A framework for assessing the tangible and intangible impacts of emergency animal diseases

Sarah-Jane Wilson BVSc, MVPHMgt

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University of Sydney

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ABSTRACT

In the thesis, a novel framework for addressing the tangible and intangible impacts of emergency animal diseases (EADs) is presented. Traditional economic assessment methodologies lack the capacity to measure the intangible impacts of EADs (which are by their definition '*difficult to measure or unable to be precisely measured*'). Intangible elements can have a great impact on decisions made relating to the response, control and prevention strategies that are ultimately used to address these EADs. Intangibles have value and worth, although this value is subjective and difficult to express in dollar terms. Consequently, the intangible elements are often lost in the scope of traditional economic analysis. Without the consideration of intangible impacts, the bottom-line for decision-making related to animal-health emergencies would be based only on financial measures. This does not reflect the reality of the consultative policy-making process.

A novel method for measuring the intangible impacts of EADs is used in conjunction with economic analysis. The intangible measurements are used to inflate or deflate the economic costs and benefits to create a 'value-adjusted' outcome. Two case studies (PRRS in northern Victoria and Hendra virus in Southeast Queensland) demonstrate the operation of the framework and outcomes from an integrated economic and intangible analysis. The case studies demonstrate the use of an intangible measurement and the calculation of an integrated value measure. This integrated value measure is used to gauge a stakeholder's response to a proposed EAD policy.

In the PRRS case studies, the outcomes indicate that overall, the pork industry would be in favour of maintaining a PRRS-free status in Australia. Other stakeholder groups would be prepared to

make some compromise on a ‘disease-free’ status. The reasons for this may include the continuation of positive flow-on effects from pork processing or to prevent animal welfare issues that may occur as a result of overcrowding and resource stress during an EAD response. The Hendra virus case study outcomes indicate that a subsidised vaccination campaign (in the form of vaccination clinics) would present a unanimously superior solution to preventing cases of Hendra virus in humans and horses when compared to flying-fox roost removal.

Using this framework to gather stakeholder data during the consultative process of policy-making aids in the identification and recording of the perceived value of intangible costs and benefits from the stakeholder perspective. These data can be used to aid decision-making or to help facilitate capacity building through the policy-making process. The use of the framework will ensure that the resulting analysis includes the full impacts of EADs, rather than only a narrow comparison of financial costs and benefits.

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Dedication:

This thesis is dedicated to my best friend of over 30 years Caitlin Maree Logan (14/12/1975 - 30/01/2013). You fought the longest and hardest battle of anyone I have ever known, and yet only those closest to you were ever aware of it. You departed onward and upward for the wild blue yonder in January this year, so you will miss my 'red shoe day', but that just gives us one more reason to have another round when we next meet. Safe travels mate. Meow.

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PUBLICATIONS & CONFERENCE PRESENTATIONS

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Wilson, S.-J, Ward M. P. and Brookes, V., 2012. An industry-level analysis of potential intangible and economic impacts affecting Australian pork producers during an emergency animal disease control program (Poster). International Symposia on Veterinary Epidemiology and Economics. Maastricht.

Wilson, S.-J, Ward M. P. and Garner, M.G., 2012. An epidemiological and economic framework for evaluating the tangible and intangible impacts of emergency animal disease outbreaks. International Symposia on Veterinary Epidemiology and Economics. Maastricht.

Wilson, S-J and Ward, M.P, 2012. Economic decision making - Japanese encephalitis as a case study. Sydney Emerging Infectious Diseases (SEIB) Symposium. Sydney.

Wilson, S-J, 2011. A framework for evaluating the economics of the control and prevention of animal health emergencies. Student Workshop. Australian Pork Limited Annual Conference. Adelaide.

Wilson, S.-J, Ward M. P. and Garner, G.M., 2010. A framework for evaluating the economics of the control and prevention of animal health emergencies (Poster). FMD Symposium. Melbourne.

Wilson, S.-J, Ward M. P. and Garner, G.M., 2009. A framework for evaluating the economics of the control and prevention of animal health emergencies. International Symposia on Veterinary Epidemiology and Economics. Durban.

Wilson, S.-J, Ward M. P. and Garner, G.M., 2009. An economic framework for assessing exotic animal disease in Australia. Australian Biosecurity Intelligence Network Conference. Canberra.

GLOSSARY OF ACRONYMS

AHA	Animal Health Australia
APL	Australian Pork Limited
APVMA	Australian Pesticides Veterinary Medicines Authority
ASF	African Swine Fever
AUSVETPLAN	Australian Veterinary Emergency Plan
AVF	Adjusted Value Figure
AVR	Adjusted Value Ratio
AW	Animal Welfare
BCR	Benefit-Cost Ratio
CBA	Cost-Benefit Analysis
CCEAD	Consultative Committee Emergency Animal Diseases
CEA	Cost Effectiveness Analysis
CGE	Computer Generable Equilibrium
COAG	Coalition of Australian Governments
CPL	Case Prediction Load
CT	Compromise Threshold
CVO	Chief Veterinary Officer
DAFF	Department of Agriculture, Fisheries and Forestry
DALY	Disability Adjusted Life Years
DCP	Dangerous Contact Premises
DP	Dynamic Programming
EAD	Emergency Animal Disease
EADRA	Emergency Animal Disease Response Agreement
EADRP	Emergency Animal Disease Response Plan
EC	European Commission
EMV	Expected Monetary Value
ENV	Environment
EV	Expected Value
FAO	Food and Agriculture Organisation of the United Nations
FMD	Foot-and-Mouth Disease
GATT	General Agreement on Tariff and Trade
GDP	Gross Domestic Product
HeV	Hendra Virus
HH	Human Health
IntangVal	Intangible Value Measure
IO	Input-Out Model
IP	Infected Premises
IRA	Import Risk Assessment
IRR	Internal Rate of Return

LAHO	Lead Animal Health Organisation
LP	Linear Programming
MCDA	Multi-criteria Decision Analysis
MCP	Multi-criteria programming
MORR	Modified Outbreak Risk Ranger
NGO	Non-Government Organisation
NMG	National Management Group
NPV	Net Present Value
OECD	Organisation of Economic Co-operation and Development
OIE	Office International des Epizooties
OIS	Outbreak & Intervention Strategy
PB	Partial Budget
PIIL	Predicted Intangible Impact Level
PIMC	Primary Industries Ministerial Council
PISC	Primary Industries Standing Committee
PRRS	Porcine Reproductive and Respiratory Syndrome
PV	Present Value
QALY	Quality Adjusted Life Years
RNA	Ribonucleic Acid
SAM	Social Accounting Matrix
sCBA	Social Cost-Benefit Analysis
SCoPI	Standing Council on Primary Industries
SLP	Successive Linear Programming
SPIIL	Stakeholder Predicted Intangible Impact Level
SPS	Sanitary and Phytosanitary Agreement
SQP	Successive Quadratic Programming
TGE	Transmissible Gastro-enteritis
ToVal	Trade-Off Value Measure
WHO	Worth Health Organisation
WTO	World Trade Organisation

INTRODUCTION

"The linkages between government policy, markets, livestock systems and animal diseases create complexity in the study of the economics of animal health and production"

Rushton (2009), Page 12.

From the end of the 19th Century, a livestock revolution occurred (Schwabe, 1982; Schwabe, 1994; Rushton, 2009). This was a phenomenon that occurred mainly in developed countries, as a response to the demand for rurally-produced product within urban areas. At the time, rural drift (movement of the young rural population into the city looking for work and new opportunities) was occurring and city populations were expanding, increasing the demand for agricultural product. The response to this demand was aided by technological and industrial advancements, campaigns of mass action and improvements in scientific knowledge. Animal health improved, human health improved and industrialisation increased with the advent of automation and improved technology. These changes allowed for cost-efficient transportation and better storage of produce and animal products. The result was longer transport times to more distant locations and more widely spread dispersion of product (to the point of globalisation for many animal products). However, along with this came increased incidence of trans-boundary diseases and the unanticipated emergence of some high impact pathogenic zoonotic diseases such as SARS, highly pathogenic Avian Influenza (HPAI), and Bovine Spongiform Encephalitis (BSE) (Perry et al., 2001; Rushton, 2009).

Globally, we have seen a trend in developed nations towards a reduction in government funding for animal health programs (Otte and Chilonda, 2000). Despite this trend, a survey of Australian farmers produced by Barclay (2005), revealed that most producers believed the responsibility for quarantine and biosecurity measures still belonged primarily, to the government. As public funding is now, more than ever, subject to stringent economic justification, policy-making for animal health emergencies involves multijurisdictional decision-making. To further complicate policy-making for animal health programs, government priorities are shifting. The development of technology and improvement of knowledge associated with combating animal diseases, has created new paradigms that must be addressed in animal health (Schwabe, 1982; Ramsay et al., 1999; Otte and Chilonda, 2000; Rushton, 2009).

Some of the major impacts that have affected animal health expenditure and policy on a global level are as follows (Davies, 1996; Otte and Chilonda, 2000; Perry et al., 2001) -

- Many major epidemic diseases have been controlled or eradicated (for example global eradication of Rinderpest and eradication of Tuberculosis and Brucellosis in Australia)
- There has been an increase in zoonotic disease from newly emerged pathogens (both novel and mutated or recombined existing pathogens), for example Hendra Virus and Highly Pathogenic Avian Influenza (HPAI)
- A greater awareness of food-borne diseases and subsequently the means of controlling such diseases, has led to the development and implementation of systems and processes to reduce the occurrences of food-borne diseases.

- Political motivation for national disease control program funding has weakened as the importance of agriculture in the national economy declines. Many other stronger sectors now receive greater priority in national political strategies (e.g. mining in Australia)
- The trend of rural decline continues, leading to decreasing rural populations and reducing numbers of people involved in primary animal industries
- Private sector responsibility is developing in response to decreasing public sector funds and the role of non-government organisations (NGOs) is increasing. This means that there is a greater expectation on return on investment than ever before.
- At both a national and global level, there is increased focus and provision of support for processes to improve and sustain food security (e.g. Food and Agriculture Organisation of the United Nations (FAO).

In recent decades, the trend towards reduced public funding for animal health programs has highlighted the need for more strategic investment. The emergence of zoonotic disease and importance of ecological sustainability means that we must address the impacts of emergency animal diseases (EADs), in both tangible and intangible terms. To do so, we must be able to clearly and accountably identify both the economic and intangible impacts that occur as a result of the implementation of an EAD response policy or decision.

In a contemporary setting, policy-making in developed nations usually employs consultative processes. Decisions relating to these policies are influenced by many factors, which may at times be competing. These influences can include (but are not limited to) political reasoning, cultural sensitivities, economic justification, environmental protection, technical limitations, public health impacts and animal welfare requirements. Decision-making criteria are often reliant on economic justification for policy decisions, although economic impacts are not always the bottom line influence (for example, a policy that was economically viable but not sustainable in terms of negative environmental impact would be unlikely to be implemented). However a method to measure intangible impacts is missing. Intangibles are by their very nature difficult to measure and highly subjective which makes them difficult to incorporate into a form that serves to aid decision-making.

Whilst empirically-focussed economic evaluation tools are in frequent use, additional insights can be gained from an economic evaluation tool with a framework expanded to incorporate processes, issues and reasoning behind the justification of an economic decision. These types of expanded framework tools are particularly useful in consultative policy-making and governance (Colebatch, 2006; Colebatch, 2009). This type of framework allows decision-making criteria to be put in context with the perspectives of the stakeholders that sustain impacts, as a result of the implementation of these policies. In this type of framework both the economic impacts and the intangible impacts must be considered for a complete analysis.

In animal health scenarios, particularly in disease outbreak situations, the overall economic consequence will be impacted by epidemiological factors such as the species affected, frequency and distribution of disease incursions, transmission cycles, host interactions and climatic anomalies. The attitude of the decision-makers and affected industries towards risk will also have an impact. It makes sense then that a framework used to measure economic impact of disease spread, prevention or control, should include epidemiological parameters at least conceptually. As a result, the integrated use of epidemiology and economics has been accepted as the norm by institutions in developed countries. Together the fields of epidemiology and economics can assist with risk analysis, prioritisation, strategy development and implementation of disease control or prevention policies and programs (Schwabe, 1982; Ndiritu and McLeod, 1995; Perry et al., 2001; Pritchett et al., 2005).

The novel concept in this thesis is the inclusion of an analysis of the intangible elements that are impacted by animal disease outbreaks (in conjunction with an epi-economic assessment of tangible elements). The aim of this thesis is to develop an integrated epi-economic-intangible framework that will aid to support decision-making during EAD policy development. The framework is proposed for application during consultative policy-making to give indications of stakeholder response to policy proposals in terms of the tangible and intangible impacts they are prepared to endure to combat EADs.

The objectives of the thesis include a review of the most commonly used economic evaluation tools pertinent to animal health decision-making. It then offers a new conceptual framework that can be used in the following situations –

1. During consultative processes with stakeholders regarding EADs, where multiple perspectives and values must be identified and considered prior to policy development

2. During the development of new policy or adjustment to current policies in light of new scientific or technical justification for EAD control
3. For the justification of changes to policy during an emergency disease situation in a response to economic and or intangible impacts, or the addition of new scientific or technical knowledge and
4. For comparing and contrasting the tangible and intangible consequences of different animal disease prevention or control policies.

This framework will be tested under simulated emergency animal disease scenarios (case studies) and the findings discussed.

LITERATURE REVIEW

Chapter 1 - Animal Health Policy

1.1 Drivers of animal health policy

Policy is a concept that '*presents action in terms of the collective pursuit of known goals…[and] both explains and validates the actions'* (Colebatch, 2009) Page 21. It is now a key organisational concept in the governance of animal health in Australia and in developed countries around the world. The 'drivers' of policy can be the stakeholders affected by changes in animal health status or the government organisations that need to respond to changes in political climate, technology, trade issues or animal health status. '*Drivers*' can also be consumer-oriented, environmental or sustainability issues.

The stakeholders driving animal health policy development are government and NGOs (such as academic and research communities, not-for-profit organisations, collaborative networks); producer groups and their representative or peak industry bodies; secondary industries such as transport, processing, manufacturing and suppliers; and tertiary industry and consumer groups (Dicks, 1996; Kahrs, 2004; Colebatch, 2006). From within these stakeholder groups, certain functional elements are required for policy-making - the experts (technical), the custodians (the policy process developers), the policy leaders, the politicians and the grass roots participants (who generally are the most affected by policy impacts). Policy development operates on two key guiding concepts - policy content and policy processes. Policy content refers to the issues, contexts and subject of action. The policy processes are the pathways used to develop the content and include advocacy, education, communication and consultation with stakeholders. Like any facilitated process where the alignment of goals needs to occur, policy development processes can have periods of ambiguity, confusion and sometimes conflict, whilst the stakeholders grasp the drivers, implications and requirements of the policy. Only when an understanding of these elements is reached, co-operative alignment of goals can occur (Colebatch, 2006; Colebatch, 2009). This is particularly apparent when stakeholders operate from different backgrounds and paradigms and/or have different and diverse expectations of the outcomes of the policy.

Policy drivers are very diverse and multi-dimensional. Figure 1 gives an overview of the scope of policy drivers in relation to the development of animal health policy (adapted from the Canadian national animal health strategy (Canadian Government, 2007)). Key focus areas for policy development include biological efficiency (ability to sustainably produce safe food), economics and trade access (disease surveillance and reporting, proof of freedom from disease). However other areas that have had an impact on policy development include public perception (food safety, animal welfare and ethical food production, environmental impacts) and the need for transparency. In recent years, we have also seen policy respond to changes in food production systems (intensification and mechanisation), emergence of new diseases (some with zoonotic potential) and globalisation of the movements of people and produce (European Commission, 2007).

Much of the policy that relates to animal health in developed countries such as Australia, focuses on benefitting the facilitation of trade. It also focuses on generating the capacity in regulatory and compliance roles, to prevent or prepare for conditions of EAD that may impact trade, human or animal health. This differs from developing countries where drivers of animal health policy are often more focused on socio-cultural aspects such as poverty reduction and sustainability of food production (Ahuja, 2009).

