BBN is constructed it is an efficient instrument for performing inferences (Campos, 2006).

In BBN the nodes represent stochastic variables. Each variable is characterized by states that can be indicated as numerical, ordinal, interval or nominal values (Wongthanavasu, 2008; Carmona et al., 2011). The relationships between the variables in a BBN are strictly acyclic (Dambacher et al., 2007) illustrated by the arcs connecting variables (Suermondt, 1992, p.12 cited in Krieg, 2001). For each variable, a conditional probability table (CPT) has to be defined relying on the available information, including Bayesian or physical probabilities. Bayesian probabilities are derived from prior knowledge including elicited judgment of experts and stakeholders in the form of the subjective estimates, whereas physical probabilities are obtained from available data in terms of statistical and empirical frequencies (Heckerman, 1996 cited in Krieg, 2001; Carmona et al., 2011).

2.5.2 Bayesian Statistics

Bayesian statistics is the probability language applied to BBNs to determine the probabilities of each variable from the predetermined conditional and prior probabilities (Krieg, 2001). Therefore, Bayesian probability is considered one of the evidential probabilities enabling reasoning under uncertainty (Paulos, 2011).

There are three key concepts in Bayesian statistics: a posterior probability, a likelihood function and a priori probability. The a posterior probability of a random event, say parameter θ, is the conditional probability that is assigned after the relevant evidence, say X, is taken into account: $p(\theta|X)$. It is different from the likelihood function, which is the probability of the evidence given the parameters:

$p(X|\theta)$. On the other hand, a priori probability is the probability distribution of the evidence. It is often the subjective assessment of experienced experts, regardless of any other information: $p(\theta)$. Although prior probabilities have been criticized as a source of unwanted bias, they are considered as an integral part of human uncertainty reasoning (Jensen, 1996, p.19 cited in Krieg, 2001).

The posterior probability is defined as;

$$p(\theta|X) = \frac{p(X|\theta)}{p(X)} \cdot p(\theta)$$

The term p(X) is a normalizing factor. Suppose, $X = \{x_1, x_2, x_3, \ldots, x_n\}$

Using the law of total probability,

$$p(X) = p(x_1|\theta)p(x_1) + (x_2|\theta)p(x_2) + p(x_3|\theta)p(x_3) + \ldots + p(x_n|\theta)p(x_n)$$

For discrete distribution, $p(X) = \sum_i^n p(\square_{\square}|\theta)p(\square_{\square})$

For continuous distribution, $p(X) = \int_i^n p(x_i|\theta)p(x_i)di$

(Krieg, 2001; Watthayu and Peng, 2004; Christopher, 2006)

2.5.3 Decision Theory

There are three elements to be considered in decision theory. The first element is actions which are the alternative choices that a decision maker can choose to make. Another element is states which are the uncertainties that the decision maker cannot control. The last element is consequences which are the outcomes of making that particular decision under the uncertainty (Lenk, 2001).

2.5.4 Bayesian Influence

Bayesian inference is a process of drawing conclusions from random events in which Bayesian interpretation is applied to illustrate how a subjective degree of belief should rationally alter the consideration of additional evidence. The advantage of Bayesian inference is that it always yields an accurate answer even when no data are available (de Finetti, 1974; Dawid, 1982; Ferson, 2005). Decision theory and Bayesian inference provide a consistent theoretical framework for decision making to solve complex and real-world problems. The management objectives are determined as a function, and the expected outcomes of management choices are calculated under the uncertainty (Dorazio and Johnson, 2003).

Expected utility:

For discrete function, $E[U(D)|p] = \sum_i^n U(\omega_i, D)p(\omega_i)$

For continuous function, $E[U(D)|p] = \int_i^n U(\omega_i, D)p(\omega_i)di$

Where, E[U(D)|p] = Expected utility or expected consequences from a decision making under uncertainty

$p(\omega_i)$ = Probability of events that decision maker cannot control

We choose D to maximize $E[U(D)|p]$.

However, in statistics, we normally use loss function instead of utility function;

$$L(\omega_i, D) = -U(\omega_i, D)$$

Expected loss:

For discrete function, $\rho(p, D) = \sum_i^n L(\omega_i, D)p(\omega_i) = E[L(\omega_i, D)]$

For continuous function, $\rho(p,D) = \int_{i}^{n} L(\omega_i, D)p(\omega_i)di = E[L(\omega_i, D)]$

The objective is to make a decision (D^*) that minimize the expected loss (ρ^*)

$$\rho(p, D^*) = \rho^*(p) \qquad \text{(Lenk, 2001)}$$

Bayesian Belief Network can be applied to solve decision problems by extending two additional types of nodes: decision nodes and utility nodes (Watthayu and Peng, 2004). A decision node is a node in an influence diagram that represents action alternatives under the control of the decision maker (Watthayu and Peng, 2004; Norsys Software Corp, 2013). When the net is solved a decision rule that indicates choices in making a certain decision for each possible condition will be found for the node that optimizes the expected utility (Norsys Software Corp, 2013). Instead of holding conditional probability table (CPT) a utility node holds a table of utility values imposed by the decision maker by manual calculation for all value configurations of its parent nodes that meet the optimization objective (Jensen, 1995 cited in Watthayu and Peng, 2004).

2.5.5 Building Networks

Designing a BBN involves these following steps (Heckerman, 1996 cited in Krieg, 2001):

a) Identify the objectives of the model

b) Identify sources of data to achieve these objectives

c) Include only the meaningful and worthwhile data in the model

d) Transform the data into variables

e) Identify thorough states of each variable

f) Determine the causal structure between the variables

Currently, BBN is becoming increasing popular for policy modeling of livelihoods and natural resource management problems such as water resource management (Cain, 2001; Ames et al., 2005), ecological risk management (Pollino et al., 2007), ecological modeling and conservation (Marcot et al., 2006), and wetland development (Gibbs, 2007). The study of Dambacher et al. (2007) proves that BBN is transparent, repeatable, makes experimental predictions statistically testable, and does not require large amounts of empirical data. However, the most significant drawback of BBN is the time, expertise and data needed to realistically represent complex problems.