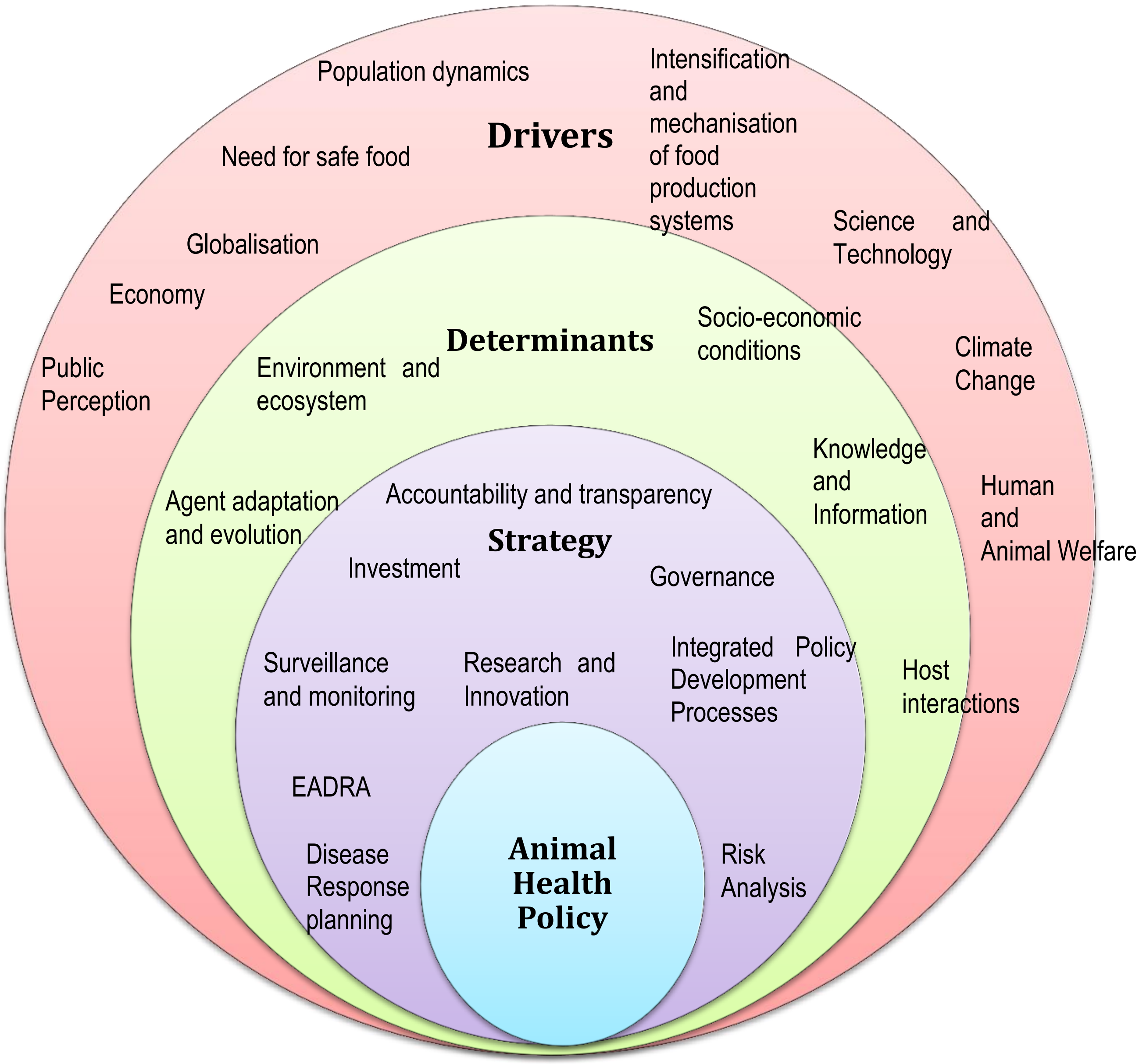

Figure 1 – A conceptual model of drivers, determinants and strategies for animal health policy development

Ideally, the processes behind the development of animal health policy, involve identifying key stakeholders, classifying stakeholder needs and running a facilitative process of stakeholder consultation. From here, a policy is drafted which undergoes further consultation with key stakeholders. Revisions are then made to this policy document before any amendments to supporting operating plans/procedures, regulation and legislation are made. Publication and communication of the policy ensues, with the implementation of the actionable policy (Kahrs, 2004; Colebatch, 2009). The reality is that this process is often less-streamlined. Elements of the process may be limited or missing and/or the influences upon the process may be out of the control of the policy development team.

1.2 Global structure of policy control for emergency animal diseases

Globally, many organisations are involved in the governance of policies and standards for animal health. The General Agreement on Tariffs and Trade (GATT) was founded in 1948 by 23 member countries in an effort to stimulate international commerce and reduce technical barriers to trade post-World War 2. It now has 100 member countries and many different agreements relating to commodities and trade. GATT grants authority as its successor to the World Trade Organisation (WTO). WTO is responsible for assigning roles to various organisations, including the roles of setting standards and developing policies relating to animal health (Kahrs, 2004; World Trade Oganisation, 2011). The WTO is an organisation (born in 1995) that provides a forum for governments to negotiate trade agreements and settle trade disputes under a system of trade rules, negotiated and signed by the majority of the trading nations (World Trade Organisation, 2011). The outline of the WTO structure is included in Appendix 1a.

The International Animal Health Organisation (Office International des Epizooties or OIE) is the *'intergovernmental organisation responsible for improving animal health worldwide'* (OIE, 2011b). The membership of the OIE is demonstrated in Appendix 1b. As a reference organisation recognised by the WTO, the OIE implements standard setting. It also maintains animal health reporting systems and criteria for different animal health status levels. The OIE also is responsible for making recommendations on sanitary measures such as testing, quarantine and health certification that facilitate the international trading of livestock (Kahrs, 2004; OIE, 2011b). Voting rights at the OIE are the sole responsibility of the Chief Veterinary Officers (CVOs) from the represented countries; however national delegations often include veterinary officials and representatives from NGOs.

As far as food production goes, especially for international trade, the WTO Sanitary and Phytosanitary agreement (SPS) provides the guidelines for import and export measures, based on risk assessment and regionalisation. These measures must be both technically and scientifically sound as well as being transparent. An exporting country must be able to demonstrate its provisions for producing safe food, to a level equal to the importing country. The SPS regulations provide provisions for control, inspection and approval procedures. The standards used by the SPS are set by the OIE (for animal health), the FAO/WHO Codex Alimentarius Commission (for food) and for plant health by the FAO's Secretariat of the International Plant Protection Convention. The Codex Alimentarius Commission *'was created in 1963 by FAO and WHO to develop food standards, guidelines and related texts such as codes of practice under the Joint FAO/WHO Food Standards Programme'* (Codex Ailimentarius, 2011).

1.3 Australian structure for animal health policy-making

In Australia, animal health policy is developed in a consultative manner through a formalised and participative process. The policy development goals are for the alignment and selection of preferred outcomes from the many perspectives and agendas of the participating stakeholders (Colebatch, 2006). The Standing Council on Primary Industries (SCoPI) (formerly - Primary Industries Ministerial Council (PIMC)) is charged with the development, implementation and review of policies related to sustainable food production and act across jurisdictions to ensure food security.

SCoPI is part of the Council of Australian Governments (COAG) – the peak Australian inter-governmental agency. SCoPI is also tasked with reforming the national biosecurity system. ScoPI is supported by the Primary Industries Standing Committee (PISC), which in addition, aids to direct and cooperate with the work of ScoPI. The membership comprises the department heads and chief executive officers of the relevant Australian state's or territory's (and New Zealand's) government agencies responsible for policy in the area of primary industries (Council of Australian Governments' Standing Council on Primary Industries, 2012a, 2012b; Council of Australian Governments, 2012).

In Australia, the bodies that coordinate the technical response during emergency animal disease outbreaks, act as the expert stakeholder in the development and implementation of policy. This group - the Consultative Committee on Emergency Animal Disease (CCEAD) - acts as a coordinating body between the Commonwealth, states, territories and industry. CCEAD membership comprises commonwealth and state and territory CVOs, representatives from the Australian Quarantine and Inspection Service (AQIS), Biosecurity Australia, the Australian Animal Health Laboratory (CSIRO) and industry bodies. The CCEAD is chaired by Australia's Chief Veterinary Officer. The CVO of Australia is also Australia's principal representative to the OIE on animal health matters.

The CCEAD plays a coordination role in response to animal disease emergencies. It provides technical response advice and decision-making on animal health incidents, as well as advice on funding matters related to these emergencies. The National Emergency Animal Disease Management Group (NMG) reviews the policy and funding advice given by the CCEAD and either approves/does not approve the cost sharing arrangements, as set out in the emergency animal disease response agreement (EADRA). The NMG is composed of representatives from industry, as well as state and territory government CEOs (CCEAD, 2008; Animal Health Australia, 2012b).

As part of the CCEAD in Australia, there is also a representative body called Animal Health Australia (AHA). AHA is a non-profit public company established by Australian federal, state and territory governments and major national livestock industry bodies. AHA manages national animal health programs and manages contingency funds for emergency animal disease incidents and animal health related projects. They are also represented on the Animal Health Committee. Appendix 2 shows a further breakdown of the organisational structure and background of animal health management committees and organisations in Australia as published by AHA (2009). Figure 2 shows the membership of Animal Health Australia.

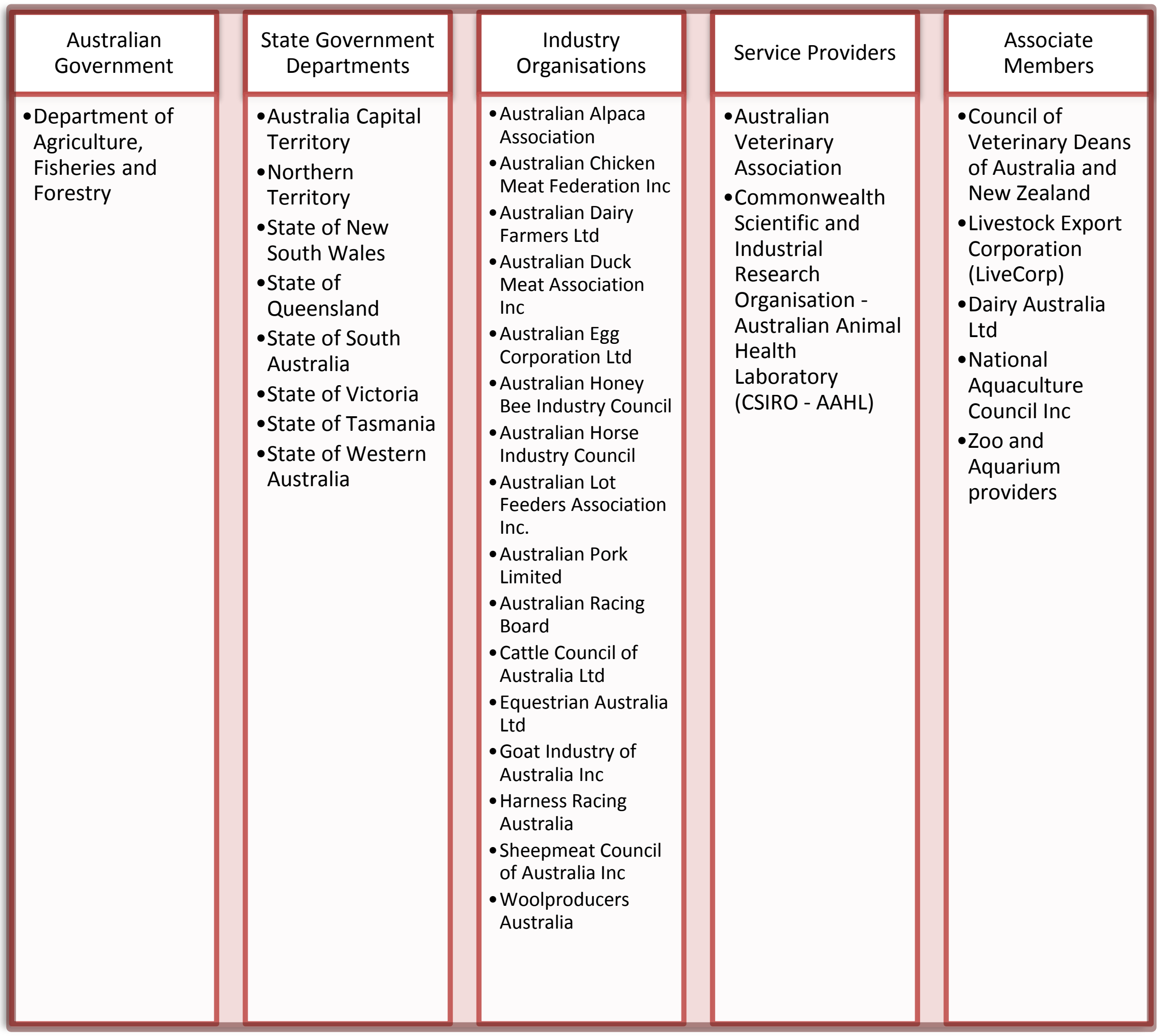

Figure 2 – Stakeholder membership of Animal Health Australia (Adapted from Animal Health Australia, 2009)

Cost-sharing agreements (under which government and industry share the costs of an EAD response) are in place in Australia, underpinned by the Emergency Animal Disease Response Agreement (EADRA). Under the EADRA, the response accommodates the relevant state or territory's legislative, industry, government and community structures and is guided by the nationally agreed plan, the Australian Veterinary Emergency Plan (AUSVETPLAN) (Animal Health

Australia, 2004a, 2012b). This contingency planning framework contains agreed response strategies and operational guidelines made by the Australian federal, state and territory governments and relevant livestock industries. The plan is designed to ensure that a response can be implemented with minimal delay and in a coordinated manner, while the EADRA ensures pre-agreed cost-sharing arrangements will operate (Animal Health Australia, 2012b).

1.4 Implications of emergency animal diseases

As described in the EADRA frequently asked questions (page two), an emergency animal disease '*is likely to have significant effects on livestock – potentially resulting in livestock deaths, production loss, and in some cases, impacts on human health and the environment' (Animal Health Australia, 2012a)*. EADs can be exotic diseases, variant non-endemic forms of an endemic diseases, a disease of unknown or uncertain cause or an endemic disease presenting in the form of an outbreak with severe consequences that require an emergency response (Animal Health Australia, 2012b, 2012a).

The implications of an EAD outbreak are many and varied. Beyond the economic cost of the disease response and any subsequent loss of trade, there will potentially be both societal and environmental/ecological impacts. Using the platform of economics, society and environment we can build a picture of the impacts of EADs. This trident approach has been coined 'the triple bottom line' (Brown et al., 2006). Table 1 shows a broad summary of these considerations.

Table 1 - Triple bottom line considerations for emergency animal disease outbreaks

Economic	**Societal**	**Environmental**
Losses to domestic and international trade	Human health though zoonotic disease	Livestock loss through disease
Costs of compensation and subsidy	Human health through provision of affordable, safe and sustainable food supply	Environmental damage through destruction or disposal of diseased animal
Cost of disease response – surveillance, diagnostics, staff resources	Loss of livelihood	Loss of other species due to disease (native and non-native)
Loss of income from activity by industries (e.g. horse-racing, agricultural shows, tourism[3,4])	Community stability, capacity and local resources[1, 2]	Loss of secondary environmental functions reliant on animals (e.g. pollination by bees)
Direct income losses for producers		

[1] Preslar (2010), [2] Barclay (2005), [3]Power and Harris (1973),[4] Lowe (2001)

In the event of an incursion of an exotic disease or an outbreak of an emergency animal disease, some of the major economic costs will include the implementation of an emergency disease response or control program. These programs encompass activities, such as surveillance and monitoring, quarantine, zoning and field activities which may incorporate destruction and disposal of stock. Depending on the size of the EAD outbreak, other major costs will include production losses and any compensation that is to be paid (as agreed in the EADRA). Additionally, with emergency diseases, there are likely to be losses in export revenues, higher import tariffs in other countries after major disease outbreaks, increased market competition, lost export taxes, harmful fluctuations in hard currency reserves, and diminished revenue from tourism and sporting activities (Power and Harris, 1973).

Societal and environmental impacts of EADs are much more complex, subjective and difficult to quantify. Also the level of development within a country or region, may affect these impacts. An example of this would be the impact of an animal disease outbreak in developing countries, which may have grave impacts on community structure, food security and public health (Preslar, 2010). Further consideration is given to the impact of such intangible elements in more detail in later chapters.

During a disease outbreak, the implementation of control and eradication policies will focus on minimising the economic impacts of the EAD outbreak on directly and indirectly affected industries. In the later stages of the disease outbreak, recovery and re-establishment programs may also be implemented. In peace time (periods of time where there are no current disease outbreaks), development and review of response plans and EADRA, resource stock-taking and inventory will likely occur (Animal Health Australia, 2012a). This may also coincide with review of response agreements and any subsequent adjustments to operating procedures that may impact the institutions capabilities in disease response.

The decisions that are made relevant to the animal disease policy during an EAD event will revolve around achieving the outcomes of the policy strategies. Such decisions can be influenced by the need for prioritisation, impact of actionable items, constraints, legislative ability, compliance, resource capacity and technology. Consideration must be given to close linkages between the epidemiological and economic aspects of the disease impact and the disease must have sufficient potential impacts to warrant priority (Perry et al., 2001).

Animal health policy for emergency disease, also involves a great deal of planning to enable preparedness in the face of a disease challenge. These preparedness policies will link to disease response policies, and may cover operations and actions such as pre- and post-border monitoring and surveillance (to support freedom from disease claims), inspection, quarantine, risk assessment and trade negotiations.

The full cost or value of an emergency animal disease outbreak is often overlooked, as the tools we currently use to measure such impacts rarely include the intangible elements. These elements are those that have value, but are not easily measured in monetary terms – elements such as welfare, culture, heritage, livelihood or the value of a human life. In the use of economic assessment tools to evaluate tangible impacts of EADs, it must be noted that while internalities (or direct effects) are often easily considered, externalities or indirect effects (the deleterious impacts of a disease outbreak that are carried by third parties) are often missed (Otte and Chilonda, 2000). Confusingly, a negative internality is not always a negative externality and so these costs and benefits are at times omitted. For example, while an emergency disease may negatively impact animal industries directly, there may be other industries (such as disposal industries) that financially benefit. Whilst the tangible elements would appear seemingly easy to measure, care must be taken when these measures are put into an economic evaluation tool to prevent miscalculation or bias. The tools available for the analysis of the economic impact of emergency animal diseases at the national level are covered further in Chapter 2.

Losses to domestic and international trade (for animal derived products) and the follow-on effects are key economic considerations. From a government perspective, economics are likely to be a driving incentive to prevent decimation of animal industries through EAD outbreaks (Preslar, 2010). Australia currently exports 80% of its total agricultural production, including 62% of all red meat production (beef, lamb and mutton), so trade bans would present enormous economic complications (Barclay, 2005; Meat and Livestock Australia, 2009). Table 2 demonstrates the breakdown of tangible costs for both EAD prevention and control programs.

Table 2 - Tangible direct costs involved in emergency animal disease prevention and control

Prevention	Control
Cost of performing risk assessment for preventing disease entry • Which diseases • How will they get in and what are the likely geographical areas • What is the likelihood of the disease going un-noticed • Which hosts will it affect	Cost of performing risk assessment or disease spread modelling for different - • Diseases • Geographical areas • hosts
Veterinary medical interventions	Veterinary medical interventions
Surveillance costs Quarantine inspection and facilities	Control options and costs
Monitoring and surveillance to support proof of freedom from disease	Primary costs due to disease Production losses Animal deaths Compensation
Audit and compliance costs	Secondary costs Costs to secondary industries (e.g. transport, processing, feed suppliers)
	Costs to tertiary industries (tourism, consumers) Cost of replacing product with a suitable safe alternative
Education and training programs	Cost of surveillance and detection
Reporting programs	Eradication costs (destruction, disposal, disinfection, clean up and re-establishment of sanitary working conditions)
Promotion of Biosecurity	Trade embargo and lost domestic and international trade
	Recovery – return to freedom from disease Re-establishing herds and livelihoods – Subsidisation of industry and community rebuilding and possibly restructure

Chapter 2 - Economic assessment of the tangible impacts of emergency animal diseases

2.1 Defining the terms and tools of economic assessment methods

Economics, in a simplistic and perhaps inappropriate view, is often considered the discipline that measures things in monetary units not physical units; however, a more comprehensive view is that economics is more concerned with decision making relating to the allocation of resources. Defining 'economic' assessment is full of challenges, relating to both working definitions and conceptual designs. The definition will also depend on the school of thought in which it is applied and the author that is using the term. The need for distinction and clarification of the terminology is an issue raised by a number of authors (Grindle, 1985; Dijkhuizen et al., 1997b; Thrusfield, 2007).

A purely financial analysis does not consider the extent of the implications of nationally-focused strategies or the indirect costs borne by society due to a disease outbreak (Bennett, 1992). This means that a purely financial perspective considers only the tip of the iceberg in terms of overall EAD impact. It is more a reflection of empirical accountancy. Economics is thought to be a more integrated and broad way of modelling the flow of resources (including capital) through a system. An alternate description of economics is that of making choices in the allocation of scarce resources (Howe, 1985, 1988b; Sloman, 1991; Morris, 1999; Thrusfield, 2007; Rushton, 2009; World Health Organisation, 2013). Economics can be used as a tool to enumerate and therefore justify the choice of a particular strategy with objective analysis (Howe, 1988a).

Definitions can be ambiguous and confusing, and to avoid the debate of nomenclature, for the purposes of this thesis, the following section is used to define the context and meaning of the use of terminology -

- A *system* is a series of interacting components that operates in time and space – this can be economic, biological, ecological, operational, managerial or process-orientated.
- A *model* is a simplified representation of a system or entity.
- A *simulation* is a simplified "run" of the system (i.e. interaction of the system components) using the model (generally this is a computerised operation). A simulation is also a form of modelling where outputs are generated probabilistically using decision rules (rather than algebraic calculations using equations as we see in mathematical modelling) (Guitian and Pfeiffer, 2006; Thrusfield, 2007).
- A *tool* is something (such as a skill or resource) seen as necessary or useful to a particular undertaking (Macquarie Dictionary, 2009).
- A *framework* is used to place aspects within a model or system. A conceptual framework occurs when a researcher links concepts from literature creating coherence to the enterprise and successful empirical research (Shields and Tajalli, 2006).

To demonstrate the application of these definitions in the animal health context, they are described as follows. An economic assessment tool is an instrument, procedure or device that is used to identify and enumerate potential costs, benefits and values of a program, policy or regulatory initiative and identify trade-offs in alternative strategies (World Health Organisation, 2013). An economic model however, is described as representation of an economic system has been simplified to demonstrate the relationships between the components of the system (Alexander and Baden, 2000). A model can be a tool and vice versa.

A slightly more elaborate type of model is the econometric model. These models combine economic theory with statistics and can be used to analyse and test economic relationships. Such models can be derived from both stochastic and deterministic economic models and are used primarily as macroeconomic forecasting models (Sims, 1980; Newman, 2009). In many cases models described as economic models fit within the definition of an econometric model. In this thesis, the terms economic model or economic assessment tool are used, but in some cases support the extrapolation to an econometric model.

2.2 Economics in animal health

People are the force driving economics. Whether the primary use of economic analysis is economic forecasting, justification of policy or planning for the allocation and use of resources, the demand for products and resources will have economic consequences. These consequences will have an impact on the analysis (Sims, 1980; Rushton, 2009). Time is also a crucial factor in economic analysis. The relevance of time is reflected in the period of time over which a disease impacts occurs, the time over which a control or elimination strategy is implemented and the length of the operational and logistical components of such strategies. These elements will all impact the costs of the disease and the impact of the control strategies.

The demand for product has economic impacts as does the speed of their consumption and the requirement for replenishment. The basic model of people-driven economics is shown in Figure 3. Source: (McInerney, 1987; Dijkhuizen et al., 1997b).

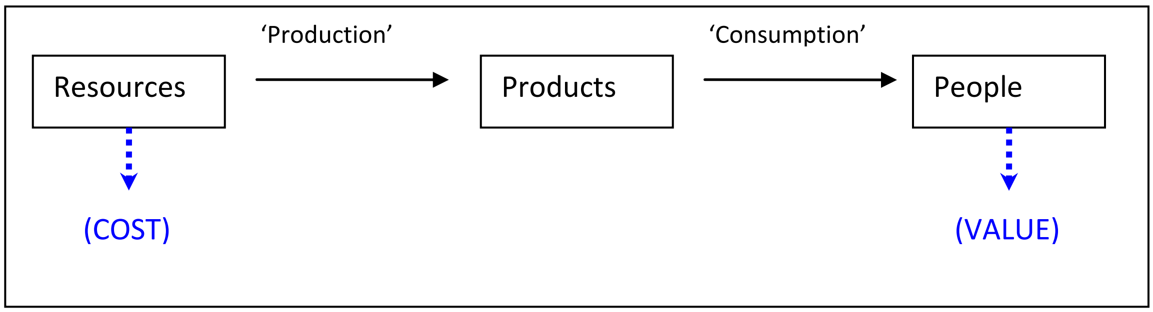

Figure 3 - The basic model of economics which underlies economic analysis.

From an animal health perspective, economically-based decision-making occurs at all levels of the animal-production hierarchy. Often these decisions involve allocating scarce resources or making decisions in the face of an emergency, such as an animal disease outbreak. It is in these situations where it becomes critical to find an optimal output for efficient use of resources (alone or in combination). The criteria for efficiency can be associated with a number of parameters - technically with biological efficiency and economically with cost-effectiveness of expenditure and allocation of resources (Blancou, 1999; Thrusfield, 2007).

Comparisons of the relative importance of animal diseases at farm-level are often made based upon information derived from economic impact studies. These studies tend to focus on either value of losses or evaluation of potential losses that could be avoided (Perry et al., 2001). If we consider animal health economics that is focused at higher aggregations of the production hierarchy (such as national-level emergency animal disease responses), it becomes imperative that more integrated and manageable tools for the economic analysis of animal disease impacts be used.

The scope of impacts at the regional or national level becomes greatly expanded, as the affected markets are generally not isolated. Therefore the tools used for economic assessment must appropriately accommodate analysis of larger outbreaks and greater direct and indirect effects to support decision-making. Decision-making under these conditions is generally justified by economic analysis, so the tool chosen must be able to provide predictive or simulated information that support the process. The main objective of the grass-roots level analysis (on-farm production tools), is to find policies that are likely to maximise profit or minimise losses (Ellis and James, 1979b). Public sector policies however (those that support the higher aggregations), carry the majority of the cost associated with EADs, particularly the costs of controlling disease outbreaks (Perry et al., 2001).

Economics in this sense (and the working definition that will be used for the purposes of this thesis), can then be considered as a framework of concepts, data and procedures to aid the selection of the most appropriate tools for disease control by the decision-maker (McInerney, 1987). Economic assessment – in the case of emergency animal diseases – is therefore not a form of accounting in which we can calculate an exact monetary value, but a system where we can make a best practice decision based on ranking alternative disease control measures (Morris, 1999).

As the objectives of different sectors and aggregations within animal health industries vary, so do the methodologies that give the most suitable information for decision-making at that aggregation. There will be a large difference in the economic impacts that may be sustained between a singular localised disease incursion and a multi-sector large-scale disease outbreak. We must therefore select the type of economic analysis tool or method that will allow us to best assess these impacts. These impacts may need to be assessed between sectors and levels of aggregation within the animal production industry, to make justifiable decisions on control policies.

Public expenditure must be able to accountably show net benefit, as well as demonstrating cost-effectiveness (Ellis and James, 1979a). This means that resource allocation using public funding, can be viewed as having a number of different priorities depending on which stakeholders' perspective is considered (Otte and Chilonda, 2000). Different impacts of EADs may be more suitably addressed by one economic assessment tool rather than another, depending on the issues that need to be solved. For example, these issues can entail efficiency, cost-effectiveness or optimisation of expenditure. They may also include elements such as relative prices, supply and demand and impact upon international trade, national welfare and employment. The scale of the industry operation as well as temporal, spatial and risk parameters will also influence the choice of an economic analysis tool. (Rich et al., 2005). These tools must also allow for transparency, interpretability and ability to be translated into relevant policy (Roberts, 1990). Factors influencing choice of economic assessment method are shown in Table 3.

2.3 Economic assessment methodologies

There are a variety of methods described in literature that can be used for economic assessment of animal disease outbreaks. The most appropriate method will be the method that best supports the decision-making process. At the higher aggregations, with larger systems and more complex interaction of elements within the systems, the methodology becomes more complex. The tools that enlist such methodologies tend to be more adaptable to new data and situations to allow multi-functionality, but also require greater design and operator skills, and an ability to interpret the outcomes (Morris, 1999).

The use of various economic methods at different levels or aggregations of the animal-production hierarchy has been studied by many specialists in the animal health economics field (Table 4). In general, there is much agreement in the literature to be seen, relating to the suitability of the methodologies that are applied at different levels. As this thesis has a focus on the application of economic methodologies at the national level, Section 2.4 provides further description and applications of these particular methods of economic analysis.

Table 3 – Examples of studies demonstrating factors that influence the choice of economic assessment method used

	Otte and Chilonda (2000)	Bennett (1992)	Dijkhuizen et al., (1995b)	Perry et al., (2001)
Nature of the problem	☑[1] Including level at which problem is addressed	☑Physical effects of disease and its effect on production	☑Controlling cost of production Optimising inputs	☑Competing national priorities relating to disease control
System involved	☑ Complexity Disease and effects	☑Level of analysis described with each assessment method	☑ Different models for different levels of analysis covered	☑ Sectoral Regional National
Availability of data	☑ Knowledge of disease and occurrence Impact upon production (direct & indirect) Cost of control measures	☑ Incidence and prevalence of disease	☑ Cost of disease Cost and benefits of disease control	☑ Focus is on data quality Sources of data Responsibilities of user
Type of model	☑ Use to which it will be put Experience/skill of model operator or builder and the perspective of decision-maker	☑ Depending on problem being modelled, information available, end use of model,	☑ Analytical tools (Discussed under resources) Static vs.dynamic	☑ Analytical tools and approaches Decision-making support
Resources available	☑ Time Money Tools Human Input	☑ Technology available for disease control Time Money	☑ Time Money	

[1] ☑ Indicates the elements covered in the study

Table 4 – Examples of economic analysis undertaken at different aggregations of animal health production demonstrating different types of methodology used.

		Herd/Farm	Sector/Industry	State/National
Enterprise analysis/enterprise budget/gross margin budget		1 2 3		
Partial budget		1 2 3 4[a] 5		
Mathematical programming	Linear programming	3 4 6[a] 7	6[a] 7	6[a] 7
	Dynamic programming	3 7	2 7	7
Partial equilibrium			4 6	4 6
Decision tree/analysis		1 2 3 5 7[a]	1 3 7[a]	1 3 7[a]
Cost-benefit analysis		4 7	1 2 3 4 5 7	1 2 3 4 5 7
Simulation modelling		1 2 3 5 7	1 2 3 7	1 2 3 5[a] 7
Social accounting matrices			4[b] 6	4[b] 6
Multi-market model			4 6	4 6
Cost effectiveness model		3	3	3
Computer general equilibrium			4 6	4 6

1, Morris (1999), 2, Rushton, Thornton and Otte (1999),
3, Otte and Chilonda (2000),
4, Rich et al (2005) (4[a] Considers Partial Budget the same as CBA, 4[b] considers SAM be the same as Input – Output models)
5, Diijhuizen, Huirne and Jalvingh (1995) (5[a] discusses integrated simulation models using epidemiology and economics)
6, Upton (2008) (6a doesn't consider dynamic programming)
7, Bennett (1992) (7[a] – also classified at the higher aggregate of network analysis)

2.4 Describing different categories of economic methodologies

There are a range of classifications that can be used to categorise economic assessment techniques. The categorisation of these methodologies revolves around compressing information relating to how the methodology will work and the predictive ability of the output from the method. Economic models are broadly divided by the way they are represented in the real world. They can be verbal/logical models (describing the system or paradigms they represent), physical models (representations of the real world, sometimes scaled down), computer driven models (giving us simulations of what could happen in the real world), algebraic models (representing systems in a series of equations or geometric models) or diagrammatic models (giving a representation of the system) (Intriligator, 1983). Applying this specifically to economic models, we can categorise the models based upon parameters such as type of input variables, intended purpose or function of the model, range and/or limitations of the method and principle process of use attributed to the method.

A further classification of each these methodologies described in Table 4 is considered in Section 2.4.1 – 2.4.6. The relevance of such classification relates to the capacity and operation of the methods when applied in different animal health situations. A summary of these classifications is given in Table 5.

2.4.1 Stochastic or deterministic methods

A deterministic model uses fixed values for input parameters, so it will always generate the same output. It does not take random variation into account. In contrast, stochastic models contain random elements enabling chance, variability and uncertainty in inputs to be taken into account. This means it can be used to generate a probability distribution of possible outcomes (Hurd et al., 1993; Dijkhuizen et al., 1997c; Ostergaard et al., 2005; Thrusfield, 2007). This allows us to examine the variability within the system as well as the mean and standard deviations. As random variation and uncertainty is inherent in biological systems, stochastic models are commonly seen applied to animal health problems.

2.4.2 Discrete or continuous models

This classification is reflected in a variety of variables that relate to animal health issues, such as parameters that incorporate time, space, choice or empirical data. A continuous model can either involve ongoing events or simulations of events, or where the model can be applied to data with potentially infinite possibilities. In contrast a discrete model will involve only a specific event with variables that are not continuous. If these descriptors are only being used to describe temporal parameters, they can also be known as static (discrete) or dynamic (continuous) models. Static models do not contain time as a parameter and involve a fixed interval (Carpenter and Thieme Jr, 1980; Small and Rosen, 1981; Dijkhuizen et al., 1997c).

2.4.3 Qualitative or quantitative models

A quantitative model is designed to produce data that can give relatively accurate predictions in terms of empirical information and tends to not extrapolate on the underlying dynamics. A qualitative model gives a description or an explanation of these dynamics without necessarily giving an empirical answer.

2.4.4 Micro- or macro-economic models

The essential difference between a micro- and a macro-economic model is the level of focus at which the study is aimed. Macro-economic models are designed to examine higher aggregate levels – such as the economy of a country or a region. This means the focus is on aggregated quantities such as total production of goods and services, total incomes and total costs. They are useful tools for governments and large organisations to model sectors or whole economies and are used to aid in decision-making. Micro-economic models are used to study individual parts of the economy such as the households, farms and firms. Micro-economics can also be used to study supply and demand and how these elements affect price in return. Conversely they can also be used to show how the price of a good or service will affect supply and demand in a specific market. These models can be computational, logical and/or mathematical.

2.4.5 Simulation models

A simulation model is a simplified representation of the system in operation (this can be an economic, epidemiological or other type of system). The model calculates an outcome for a predefined set of input parameters. To simplify, a simulation gives you an outcome given a set of variables.

2.4.6 Optimisation models

Optimisation refers to finding an optimal solution to a given problem within the system through maximising or minimising functions within boundaries or constraints on resources (Dijkhuizen et al., 1997c). In an optimisation model variables are manipulated (maximised or minimised) to achieve set outcomes.

Table 5 – A descriptive categorisation of economic models

	STOCHASTIC /NON STOCHASTIC	DISCRETE/ CONTINUOUS	QUALITATIVE/ QUANTITATIVE	MICRO/ MACRO	SIMULATION CAN BE APPLIED	OPTIMISATION CAN BE APPLIED
Budgeting	Non-Stochastic	Discrete	Quantitative	Micro	Yes	
CBA	Non-Stochastic[a]	Discrete	Can incorporate both	Micro or Macro	Yes	
I-O/SAM	Non-stochastic	Discrete	Quantitative	Macro	Yes	
Computer general equilibrium	Non-Stochastic	Discrete	Quantitative	Macro	Yes	
Decision analysis	Non-stochastic	Continuous	Can incorporate both	Micro or Macro	Yes	
Linear programming	N/A	Discrete	Quantitative	Micro or Macro		Yes
Dynamic programming	N/A	Continuous	Quantitative	Macro		Yes
Partial equilibrium/ economic surplus	Non-Stochastic	Discrete	Quantitative	Macro	Yes	Yes

[a] Can be designed to include elements of a stochastic nature through simulation

2.5 Methods of economic analysis applied at state/national levels

2.5.1 Partial budgeting/financial analysis (accounting analysis)

This type of analysis is primarily accountancy within a system and rarely takes indirect costs into consideration. The variables mostly relate to net outcomes of a change within the system, that affect the profitability of the enterprise or system being analysed. The most commonly used financial analysis technique at the enterprise (herd/farm) level is partial-budgeting (PB). This technique is used for measuring net changes within the system (Rushton et al., 1999). Partial budget is a tool of accountancy and does not make assessment of financial feasibility or social acceptability. A partial budget would be used to measure the net profitability of a change in a system such as the implementation of vaccination in a herd, or a change in productivity associated with increased nutritional supplementation.

Although rarely used on its own at the national level, it has been included in this account of economic analysis techniques, as a partial budget can underpin the structural development of a Cost-Benefit-Analysis (CBA) in terms of financial inputs and outputs. Appendix 3 lists a number of studies that have been completed in the field of animal health economics, using partial budget as their approach to economic analysis.

2.5.1.1 Parameters used in partial budgets

Partial budgeting allows for identification of a net change in income for a particular decision – that is a profit, a loss or status quo within a discrete time period for that decision (Lessley et al., 1991). It is a flexible and relatively simple tool in terms of use, if some enterprise parameters within the analysis remain constant (Huirne and Dijkhuizen, 1997). It is designed to measure singular changes within a system and is limited by its inability to cover multiple aspects of influence in the analysis. If partial budget is used as a tool to compare decisions in different time periods, then discounting for the different time periods must be addressed (Ellis and James, 1979a; Rushton, 2009). Discounting is covered in section 2.5.2. The basic parameters that are measured in partial budgeting include a summary of costs and losses that are encountered. These are displayed in Table 6 below.

Table 6 - Parameters to be considered in partial budgeting

Costs	Benefits
New Costs Revenues Foregone	Costs Saved New Revenues

New costs are additional expenditures on resources for implementing the proposed change. *Revenues foregone* are losses as a result of change (e.g. reduced productivity, mortality loss). *Costs saved* are the reduced costs as a result of the change or costs that will be avoided if the change is implemented. And n*ew revenue* is the additional returns as a result of the proposed change that would not be received if the change was not implemented (e.g. productivity gains). The applications, advantages and disadvantages of partial budgets are described in Table 7.

If there is a positive output from a partial budget, this will help ascertain that a change is financially viable. This means the change should be considered for action as a net profitable change when the sum of the benefits outweighs the sum of the costs. This can also be considered as marginal benefits returned as a result of the change that is proposed. An example of this scenario would be as follows - a dairy farmer increases his level of supplementary feeding to his milking herd, thus increasing the milk yield and therefore the returns from the milk. The returns on the milk are higher than the expenditure on the supplementary feeding, so a net positive outcome is achieved, in other words a net profit.

Table 7 - Advantages, disadvantages and applications of partial budgeting

Advantages	**Disadvantages**	**Applications of use**
Gives simple economic comparison of an anticipated change to a system	Can only deal with small changes in the system[1,4] Not designed to deal with multiple areas of influence or comparison of different enterprises or time periods[5,8,9] Does not determine which is the best change for the system, only the most financially beneficial change[5] Does not allow for a high degree of uncertainty or risk[1,2] Does not consider externalities[9] Does not consider the technical feasibility of the change[6] Failure to account for all costs and benefits possible as they are not always clearly identifiable[2,7] Evaluation is influenced by structure of the system being studied, disease related factors and the technique used by the operator of the study[8]	Herd/farm level economic evaluations[1,2,3] but can be used for investment appraisals as part of a CBA[1] Focus on productivity gains so useful for endemic diseases[3]

[1] Rushton et al., (1999), [2] Huirne and Dijkhuizen (1997), [3] Morris (1999 , [4] Dijkhuizen et al., (1996), [5] Lessley et al., (1991), [6] Rushton (2009), [7] Perry and Randolph (1999), [8] Rougoor et al., (1996), [9] Ellis and James (1979b)

There is one school of thought that considers the partial budgeting approach to be synonymous with CBA due to the similarities in reliance on budgets for structural development and the consistencies of format within the analysis (Rich et al., 2005). This could be considered to be true if it was specifically compared to conventional CBA (but not in a social CBA as further described in section 2.5.2), which guides decision making according to principles of accountancy (McInerney, 1987). Other authors contrast this view for the following reasons (which indicate that the comparison being made with social CBA rather than conventional CBA) -

- Partial budgeting relates to on-farm economic measures, without necessarily including a discrete time frame, in contrast to CBA, which covers longer term projects at regional or national level and includes the use of decision criterion (Dijkhuizen et al., 1995b; Dijkhuizen and Morris, 1997). This differs to the description given by Lessley et al (1991), who claim PB can be used to measure net changes in outcome for a decision within a time period.
- Partial budget is usually applied at the herd/farm level whereas CBA is more appropriate at the industry or national level because it considers externalities and investment of scarce resources (Morris, 1999).
- Partial budget can only be considered for use where the system encompassing the change to be assessed can be isolated, however the concept of partial budgeting can be transferred to CBA and used as an investment appraisal (Rushton et al., 1999).
- Partial budgets can used at the farm/herd level with the choice indicator as marginal benefit, whereas CBA is used at the industry/national level with the choice indicator

being net present value (NPV), internal rate of return (IRR) or benefit-cost ratio (BCR) (Otte and Chilonda, 2000).

- Partial budgets are an accountancy approach used on individual farms whereas CBA is used for large scale investment policies which cover more than simple financial values (Thrusfield, 2007).

2.5.2 Cost-Benefit Analysis

McInerney (1991) describes CBA as a formalised technique for logically assessing the pros and cons of a decision to be evaluated. CBA can be used as tool for assessing the feasibility of a program prior to implementation or it can be used to review the outcomes of the project after implementation (James, 1987). Rich et al (2005) state CBA is analogous with partial budgeting and that the use of CBA is limited to low-level scales of analysis. This is contrary to the view presented by Bennett (1992), Morris (1999), Rushton et al (1999), Dijkhuizen et al (1995), Otte and Chilonda (2000) and Dagupta and Pearce (1972). It could be considered that the reasoning behind the divergence in these views relates to the definition of CBA that the author subscribes to, or the functional use of the CBA methodology.

The literature reflects two different descriptions of CBA – conventional and social. By definition social CBA (sCBA) can only occur at the highest level of the aggregation as a representation of social preferences and net social benefits, whereas conventional CBA can be used at all aggregations because it only measures economic outcomes. Conventional CBA can be used to compare economic consequences of alternative scenarios or changes within a system (Berentsen et al., 1992a; Rich et al., 2005). For example the application of CBA measurements still includes costs averted due to the implementation of the program and losses through animal deaths and production loss. This is similar to that seen in a PB, however, because the focus of the CBA is generally at a higher level of aggregation, it also includes loss of trade and export markets, encompassing a much broader scope (Krystynak, 1985). This scope will generally include the impacts that are felt by indirectly affected industries.

CBA is often used synonymously with sCBA, although they not strictly the same. Ellis (1981) describes a simple formula for CBA that emulates the model of a partial budget, but later goes on to state that if referring to sCBA then there is also reference to intangible effects/benefits. Social CBA contains an underlying value premise as to society's preferences for an outcome choice and gives recognition to the net social benefits of a project or change within the system (Dagupta and Pearce, 1972).

In research conducted by Bernués et al (1997), CBA was used to compare the economic efficiency of different control and eradication programs for bovine tuberculosis and brucellosis in Spain. In this instance, costs and benefits were identified and clarified, and adjustments made to economic data to account for inflation. Despite the economic outcome for disease control strategies being unfavourable, it was identified that human health aspects were not considered during the appraisal. It was decided that even with unfavourable economic results, project termination was not indicated, because benefits to the community from control of zoonotic disease was paramount. These outcomes reveal the differences that can be demonstrated when using the broader perspective of sCBA when compared to CBA.

In another study by Berentensen et al (1992a; 1992b), CBA was used to analyse the costs of controlling Foot and Mouth Disease (FMD) in the Netherlands. Here it was also identified that by incorporating value judgments to more thoroughly assess the impacts of animal disease (especially at the lower levels of the production hierarchy), policy-makers were able to make better decision regarding alternatives for disease control. This finding was also supported in studies by Aulaqi and Sundquist (1978), McInerney (1991), Disney et al (2001) and Barasa et al (2008), indicating that conventional CBA can be deficient without the additional consideration of costs and benefits from a net social perspective.

Social CBA is a more encompassing method of CBA that takes social welfare into consideration. It can guide the decision-maker by accounting for positive and negative aspects of change within a system and by giving an approximation of the net social benefits for that decision. It reflects the changes (positive and negative) resulting from different decision criterion and accounts for internalities, externalities and intangibles as changes that are indirectly measured within the economy to give us net social benefit (Dagupta and Pearce, 1972; Bennett, 1992; Thrusfield, 2007; Rushton, 2009). The concept of measuring social net benefits began as early as 1844, with further development in the 1930s and the formal advent of sCBA arriving in the 1950s (Dagupta and Pearce, 1972).

One of the first thorough sCBA evaluations used in animal health was conducted by Power and Harris (1973). The use of sCBA appears almost solely in the domain of public expenditure (Dagupta and Pearce, 1972; Gittinger, 1982). On the occasions when this method is used at lower aggregations of the animal health production hierarchy (farm, enterprise or regional) it can be considered to be analogous with investment appraisals (Rushton, 2009). Some debate has occurred as to whether the nature of the sCBA is philosophical rather than scientific, when we are unable to value intangibles (Dagupta and Pearce, 1972). The concept of measuring intangibles is covered further in Chapter 3 and is a key novel feature of the framework presented in this thesis.

2.5.2.1 Parameters used in CBA

Economic input variables make up the base data requirements of a CBA. These data can be simulated or real data and can incorporate economic data that is derived with the inclusion of epidemiological studies or simulation and/or risk analysis. The inclusion of these epidemiological data has great benefits in allowing comparison of mitigation strategies or policy decision options for animal disease control (Rich et al., 2005). Key benefits of the considered changes to be measured in the CBA are also identified and highlighted during the process, including the intangible effects as a result of the change.

Interpretation of the outputs from a CBA can be complex and require an understanding of both the technical aspects of the system and the analytical methodology. The key danger in the use of CBA is that the final answer will be biased towards the judgments of value made by those carrying out the analysis (Dagupta and Pearce, 1972; Bennett, 1992; Miller et al., 1996; Rushton, 2009). For this reason the methodology must be consistent and clearly recorded so it can be appraised for its effectiveness and adjusted if necessary without impacting the support it provides to decision-making (Bennett, 1992; Morris, 1999; Perry et al., 2001). Regardless of these issues, the use of CBA commonly highlights the major impacts that are to be considered in the decision-making process and this is one of the reasons why it is so useful at the higher aggregates (Dagupta and Pearce, 1972; Power and Harris, 1973; Miller et al., 1996; Rushton et al., 1999).

The indicators or measures of profitability normally referred from CBA are generally expressed as economic measures such as Net Present Value (NPV) – which indicates the economic value of the investment, Benefit-Cost Ratio (BCR) – which indicates the ratio of benefits to costs for a project (Dagupta and Pearce, 1972; Bennett, 1992; Huirne and Dijkhuizen, 1997; Rushton et al., 1999; Otte and Chilonda, 2000; Rich et al., 2005; Thrusfield, 2007) or Internal Rate of Return (IRR) – which is a performance measure, indicating the yield of an investment as a rate quantity.

<u>Discounting:</u> The conventional CBA (which considers the economic measure of change in profit or income structure at any aggregation level over a period of time), generally includes discounting or price adjustment. This means that economic measures are adequately comparable regardless of the timeframe they were applied in. As timeframes in CBA often cover timeframes of greater than one year, it is important that the changing value of money over the extended time period is accounted for. As identified by Aulaqi and Sundquist (1978), lack of discounting when making comparisons between time periods is a common issue with reconciling data between CBAs. This complication is both preventable and manageable by adjusting data to present values (PV) prior to comparison (Equation 1 found in Appendix 4) (Dijkhuizen et al., 1995a).

Discount Rate: The rate used within a CBA for adjustment of the outcomes, to allow comparison between time periods, is called a *discount rate.* It is generally a reflection of annual interest rates (*r*). This renders future values (generally under the influence of inflation) to a level suitable for comparison with current values, enabling decision-making criterion to be correctly applied (Dijkhuizen et al., 1995b; Huirne and Dijkhuizen, 1997). If historical analysis is being considered, the calculation of the discount rate (as described by Antoñanzas (2010b) and cited in Bernués et al (1997)), can be considered as public debt interest minus inflation rate, allowing reflective comparison to the historical time periods. This does not alleviate the issues that arise in very long term projects, where we see the project sometimes disadvantaged by use of high discount rates, which reduces benefits in the longer term (Ellis et al., 1976).

Net Present Value (NPV): expresses the present value of net benefits (i.e. value of benefits – value of costs at the present time). If the NPV is greater than zero, it indicates that the project or activity gives a net benefit. One of the advantages of using NPV is that it '*gives an answer in absolute terms'* (Power and Harris, 1973). Theoretically NPV is the criterion of choice in most projects (Winpenny, 1991). The mathematical process is described in Equation 2 found in Appendix 4. Although NPV gives an indication of the net benefits, it gives no indication of the scale of the analysis (James, 1987; Huirne and Dijkhuizen, 1997). Discounting is required if comparing projects or activities in different time periods. In many cases the calculation of the discount rate may require gathering large amounts of information or predicting future discount rates (Just et al., 2004).

Benefit Cost Ratio (BCR): is a ratio that depicts the benefits as a share of the costs. A BCR of greater than one indicates a net benefit in the project or activity (James and Ellis, 1979). Equation 3 (found in Appendix 4) demonstrates the calculation of BCR. Like NPV, BCR gives no indication of the scale of the project, which can be an issue if different projects are to be compared (James, 1987). However, if projects of different size, with different NPVs are to be compared, then the use of BCR as the choice criterion is useful (Winpenny, 1991). Caution must be used when interpreting the value of the BCR. A higher value BCR does not necessarily mean a more worthwhile option (particularly in the case of disease control), as the dependability of the value is effected by the loss-expenditure relationship and the social consequences (i.e. the intangible impacts) aside from the economic outcomes (McInerney, 1991b; Ramsay et al., 1999). Therefore, use of BCR to compare more than two options for disease control does not enable us to rank alternatives in order of economic viability as it *'fails to discriminate appropriately between alternative schemes which is acceptable'* (McInerney, 1991b) page 152. Dagupta and Pearce (1972) claim that although there are drawbacks to the use of BCR as an indicator, it can be useful for ranking options within a single time frame. The polarity in these opinions can be explained by the consideration of CBA versus sCBA, the scale of the project and the timeframe during which the expected benefits of the project will continue.

There are some special cases applicable to the CBA evaluation methods where a modified approach must be taken. These can arise where difficulties in assigning values occur or where a full CBA is not required. A modified CBA is used as a method of assessing investment options, seen more frequently in human medicine where costs and benefits cannot be measured in the same units (Otte and Chilonda, 2000). A modified form of CBA known as Cost Effectiveness Analysis (CEA) is described by Huirne and Dijkhuizen (1997), Ellis et al., (1976) and Otte and Chilonda (2000). This is used where benefits are difficult to quantify and parameters cannot be expressed in monetary terms, for example when a full assessment of costs and benefits is not required, but where a goal is desired at least cost.

Internal Rate of Return (IRR): is an estimate of the interest rate earned on the project or the return on investment for the project (James and Ellis, 1979). It is the discount rate that makes the net present value (NPV) of all cash flows (both positive and negative) from a particular investment equal to zero. In real terms it is a useful measure, because it can be used to compare the project's return on investment with national interest rates. It does not require the application of a discounting rate.

If the IRR is greater than the reference interest rate, the project or activity gives a net benefit. It reflects the interest rate that would make the present value of the benefits equal to the costs (i.e. the discount rate that allows present benefits to be equated with present costs) (Thrusfield, 2007). Use of IRR is beneficial as it helps to avoid the issues with selection of a discount rate, when comparing projects in different time periods, or over long time periods, as seen in NPV. Potential issues with the use of IRR do exist. These problems include when annual costs never exceed annual benefits (so the IRR algebraic problems can never be solved) or when you have multiple IRRs for a multi-year problems, such as when the relative size of costs and benefits from year to year vary (Dijkhuizen and Morris, 1997). An example of this problem would also include long term projects where the discount rate is changing from year to year or varies greatly over the length of the project.

The IRR is generally calculated using an iterative process until the correct rate is found, as there is no simple way to solve the algebraic solution to the IRR formula (James, 1987). This formula is described in Equation 4 in Appendix 4. Today the ability to calculate IRR is greatly improved by the inclusion of a function in Microsoft Excel™ spreadsheets. This allows the profitability and potential for growth in the project to be assessed within the CBA methodology.

Overall, CBA is a commonly used tool for making economic assessments of animal health issues. It has an element of flexibility missing from many other tools that allows it to incorporate collateral information from epidemiological or economic modelling. It has many applications from project appraisals to comparing different strategic approaches to animal health issues (Gittinger, 1982; Bennett, 1992; Rushton et al., 1999; Rich et al., 2005). CBA also is an encompassing process that allows a systematic investigation of the problem at hand (Dagupta and Pearce, 1972). The advantages and disadvantages of CBA are summarised in Table 8 and Appendix 3 lists a number of CBA studies in animal health economics.

CBA is not, however, without drawbacks. Arguably one of the biggest disadvantages of CBA is the amount of data it requires (Thrusfield, 2007; Rushton, 2009). This drawback is not unique to CBA, but certainly can present major limitations when data are lacking. CBA can allow for the incorporation of modelled data in lieu of missing data, but that increases the complexity of the operation of the analysis (Bennett, 1992; Rushton et al., 1999).

Table 8 - Advantages, disadvantages and applications of the use of Cost-benefit analysis (CBA)

Advantages	**Disadvantages**	**Applications of use**
Can incorporate epidemiological studies[1] Can be made dynamic by discounting projected future revenues[1] Can incorporate stochasticity into CBA for risk analysis probability distributions[1] Is very comprehensive[6] Has high interpretability for non-economists[10] Costs and benefits identified may be subjective but at least they are identified and accounted for[13] Can use sensitivity analysis to reduce uncertainty [4]	Does not allow optimisation within model framework[1,3] Data requirements are high[2] and base data may be lacking[3,4] or insensitive[8,9] Difficult to appropriately address societal values[2] of costs and benefits of intangibles and externalities[3,4,5,6,7,] Sensitive to changes in discount rates, adoption rates and changes in production[2,6] Requires technical understanding of the system involved[3] Difficulty in predicting future market prices[3] Risk of double counting externalities if more than one sector involved (transfer payments)[4,5,8] Requires high levels of analytical skills [5, 6] If interdependencies of the system in macro economy is ignored, scope becomes 'partial'[11] Aggregation to higher levels may interfere with data[16,17] Can be biased towards decision-makers functions [2,4,5,13,14,12]	Project appraisals[6, 5, 15] Compare and contrast different strategies such as for disease control[6] Useful where evaluation of decisions or strategies is needed particularly for national policy development[5]

[1] Rich et al (2005), [2] Rushton (2009), [3] Thrusfield (2007), [4] Power and Harris (1973), [5] Bennett (1992), [6] Rushton et al., (1999), [7] Otte and Chilonda (2000), [8] Morris (1999), [9] Grindle (1985), [10] Elbakidze et al.,(2009), [11] Aulaqi and Sundquist (1978), [12] Power and Harris (1973), [13] Dagupta and Pearce (1972), [14] Miller (1996), [15] Gittinger (1982), [16] Beretson (1992a), [17] Disney (2001)

2.5.3 Decision analysis

Decision analysis is a collective term that describes practical and defensible analysis of risk-involved choices, made using a systematic approach, under a particular set of circumstances (Ngategize et al., 1986; Kirkwood, 1992; Dijkhuizen et al., 1995b; Huirne and Dijkhuizen, 1997; Hardaker et al., 2004). Initially decision analysis was mainly used as a farm level tool for decision-making, in particular for making decisions relating to treatment options. It is now used at higher aggregations for strategising responses to disease outbreaks and identifying best-practice options for economically sound responses to disease outbreaks. Decision analysis is a useful tool to deconstruct the large problems of animal health analysis into smaller pieces, to allow better judgements and assessments to be made at each step (Christiansen, 1985; Perkins and Pfeiffer, 1999; Tomassen et al., 2002; Mourits and van Asseldonk, 2006; Mourits et al., 2010).

Like many other strategic planning and evaluation tools used in the veterinary field, decision analysis has its roots in military planning, before the methodology was extended to economics, medicine and more recently animal health (Weinstein, 1980; Carpenter and Dilgard, 1982; Ngategize et al., 1986). Decision analysis frameworks are a logical way to define the problem at hand and formulate a chronological set of potential options and outcomes. It can also be extrapolated to encompass quantitative methods such as epidemiological, mathematical and statistical approaches, allowing us to address elements of risk and uncertainty and to investigate trade-offs that need to be made (Christiansen, 1985; Ngategize et al., 1986; Bennett, 1992; Perkins and Pfeiffer, 1999; Tomassen et al., 2002).

Often we see decision analysis presented in diagrammatical form – that of a decision tree or process chart (as shown in Figure 4). Depicted in this way, the main components of the diagram are decision nodes (where our decisions that are made reflect a choice), chance nodes (that indicate there is a probability or likelihood associated with the outcome of the decision node on that branch of the decision tree) and terminal nodes (which represent the value of the end outcome along that branch of the decision node). Decision nodes are generally represented by squares and chance nodes by circles (Christiansen, 1985; Ngategize et al., 1986; Perkins and Pfeiffer, 1999). Decision analysis makes a useful visual evaluation tool for decision makers.

Decision analysis can also be tabulated as a payoff table/matrix, but frequent is seen presented as a decision tree, if not a large and complex problem. Decision trees are particularly beneficial as they represent a chronological series of events involved in the final outcome possibilities (Ngategize et al., 1986; Dijkhuizen et al., 1995b; Huirne and Dijkhuizen, 1997; Rushton, 2009). More recently the decision tree concept has been adapted into influence diagrams, often used at managerial levels to improve communications that relate to key dependencies within decision frameworks for an organisation or business (Kirkwood, 1992). We can also use decision analysis for complex problems that outgrow decision trees, by formulating the problem as an algebraic equation (Kirkwood, 1992) as displayed in Equation 5 found in Appendix 4.

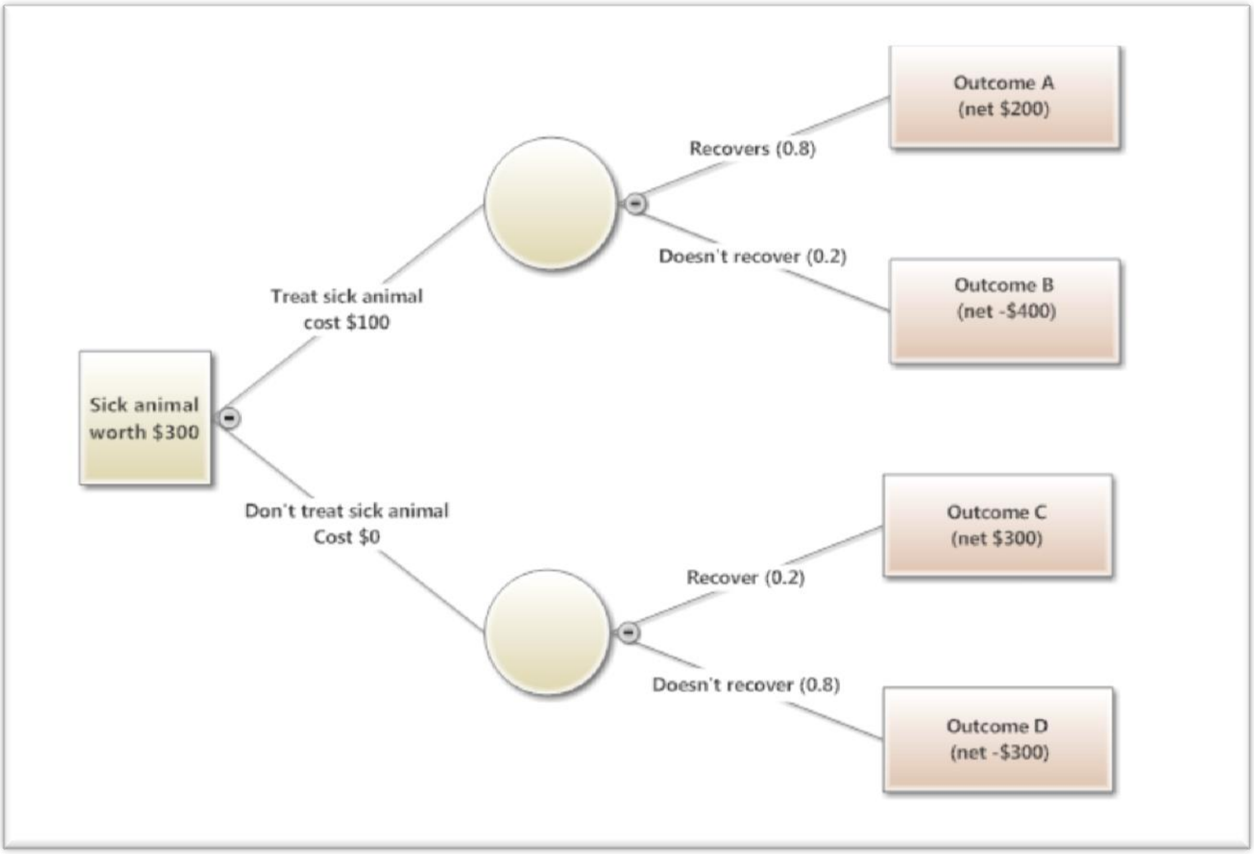

Figure 4 - A decision tree or process chart diagram

2.5.3.1 Parameters and processes used in Decision Analysis

The three key elements at play in decision analysis are (Carpenter and Dilgard, 1982; Rushton et al., 1999) -

1. The alternative approaches to the problem the decision-maker has control over
2. The probability of the event happening
3. The economic value of the outcomes

These elements can be influenced by the decision-makers attitude toward risk and uncertainty (i.e. the impact of risk aversion), the number of conflicting objectives that arise and the impact of multiple evaluation measures that may be required to capture all the decision consequences. Additionally, there may be an impact on the outcomes when discrete approximations rather than stochastic modelling is used in algebraic equations (Kirkwood, 1992).

The chronological process of decision analysis is composed of the following steps (Perkins and Pfeiffer, 1999; Rushton et al., 1999; Mourits and van Asseldonk, 2006).

1. Identify and define the problem
2. Identify the alternative courses of action
3. Identify objectives and criteria for each action identified
4. Construct a decision tree or matrix
5. Score, weight (assign probabilities) and calculate overall values within the framework
6. Examine the results to identify preferred options
7. Conduct sensitivity analysis
8. Implement decision

2.5.3.2 Outcomes from Decision Analysis

The terminal node represents the end outcome for the decision tree branch and must have reached an exhaustive conclusion. At the terminal node we find the expected values (EVs), which are generally used as the basis for the decision criteria. EVs are the product of the probability that the event will occur and the value of that outcome. Most often the EV is associated with a monetary return, hence the generation of the expected monetary value (EMV). In some studies however, other utilities of value, such as life expectancy are used instead of monetary values (Peters and van Sluijs, 2002). The advantages, disadvantages and applications of decision analysis are shown in Table 9.

The EMV should be interpreted with caution. The decision tree aids to support the decision about the best action to take, when you have multiple choices to select from. However the outcome of each choice is not guaranteed. Probabilities that are identified within the decision analysis may relate to previous experiences, or may be expert opinion. In some cases the probabilities may have to be estimated. Therefore the EMV for each terminal node will be an all-or-nothing event, not an averaged outcome. This means that it is unlikely the EMV will ever be actually realised as an outcome.

An additional note to the discussion of decision analysis includes the complexities of multi-criteria decision analysis (MCDA). This occurs when there are trade-offs between outcomes to be made, multiple conflicting objectives occurring or when more than one measure of a parameter is required. Recently there has been an interest in MCDA and its application to animal health, as it appears to enable the facilitation of both qualitative and quantitative information into usable intelligence for the development of prioritised strategies to deal with animal health issues (Del Rio Vilas et al., 2009).

In the applications of MCDA to animal health problems, it was found that the methodology improved both transparency and quality of the process of decision-making (Mourits and van Asseldonk, 2006). These studies used the combination of reflective objective outcomes incorporating economics, epidemiology and socio-ethics. In a study currently being completed, MCDA was used to establish a system of ranking diseases of importance to the Australian pork industry. This ability to rank diseases using qualitative and quantitative data collected from grass roots producers, allows strategic investigation and response to concerns from industry and government (Brookes et al., 2012).

Table 9 - Advantages, disadvantages and applications of use for decision analysis

Advantages	**Disadvantages**	**Applications of use**
Can incorporate risk (probabilities)[1,2,3,4,5,13] uncertainty[4,13] epidemiological information[8] and attitude towards risk[1,9] Portrays a visual representation that can be easily understood [4,7, 13] Flexibility in handling animal health problems[6] Computer-based decision analysis can improve speed of model use[7] MCDA are useful tools to explore different management options where conflict between objectives exist [11] and allow the deconstruction of large problems into smaller sections [9,10, 11,12,] Allows stakeholder input on weighting of preferences for decisions [12,13]	Time and complexity involved in developing the model[6] May end up a large and cumbersome process or model May be difficult for all but the designer to interpret and subjective outcomes depending on the decision-maker, their experience, knowledge and attitude[6] Construction and application assumes analyst has a knowledge of the problem[7] Decision criteria can be uncertain[6] so problem needs to be clearly defined Cost of data sourcing, collections or simulation can be extensive[6] Probabilities do not offer certainty to the decision maker[6, 13] Difficult establishing market or judgement values of input and output parameters [10], or there can be intangibles involved[6]	Used at all hierarchical levels[1,3,4]

[1]Otte and Chilonda (2000), [2]Rushton et al., (1999), [3]Morris (1999), [4]Bennett (1992), [5]Dijkhuizen et al., (1995), [6]Ngategize (1986), [7]Carpenter and Dilgard (1982), [8]Tomassen et al., (2002), [9]Kirkwood (1992), [10]Mourits and Van Assekdonk (2006), [11.]Xevi and Khan (2005), [12]Mourits et al., (2010), [13]Dijkhuizen (1997a), [14] Perkins and Pfeiffer (1999)

2.5.4 Input-output models

Input-output (IO) models were developed by Wassily Leontief in the 1930s. Leontief had an interest in the structure and components of economic systems and how the sectors melded together under different conditions (Miernyk, 1965; Duchin and Steenge, 2007). The IO model measures the direct and indirect financial interconnectedness of interactions between different sectors, at a national or regional level of the economy. It thus tracks the flow of finances between sectors. It is commonly displayed as a matrix or transaction table depicting inter-industry exchanges as is shown in Figure 5 (Roberts, 1990; Garner and Lack, 1995; Caskie et al., 1999; Ekboir, 1999; Mahul and Durand, 2000; Rich et al., 2005).

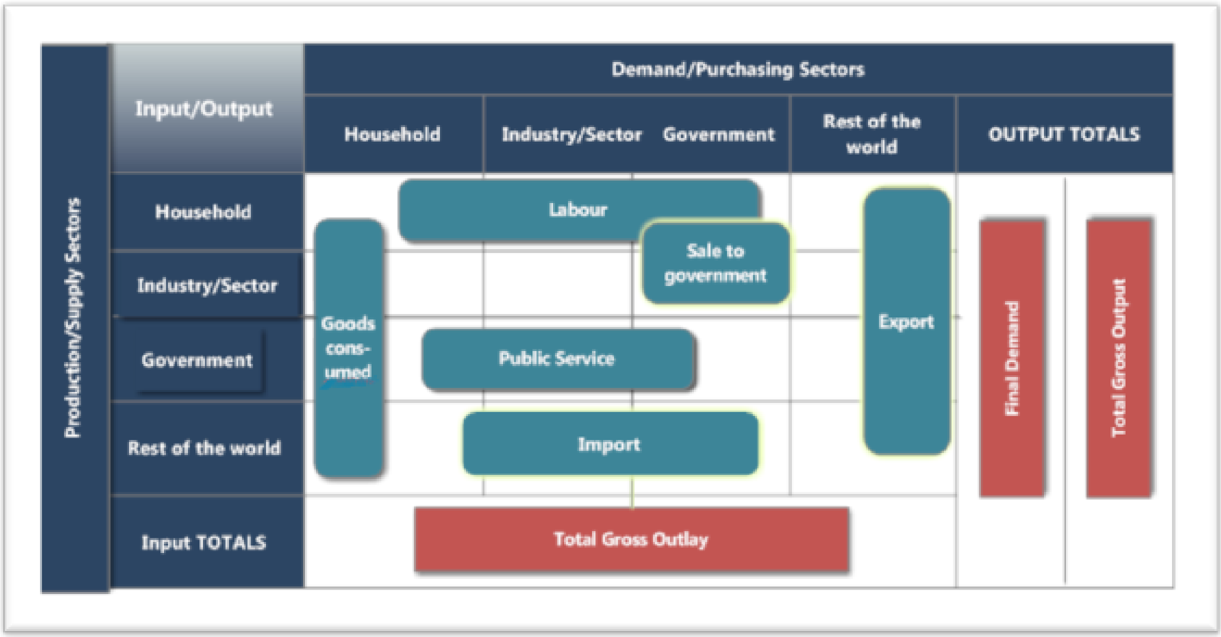

Figure 5 - Representation of an Input-Output Model

Within the matrix, economic sectors are often aggregated into broad categories or sectors (for example - processing, payment or demand). These sectors are represented by a row and a column that summarise the economic transactions within the economy (Miernyk, 1965; Rich et al., 2005). The mathematics of IO economics is straightforward – based on budgets and accountancy (simply a double entry book-keeping), but the data requirements are enormous because the expenditures and revenues of each sector of economic activity have to be represented (Miernyk, 1965; Roberts, 1990).

IO models are useful to policy-makers and analysts as they can be used to prepare and examine projections under alternative policy scenarios. They can help to reveal economic data about a region or an industry and are also useful for forecasting. Issues with the use of IO models for animal health economics arise, due to the impacts of exogenous shock when the agricultural sectors are not disaggregated within the matrix. Often a matrix is designed in such a way to maintain a compact table, however a broad aggregation of the many and varied agricultural sectors will desensitise the model for impact on a singular sub-set within the agricultural sector (Roberts, 1990). The advantages and disadvantages and applications of IO models are displayed in Table 10.

An example of where highly-aggregated sectors could create an issue with desensitised outcomes in an IO matrix, is during a national animal disease outbreak. A disease incursion would create a lag in production for the animal industry, but the impact of this reduced capacity to supply product, may not be adequately represented in an aggregated model, because other agricultural sectors or other non-affected animal sectors may hide the impact. So there is potentially benefit in creating maximum disaggregation within the table in this case, so the real impacts of the disease outbreak are not hidden. Disaggregation is especially useful if the IO model is being used as a tool for forecasting flows of capital within the industry (Miernyk, 1965; Rich et al., 2005). Some examples of IO models used in animal health are given in Appendix 3.

2.5.4.1 Parameters used in I-O analysis

Inputs: Budgetary/financial estimates of sectoral activity for final demand, final payments, industry output and employment for each region, industry or sector along with state and national totals.

Outputs: Being demand-driven, most input-output models are structured to trace changes in the flows of capital and labour between industries in response to changes in final demand (Caskie et al., 1999; Vargas et al., 1999).

Coefficients: Simplified, input coefficients (also called technical coefficients) are created for the processing sector industries by calculating the amount of inputs required from each industry to produce one dollar's worth of the output from a given industry, in other words, the amount of commodity *a* required to produce one physical unit of commodity *b*. The reality is more complicated as most sectors will both consume and produce a number of commodities. There are many methods of constructing coefficient tables and often the choice of which to use is based upon the prior experience of the operator, recommendations from other users and the region in which you are operating (Miernyk, 1965; Bennett, 1997).

Multipliers: proportionately measure how much an endogenous variable will change in response to a change in some exogenous variable in terms linking directly to monetary units (Liew, 2005). They can be formulated by adding the direct and indirect effects of the change and dividing by the direct effects of change. The algebraic equations (Equation 6) for IO models can be found in Appendix 4.

Table 10 - Advantages, disadvantages and applications of the use of input-output models

Advantages	**Disadvantages**	**Applications of use**
Mathematically straightforward based on budgets Modification from demand to supply driven models is able to be facilitated[3] Captures transfer payments[5] Use of dynamic IO models can account for longer term forecasting[6,9] and are price sensitive[7]	Collection and preparation of data time consuming, labour intensive and costly[1,5,] so delays between data collection and publication may occur Do not thoroughly address dynamic issues such as changing prices, technology or behaviour[1,7] Driven by economic changes in demand[9] not supply, so effects of an animal disease outbreak on supply may not be relflected[1,2, 8] Makes the critical assumption that production is demand driven [1,4] Input coefficients only useful for short term forecasting[6,10] Calculation of input coefficients is complicated[11]	Comparing/predicting policy change impacts on other sectors within an economy Allocation of government funds and increasing efficiency by determining which sectors have the greatest national economic impact Impact of international trade restrictions on sectors of the national economy[1,2]

[1] Rich et al (2005), [2] Mahul and Durand (2000), [3] Anon, WHO (2010), [4]Vargas et al (1999), [5] Roberts (1990) , [6] Miernyk (1965), [7] Liew (2005), [8]Caskie (1999), [9] Duchin and Steenge (2007), [10] Garner and Lack (1995), [11] Jansen and Raa (1990)

2.5.5 Social accounting matrices

Stone and Brown (1962) developed the first social accounting matrix (SAM) as part of a community growth project in the United Kingdom. SAMs are an extension of IO analysis and include the distribution of factors down to the household level, rather than a primary focus on aggregations within major production sectors in the economy. They are set out as a square matrix of "accounts" represented by rows and columns. The main differences between a SAM and an IO matrix is the disaggregation of the accounts (down to the household level) and the highlighted distribution of income and expenditure within the economy (Roberts, 1990; Vargas et al., 1999; Rich et al., 2005; Breisinger et al., 2010).

Using a SAM as a representation of an economy we are able to see links and flows between elements such as production activities, income distribution, consumption of goods and service, investments and savings and foreign trade (Nwafor et al., 2006; Breisinger et al., 2010). Data discrepancies or missing data will be highlighted in this development process. SAMs will also capture transfer payments and in doing so give an indication of the distributional impacts of an exogenous shock (Roberts, 1990; Breisinger et al., 2010). A diagrammatic representation of a SAM framework is given in Figure 6.

A SAM can be used in the initial stages of an economic study, to organise the information about the economic (namely financial flows) and social structure of a country (or other unit of analysis). On its own a SAM is not a model, but a dataset that represents an economy. To turn the SAM into a SAM based model a number of steps ensue. Firstly accounts must be classified as either endogenous or exogenous (traditionally government, capital and rest of the world accounts are considered exogenous), then these accounts are linked through mathematical relations. The advantages and disadvantages of SAMs and their applications of use are given in Table 11.

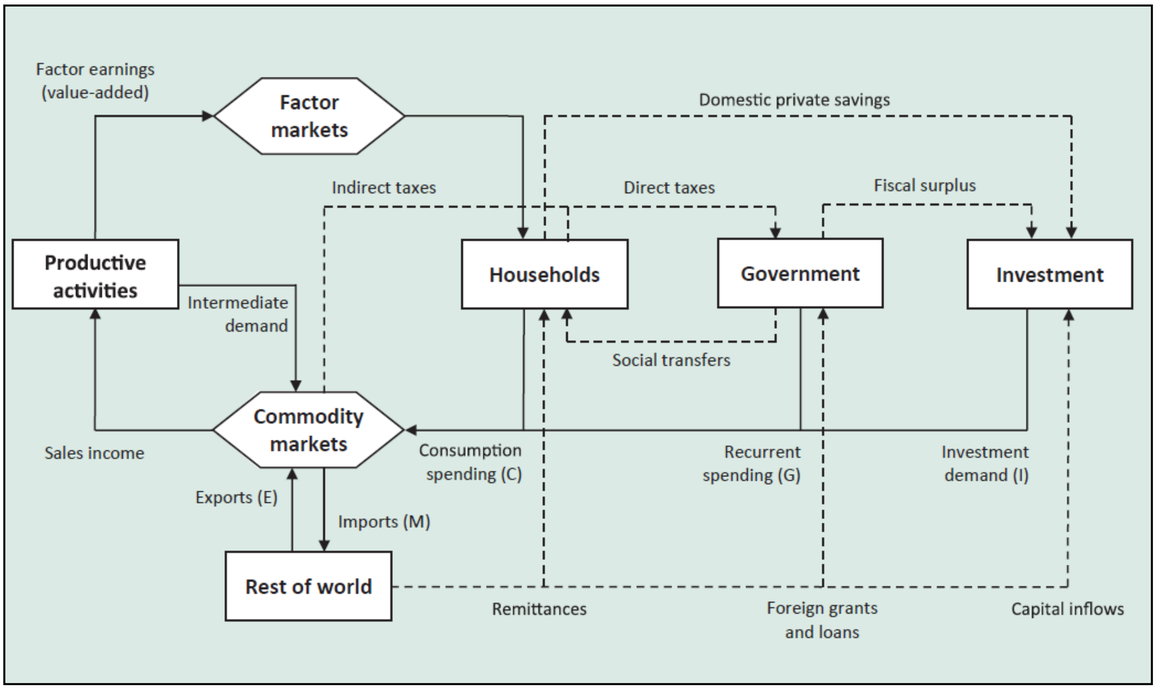

Figure 6 - Economy wide circular flow of income in a social accounting matrix. Figure from Breisinger et al (2010)

The linkage of accounts is done using the matrix multipliers. Once these steps have been completed, the model has the capacity for simulation, allowing it to be used to monitor changes in the economic environment. These operations enable a more comprehensive analysis or investigation of policy scenarios and their impact on a wider economic scale (Roberts, 1990). The use of SAMs in animal health tends to be applied to changes in demand for a commodity – such as with the occurrence of a disease outbreak, and the subsequent impacts within a sector, industry or household (Caskie et al., 1999; Poulton et al., 2003; Upton, 2008).

2.5.5.1 Parameters used in social accounting matrices.

Inputs: The matrix/table is divided into disaggregated accounts. The budgetary incomes and expenditures relevant to a national economy are those of - activities, commodities, factors, institutions or agencies (farms, firms, household and government), government capital and rest of the world (Nwafor et al., 2006; Upton, 2008). Some schools of thought, as reported in Roberts (1990), consider five accounts having merged the activities and commodities accounts together into production accounts.

Nwafor (2006), describes the actual data needed for construction of the SAM as follows –

1. National accounts
2. Balance of payments
3. Monetary accounts
4. Public sector budget
5. Input-output matrix
6. Secondary data on household consumption, factor employment and capital stock.

Outputs: Although theoretically a SAM will balance, it is rare that the empirical data collected is consistent and comprehensive enough for this to happen. As a result, the outcomes are often indicative rather than exact. By using estimation techniques, reconciliation of the accounts can still occur, making the use of the outcomes feasible in studies (Mansur and Whalley, 1984; Poulton et al., 2003; Breisinger et al., 2010).

Matrix multipliers: Are generally tabulated indices (Roberts, 1990; Poulton et al., 2003; Round, 2003). They are used to turn a SAM into a SAM model. A multiplier is a measure of the impact of an exogenous shock on an account, in terms of both production and consumption, (i.e.) how much the direct and indirect linkage effect is amplified. Multipliers can be input, output or GDP multipliers (Breisinger et al., 2010). Like IO, matrix multipliers can be formulated as the sum of the income derived from the direct and indirect effects of change, divided by that of the direct effects of change.

Table 11 - Advantages, disadvantages and applications of use for social accounting matrices

Advantages	**Disadvantages**	**Applications of use**
Extensive data framework allows investigation of a wider range of policy scenarios[2] Allows for flexibility in disaggregation - ability study part of an economic system[3,5] Brings data together from many different sources and improves economic estimates through highlighting data needs [2,3] Provide a base framework for modelling[2,3] Captures transfer payments and income distribution[2,6]	Massive data requirements[4] Incorporation of disaggregated data can be inefficient, time consuming and costly[1] The further the SAM is disaggregated the greater the data requirements and therefore cost[3] SAM-based multipliers rely on strong assumptions so transparency required[2,3] Not useful for finding optimum allocation of resources[4]	Inter-sector impact analysis on a regional or national level.

[1] Robinson (2000), [2] Roberts (1990), [3] Round (2003), [4] Upton (2008), [5] Poulton (2003), [6] Breisinger et al,. (2010)

2.5.7 Computer general equilibrium

Computer general equilibrium (CGE) models are utilised to monitor the impacts of changes or adjustments in policies across multiple markets (Wing, 2004). A CGE model simulates the working of a market economy as a dynamic integration of the relationships between sectors that are representative of a total economy. As a result of the large scope covered by CGE models, they are very data intensive. The first step in the development of a CGE model is the identification and organisation of data – generally into a SAM or IO matrix. The dynamic nature of the linkages and dynamic economic flows gives CGE models advantages over the matrices (Vargas et al., 1999; Rich et al., 2005). The additional value of the model lies not in predictive ability but in their ability to illuminate economic adjustments amongst markets (Wing, 2004).

An advantage that a CGE model has over a SAM model is that market equilibrium can be accounted for, as well as the macro-economic variables. This means that although the initial impact of a shock will be captured in a static SAM model, the after-effects and adjustments to the shock will be captured by the more dynamic CGE model (Nokkala, 2002; Upton, 2008). Other advantages and disadvantages, and the application of the use of CGE are displayed in Table 12. There are few examples of CGE models in animal health, likely due to the data requirements; however they can be a useful tool in assessing implications of policy changes or disease effects. Of the applications of this model to animal health that do exist, an application of this model combined with an epidemiological disease spread model, shows potential for future studies if skilled operators are available to deliver and interpret results (Carpenter et al., 2011). Some examples of CGE models used for animal health studies are displayed in Appendix 3.

2.5.7.1 Parameters used in CGE

As previously mentioned, building blocks of a CGE generally begin with data organised into a SAM or IO matrix. This leaves the CGE model open to the same restrictions and benefits as SAM or IO models that they are built around. Algebraic computations (with equations derived from constrained optimisation of the production and consumption functions) are then used to calculate the effects of the impact in question (Vargas et al., 1999; Wing, 2004).

Table 12 - Advantages, disadvantages and applications of use of computer general equilibrium models

Advantages	Disadvantages	Applications of use
CGE models are useful whenever we wish to estimate the effect of changes in one part of the economy upon the rest of the economy[1,4] Can cover longer time frames and is dynamic in in price adjustments[2,3] Can incorporate epidemiological data Can examine data down to the household level[4,5]	Complexity and cost to build and interpret high, however dynamics can be illustrated in an algebraic framework[1,4] Model is not easily transparent due to complexity[3, 4] Large numbers of relationships need to be estimated[2] Model is essentially static so not useful for forecasting[2,4] May lose focus on some areas of analysis in the data storm.	National impact of policy changes[1,2,3,4] (e.g.) trade policies, development policies, taxation Impact of natural disasters on specific sectors of the economy

[1.] Rich et al., (2005), [2.] Upton (2008), [3] Nokkala (2002), [4.] Wing (2004), [5] Roland-Holst et al., (2010)

2.5.8 Mathematical programming

Mathematic programming methods, also known as optimisation methods, are quantitative planning techniques that assist in finding best available solutions to allocation and distribution problems (Bennett, 1992; Otte and Chilonda, 2000). They were originally developed during the Second World War as a method to evaluate the optimisation of transport logistics to supply goods to the troops and their use in the agricultural sector began during the 1950s (Jonasson, 1996).

From an animal health perspective, they can be prescriptive or predictive applications to economic problems and useful for purposes such as - estimating adoption of new technology or predicting impacts of policy change on certain elements of sectors of the economy (McCarl and Apland, 1986). They are especially useful when typical economic and behavioural predictors are of limited value. Examples of such predictors would include historical trends, or when new and large changes are expected (Apland et al., 1994).

Mathematical programming can be used to either maximise (e.g. profits) or minimise (e.g. costs) an objective or function, whilst satisfying constraints, which include the following -

- Physical restraints such as on-ground resources available and technology
- Subjective constraints reflecting operator preferences
- Accounting/financial constraints

Assumptions that relate to the data used in mathematical programming are imposed. These are the assumptions of linearity, divisibility, finiteness, certainty and non-negativity (Jalvingh et al., 1997; Zepeda et al., 2000). Mathematical programming has a high requirement for data and the capacity for data extrapolation is limited, which means it has little use in inter-sector analysis (Rich et al., 2005). It does however, have many applications and usages in animal health, including at the national level (Rushton et al., 1999). Advantages, disadvantages and applications of mathematical programming are contained in Table 13.

Mathematical programming can be further dissected into the follow methods -

a) **Linear programming** (LP) is used to determine an optimal solution (maximisation or minimisation) for a defined set of objectives and constraints, where one parameter at a time is changed, and its influence on the optimal outcome determined over a single time frame (Jalvingh et al., 1997). One of the benefits of the LP model is that it can help make logical frameworks for complex economic problems, allowing for easier evaluation of alternative paths of action (Habtemariam et al., 1984). LP can be used to solve micro- or macro-economic problems. The variants of LP include integer programming and multi-period linear programming. Another variant is that of dynamic linear programming, not be confused with dynamic programming (DP) described below. The key difference between DP and dynamic LP, is that in dynamic LP, the constraints do not change. Dynamic LP generally involves longer timeframes with the same key optimisation functions (Zepeda et al., 2000; Acs et al., 2007). Non-linear programming is also a variant of LP that is covered further in Multi-Criteria Programming. The algebraic function for LP is described in Equation 7 found in Appendix 4.

b) **Dynamic programming** (DP) – is not a direct variant of LP, but a model of multistage decision-making. This decision-making occurs over a period of time where the constraints may change, creating a series of partial optimisations (Bennett, 1992; Acs et al., 2007). Like LP it can be used to solve both micro- and macro-economic problems. DP is used to devolve large problems into a series of partial optimisations, which reduces the complications associated with finding optimal solutions to large and complex situations (Pike, 2001). This process is algebraically described in Equation 8 found in Appendix 4.

c) **Multi-Criteria Programming (MCP)** – also known as multi-objective optimisation, is a method used when multiple objectives are sought from the same process (Bennett et al., 1999). Currently this is more commonly seen used is areas such as environmental development and petrochemical engineering. Applications of MCP in animal health appear to be uncommon, although a few examples exist in the agricultural sector. The methodology tends to be an extrapolation of the LP methods as mentioned above, with compensations made to adjust non-linear equations into linear equations. The simplest method is the successive/sequential linear programming (SLP) and successive quadratic programming (SQP). More commonly SLP is used. SLP works by replacing non-linear functions in non-linear programming with an approximation as a series or sequence of linear functions to enable LP to occur. Benefits of using this method include being able to handle large and complicated problems, as well as handling problems with many constraints and variables. The process is relatively easy to implement, as long as the LP functions have associated flexibility (Zhang et al., 1985). Equations 9 and 10 found in Appendix 4 show the algebraic expression of MCP and SQP respectively.

2.5.8.1 Mathematical programming parameters:

Inputs: Inputs vary depending on the function to be optimised. They can be biological, epidemiological, economic, environmental or technical parameters depending on the situation being optimised.

Outputs: The solution from the model will be an optimised goal as specified by the designer in response to a specific problem. It can be a maximisation, minimisation or best option solution. This can then act as a proxy for net social benefits, which in turn provides decision strategies, best-cost alternatives or functional goals to support decision-making (Hall et al., 1998; Acs et al., 2007).

Table 13 - Advantages, disadvantages and applications of use for mathematical programming methodologies

Advantages	Disadvantages	Applications of use
Can address multiple objectives if designed to include them[1,2] Can give a logical format to a complex problem	High data requirements[2,5,6] Require strict specification of the decision problem[1,2] In biological systems assumptions for constraints and interaction of biological parameters may be oversimplified[3,8] Inter-sector linkages generally excluded as a result of data limitations[4] Temporal dimensions are missing in many models[5] Reliant on economic theory and extrapolation from producer level data which may produce a conflict of interest in private vs. public objectives [6] Costly to develop[6] May be prone to receiving only superficial validation[7] Assumptions of divisibility, additivity, non-negativity, certainty, linearity and finiteness must be made [3, 9]	Suitable for structured decision-making where no intuitive judgment is required especially when using LP[1] Used when large changes are expected or when historical trends are not good predictors of future changes[5]

[1] Bennett (1992), [2] Rushton et al., (1999), [3] Habtemariam et al.,(1984), [4] Rich et al., (2005), [5] Jonasson (1996), [6] McCarl and Spreen (1980), [7] McCarl and Apland (1986), [8]. Hall et al.,(1997), [9] Zepeda et al., (2000)

2.5.9 Economic surplus methods

Economic surplus methods attempt to quantify the shifts in the supply curve and are used at the national level to assess the impacts of these changes. In the 1970s these methods were viewed as controversial. In part this occurred because the old *versus* new welfare economics debate challenged the usefulness of the concept to contribute to policy decisions. At the time, their main uses were considered to be - 1) for measuring the welfare effects of deviation from an optimum competitive equilibrium and 2) international trade (Currie et al., 1971).

Today economic surplus models are often used as models to analyse impact of changes, particularly new technologies. This makes economic surplus a useful framework to measure the aggregated social benefits of research projects, by comparing the gains made from uptake of the research with that where there is no uptake of the research. Hence they are often used for assessing research activities (Masters, 1996; Wander et al., 2004; Rushton, 2009; Sumner et al., 2012). The method is based around supply and demand curves and the resulting level of equilibrium achieved when supply and demand intersect, even if only temporarily. It can be noted that economic surplus can be divided into consumer or producer surplus. If we are conducting a study of impact assessment (for example - research benefits), the total economic surplus (consumer plus producer surplus) is the assessment figure that is considered (Masters, 1996). The visual representation of supply and demand curves can be seen in Figure 7.

The supply curve is an upward sloping curve, therefore it reflects that the change in quantity supplied and must be accompanied by a change in price, unless there is another factor that will impact to "shift" the supply curve, such as a change in the price of land or labour, or a new technology (such as a new crop). The supply curve is described mathematically in Equation 11 (Appendix 4). The demand curve is described mathematically in Equation 12 (Appendix 4), and is a downward sloping curve that reflects the function of price and quantity supplied.

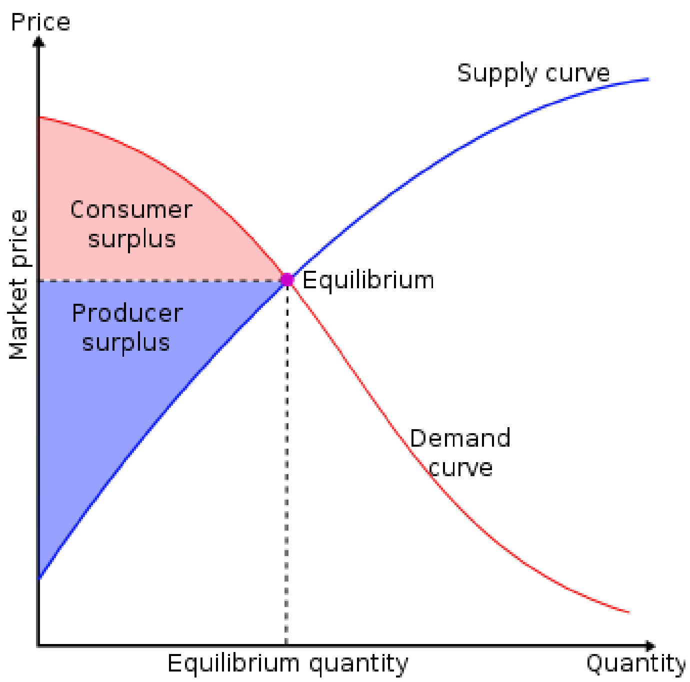

Figure 7 - Graph depicting supply and demand curves. Source: (Frakt and Carroll, 2010)

As the demand curve is a downward sloping curve, it reflects that increased demand prices are associated with decreased demand quantity (i.e. – the less demand for a product the more costly it is). "Shifts" in the demand curve can come from changes in willingness-to-pay for a good, or ability to pay for a good (such as changes in income) (Masters, 1996).

The advantages and disadvantages of the use of economic surplus methods are described in Table 14. Like many other economic methods, the main practical limitation of the method is the requirement for technical and economic data such as the following (Masters, 1996; Rushton, 2009):

- Market data – costs, prices, elasticities
- Agronomic data – adoption rates, yields, cost of technology to implement
- Economic data – market responses to chance
- Research data – research, development and extension costs

2.5.9.1 Parameters used in economic surplus methods.

Input: There are three main inputs that are considered when using economic surplus methods (Masters, 1996) -

1. Supply – which is equal to the production costs
2. Demand – which is equal to the consumption values and
3. Equilibrium – where price and quantity intesect as a result of these previous forces

Output: The measure of output in an economic surplus method is that of total economic surplus. This is the primary measure to indicate if a change in the system has been positive (e.g.) uptake of a new technology has been beneficial. It is also used in welfare economics to evaluate the efficiency of a proposed policy.

Table 14 - Advantages, disadvantages and applications of use for economic surplus models

Advantages	Disadvantages	Applications of use
Able to make predictions regarding how changes to the livestock sector will affect markets and who will lose or gain[1]	Value judgments required for analysis[1,5] May not be policy relevant[4] Collecting, processing and analysis of technical and economic data [1,5]	Main use is for determining the economic benefits or consequences of research[1,2,3]

[1] Rushton (2009), [2] Masters (1996), [3] Alston (1998), [4] Currie (1971), [5] Falconi (1993)

2.5.10 Partial equilibrium models

Partial equilibrium models are dynamic models that operate around the supply and demand functions. The methods are a mathematical process for modelling a specific commodity in a specific time and place. These models operate in an optimisation framework, but have spatial and temporal limitations as constraints in the model. The dynamic process operates so that prices adjust until supply equals demand and makes the assumption that all other parameters remain constant. Although it can be applied at higher aggregations, it only examines markets that are directly affected, although can be designed as multi-market or single-sector models.

These models either ignore other industries or make the assumption the industry in question is too small to impact on national economy - which is rarely the case in animal health emergencies (Rich et al., 2005; Suranovic, 2010). Partial equilibrium models tend to only look at a single industry and therefore do not reflect changes to a regional or national economy. They also lack the capacity to give detailed information on program costs when aggregated to the national level.

2.5.10.1 Parameters used in partial equilibrium models

<u>Input:</u> Unit of analysis – market (i.e.) price *versus* quantity, with supply and demand vectors forming the optimisation intersection.

<u>Output:</u> Measured impacts are for aggregations of consumers and producers within a singular market/industry (Rich et al 2005).

2.6 Using economic models in the real world

2.6.1 Simulation models and system analysis

Simulation modelling and systems analysis are slightly different approaches to the economic analysis tools mentioned above, as they emulate functions within the system under certain conditions, to predict what happens. They allow the application of dynamic parameters and allow for the inclusion of risk parameters within the simulation. This makes the method useful for application to livestock diseases as an integrated epidemiological/economic model (Bennett, 1992; Otte and Chilonda, 2000). These methods can also be used to develop empirical data through modelling. These data can then be used for analysis in other economic assessment tools such as CBA and economic surplus methods. A major benefit of using simulation is to represent a system when experimentation cannot be used or to help generate data that would otherwise not be available. It can also be used to cover many or different time periods and allows stochasticity within the analysis.

2.6.2 Sensitivity analysis

Sensitivity analysis is a method of determining how changes within the system will affect the outcome of the model being used. If small changes to the input parameter values create large changes to the output values, then the model is said to be highly sensitive to that parameter. The benefit of sensitivity analysis is that it allows us to be aware of the variables that are most important when changed. Sensitivity analysis can also be used to highlight cautionary use of data of dubious quality that creates high sensitivity, and to indicate the stability of the model in relation to the variability of the input data (Thrusfield, 2007).

Changes to the structure of the model will have greater impacts than changes to the parameters used within the model, which highlights the need for a clear and precise objective for the model (Breierova and Choudhari, 1996; Pannell, 1997). Sensitivity analysis performed in relation to economic modelling processes can help to guide decision-makers. It will assist in identifying the variables that hold the greatest sensitivity to change, which may impact the choice of the most optimal or effective policy (Pannell, 1997).

An example of where sensitivity analysis has been used in animal health studies is a study by Barasa et al (2008), who performed sensitivity analysis following a conventional CBA (used to identify benefits of Foot-and-Mouth Disease (FMD) vaccination in South Sudan). In this case concerns were raised over the exaggeration of mortality figures presented by farmers, which were collected via participatory epidemiology. When sensitivity analysis was performed, it was found that net benefit was gained, even when an exaggeration of 75% mortality was modelled. This allowed decision-makers to justify that even if mortality figures were greatly inflated, the net benefit (in terms of humanitarian impact) from the vaccination program could be justified.

2.6.3 Validation of models

Validation processes, will ascertain if the model performs sufficiently enough to effectively represent the system it was created to mimic. These processes may include both internal and external validation, as well as sensitivity analysis to strengthen the assessment of performance (Dijkhuizen et al., 1997c). The strengths and weaknesses of a model found in a systematic approach will provide for a semi-objective evaluation, despite the fact that real-world systems contain more constraints and details than can be represented in a model (McCarl and Apland, 1986; Kennedy et al., 2008). Validation can be qualitative, quantitative, statistical, risk-based, descriptive and/or corroborative. The process of validation should be consistent, accurate and stable enough to provide effective predictive ability in the future use of the model and its credibility. This is particularly important if there are changes to policy that are to be derived as a result of the outcomes of the model.

Independent validation processes are valuable, because the conclusions that can be drawn from the model and from the process of validation, are subjective. It is usual that more than one method of validation is undertaken and it should be expected that the process of validation is iterative (Hilton, 2002). As for designing and operating models, great skill and experience is required for validating models, so with cost reduction often paramount, the ultimate validation is the adoption of the model by decision-makers (McCarl and Apland, 1986).

There are many levels at which a model can be validated, but the most detailed evaluations will look at all levels (although it is likely to be impossible to test all inputs and parameters – and the sensitivity analysis should help to identify the limitations). These can include -

- Research question validation (scientific or economic)
- Structural validation - model coding (mathematical program, decision tree, matrix)
- Parametric validation
- Interpretive validation of outcomes (whether they are specific enough for predictive use)

2.7 Summary of economic analysis methods

It is evident that none of the economic assessment tools described in this chapter are without limitations. While each tool has individual merits, none are without issues related to its application. Many of the tools can be used for multi-level analysis, with the more complex tools able to simulate and analyse impacts on a nationwide economy. Data requirements appear to be the most common limiting factor in the use of economic analysis tools; however, simulation techniques and extrapolation of available data can help to reduce this impact. Complexity in the design, application and usability of the assessment tool, as well as the interpretability of the outcome of the analysis are also limitations of many tools.

When considering the assessment of the economics of animal disease control, it needs to be kept in mind that the outcomes will need to be policy-relevant, which means that budgetary restraints are not the only consideration, but a part of the holistic policy picture which includes the epidemiology of the disease, intangible impacts, biological and economic optimums, the availability of resources (including data), the priorities of the stakeholders concerned and the information available to support the decision being made (Thieme Jr, 1987; Rich et al., 2005; Rushton, 2009).

In the review of the literature undertaken for animal health economics, CBA is certainly a very commonly (if not the most commonly) used economic assessment tool in animal health. It has practical applications at all levels of the animal production hierarchy and allows the user some flexibility in its application. CBA can incorporate data from many different sources and can be expanded to include epidemiological studies. CBA is made dynamic by inclusion of discounting for future revenues and can incorporate risk through stochastic modelling (Rich et al., 2005). The limitations of CBA include the high data requirements and sensitivity to changes within the economy. As reported by James and Ellis (1979), quantifying some benefits and costs can be very difficult. Many of the intangible costs and benefits (such as human health, environmental impacts and livelihood of producers) are taken into consideration by decision-makers anyway, so must be described in some way. This issue will be further explored in chapter 3.

Chapter 3 - Assessing the intangible impacts of emergency animal diseases

3.1 Defining intangibles

The difficulty in making a complete assessment of EAD impact is exacerbated by the need to address both tangible and intangible impacts. Intangibles are described by the Oxford English Dictionary (2010) as those '*which cannot easily or precisely be measured'.* Zambon (2003) offers the alternative definition of- *'non-physical sources of expected future benefit'*. Lev (2001), Wagner (2001), Zambon (2003) and Eustace (2003) all suggest that intangibles can contribute more to the value (and growth) of an enterprise or organisation than physical assets. This suggests that if intangibles are impacted during an EAD, the value of these impacts can potentially be greater than the physical impacts.

Value can be placed on elements such as intellectual property, innovation, biodiversity, environment, human life, knowledge and culture. Yet to define such '*value*' in dollar terms requires more than straightforward accounting under the usual financial standards. The concept of value is highly subjective and studies in behavioural and psychological economics show the existence of certain effects that impact the perception of value. These effects include anomalies in 'preference', particularly choices that are made in the face of certain market options (Gowdy and Erickson, 2005).

The intangibles are also susceptible to the impact of societal factors such as culture, religion, ethical considerations, biases and prior experience. This means that the use of "value" alone, as a measure for the intangible impacts of EADs, is not a practical assessment tool. Value has no yardstick for measurement and lacks defined increments upon which to create a set of measurement rules. It also has no associated measure of time over which to evaluate changes. Value is simply a measure of preference (Gowdy and Erickson, 2005).

However from a policy development perspective, the importance of the intangible impacts are of great concern to stakeholders. At present there is no agreed system of classification (or taxonomy) for either the collection of data relating to intangibles, or for measuring and reporting the intangible impacts. There are no commensurable monetary units to assess this intangible-impact value, unless there is an associated marketable price (for example ecotourism). This lack of a measurement parameter raises the problem of how 'value' can be used to support evidence-based decision-making. As a result, many authors report decision-making relating to intangibles is less transparent by comparison than financial accounting (Guilding and Pike, 1990; OECD, 1992; Sveiby, 1997; Canibano et al., 1999; Mortensen, 1999; Canibano et al., 2000; Croes, 2000; MERITUM, 2001; Blair and Wallman, 2003; Bounfour, 2003; Eustace, 2003; Zambon, 2003).

In this thesis it is proposed that there are differences between intangible assets that have a commercial value (albeit difficult to define or estimate), such as intellectual property or 'good-will' (these are subsequently referred to in this chapter as the commercial intangible assets) and non-commercial intangible elements that have social/moral value. A brief outline of methods used for classification and measurement of commercial intangible assets is given in section 3.2 (for reference only) and relate to the commercial intangible assets listed in Table 15. For the remainder of work in this thesis, the commercial intangible assets impacted by EADs are assumed to be sufficiently enveloped within the commercial value of tangible costs and benefits identified in the economic analysis.

Table 15 – A categorisation system for commercial intangible assets

Intangible assets with commercial value	**Intellectual property**	Intangible assets with **legal** or **contractual** elements[1] - trademarks, designs, patents , copyrights, software
	Capacitating property	Intangible elements requiring **knowledge** and **innovation.** Functions that keep the organisation generating income Education, research and development, trade secrets, market and technical knowledge Information systems, brands, intangibles embodied in capital equipment, internally generated software that does not generate intellectual property
	Organisational property	Unique **Human capital** and **Organisational structure** – Geographical location Human elements such as leadership, networks and administrative structures and processes

[1] Lev (2001)

3.2 Classification and measurement of commercial intangible assets

Taxonomic classification of intangibles is a well-cited problem (Guilding and Pike, 1990; Edvinsson, 1997; Sveiby, 1997; Young, 1998; Canibano et al., 1999; Johanson, 1999; Canibano et al., 2000; Eustace, 2000; Lev, 2001; MERITUM, 2001; Wagner, 2001; Eustace, 2003; Zambon, 2003; Grasenick and Low, 2004). There is still no standardised categorisation (taxonomy) of intangibles that exists, or a globally agreed reporting system. The method of *'classifying'* intangibles that is used will depend on the needs of the user and the paradigms in which they are operating, for example – managerial, statistical, accounting, academic or banking (Johanson, 1999; Croes, 2000; Blair and Wallman, 2003; Eustace, 2003; Grasenick and Low, 2004; Mouritsen, 2004; Sveiby, 2010). Despite much work by the Organisation for Economic Co-operation and Development (OECD), in trying to develop a consistent, harmonised global system of classifying and reporting intangibles, it does not yet exist. Approaches offer a range of complexity and comprehensiveness and vary according to measurability; structure and function of the intangible; and saleability and their ability to create wealth.

The methods that are currently used to *'measure'* the commercial intangibles will also depend greatly on the needs of the end user. The most likely uses will revolve around monitoring performance (control), purchasing or selling (valuation), creating stakeholder reports (public relations), guiding investments (decision support) and value discovery (learning) (Sveiby, 2010). Traditional financial accounting methods have been adopted to assess commercial intangible assets where possible, but there has been a general reluctance to reform the methodology to produce a more suitable tool. The lack of such a tool, limits the recognition and measurement of the magnitude of an intangible as an asset (Guilding and Pike, 1990; Canibano et al., 1999; Mortensen, 1999; Lev, 2001). Of the measurement approaches that are available for commercial intangibles, there is categorisation into four broad areas either as a monetary or non-monetary measure, in either an aggregated system or as a component by component system (Luthy, 1998; Zambon, 2003; Pike et al., 2005; Jurczak, 2008; Sveiby, 2010). These categories are described in Appendix 5.

3.3 Classification and measurement of non-commercial intangibles

The remaining classes of intangibles (non-commercial) displayed in Table 16, are drawn out in this thesis, as important components that have the potential to be affected by the impact of EADs. For the remainder of this thesis, the 'intangibles' refer only to these non-commercial intangibles. For application in animal health and especially for the quantification of societal/moral intangibles impacted during EADs, a modified system of classification and measurement needs to be developed. These intangibles can be broken down into further categories under the broad headings of 'societal' and 'environmental' impacts. For the purposes of this thesis, intangibles are described as *non-physical, non-consumable elements, that are unable to be easily or precisely measured by a common standard or given a commercial value due to their subjective nature, and yet are a source of great worth to those that consider them necessary or useful to the fulfilment of life.*

There is sparse literature available relating to the assessment of such intangibles. Their inclusion in this paper is an essential component of EAD impacts upon - human health, lifestyle and quality of life; heritage and culture; animal welfare; and environmental sustainability, preservation and biodiversity. Conceptually these are the most difficult intangibles to measure. Their measurement will require subjective judgements on the value of human life, animal welfare, the worth of decisions that have future impacts (that may be undiscovered) and be completely dependent on the perspective of the stakeholder (Ellis and James, 1979a; Daily et al., 2000; Gowdy, 2005).

Table 16 – Intangible elements that are impacted during emergency animal diseases

Societal intangibles	Individual	Human life[3,4] Human health[3,4] Human "well-being" (quality of life) Freedom Skill development
	Anthropological	Culture Heritage Legacy/succession[3] Food security[4] Community capacity[4]
	Welfare	Animal welfare
Environmental intangibles	Ecosystem/biological impacts	Biodiversity[4] Sustainability[4] Aesthetics[2] (beauty and serenity, ecotourism[1]) Preservation[2] Scientific discovery (e.g. future pharmaceuticals[2] in rainforest plants, genetic information[2]) Regenerative[2] and stabilising processes[2] (fertilisation, filtration, soil stabilisation) Existence (water, soil, oxygen)

[1] OECD (2004), [2] Daily (2000), [3] Green (2007), [4] Otte et al., (2004),

3.3.1 Measuring individual and anthropological intangibles

In the assessment of EADs, financial losses rather than the human costs have been the measurement focus. Livelihoods, human mental and physical health and loss of succession plans (legacy), are often neglected in such economic assessments (Green, 2007). This may well be because there are no tools that allow the measurement and incorporation of these impacts into commonly used economic assessment tools for animal health. In the field of human medicine, outcome indicators for human health status have been created in order to minimise the problematic issues surrounding measuring and valuing human life. These indicators involve a measure of morbidity or mortality, by creating an adjustment to the expectation of years lived, or the quality of life, if there is an impact on health status. These techniques are used to aid the allocation and prioritisation of healthcare resources in human medicine and health care policies (Morrow and Bryant, 1995; Whitehead and Ali, 2010).

The most commonly seen measurement indicators used in human health policy literature, include quality-adjusted life years (QALYs) and disability-adjusted life years (DALYs) (Mehrez and Gafni, 1989; Murray, 1994; Morrow and Bryant, 1995; Whitehead and Ali, 2010). QALYs can incorporate both morbidity (quality) and mortality (quantity). They are used to measure the health outcomes from a medical intervention in a common, comparable unit of measure. QALYs reflect the preference of an individual for a certain health status as an assessment of efficiency of therapy reflecting both quality and quantity of life (Mehrez and Gafni, 1989; Encyclopedia of Public Health, 2008; Whitehead and Ali, 2010).

DALYs are commonly used as a comparative measure of health gaps between different populations. DALYs include a disaggregation by demographics, which allows age-weighting of certain diseases, to reflect the impact of the disease condition at different ages. DALYs include a measure of the sum of years of life lost due to premature mortality as well as years lost due to disability as a result of disease (Murray, 1994; Morrow and Bryant, 1995; Encyclopedia of Public Health, 2008; Whitehead and Ali, 2010).

The use of these indicators are not without limitations; the greatest (for the purpose of this thesis) being that although they are making a measurement of certain components of life, they are not assigning a ‘value’ to life. Neither method captures social consequences of human health impacts such as mental or emotional health, both of which are highly impacted by EADs. Human health is arguably the most subjective of all the parameters to measure and although these concepts offer frameworks, they are not considered for the measurement of intangibles in this thesis. Some key concepts that these methods introduce, is that value can be assessed in terms of preference (desirability for an outcome) and that this preference can be aggregated for the group (Weinstein et al., 2009; Whitehead and Ali, 2010). These methods also include the use of a 'willingness-to-pay' analysis approach which is a concept also reflected in other intangibles (Morrow and Bryant, 1995; Whitehead and Ali, 2010).

The 'value-for-money' health assessment methodology expresses the ratio of some measure of valued health system output to the associated expenditure. The main use of this method is to prove accountability for the expenditures on health care (either for an individual or an aggregate as high as a whole health care system), generally by a government body. It is a combined measure of both allocative and technical efficiency in terms of provision of health care services. The methodology often relies on output measures such as measurement of activities performed rather than actual patient outcomes due to data limitations. It is most suited to assessing the impact of technologies and performance, rather than human health parameters (Smith, 2009).

3.3.2 Measuring animal welfare intangibles

Welfare assessments in animals are usually based on physical or behavioural parameters (Mason and Mendl, 1993; McGlone, 2001; Mellor and Stafford, 2001; Paton et al., 2010a). When there is a change to the animal welfare status, there are generally quantitative changes to physical parameters such as loss or gain in production, change in health status or increased/decreased mortality. With such physical changes, an economic value in terms of financial loss or gain can be assigned to the change in status, for example - the cost/loss associated with a dead animal or a gain associated with an increase in milk production.

In addition, the commercial 'value' of good animal welfare can be seen used in niche marketing, for example, free-range eggs or sow-stall-free pork. This concept can measure the difference in commercial returns for niche products when consumers are given choice to purchase 'welfare-friendly' products, in other words a measurement of 'willingness-to-pay' (Bennett, 1997; Blokhuis et al., 2003; Black, 2006). Most measures of animal welfare (in production animals) are a measure of social choice rather than a set of economic or scientific criteria, and are a subjective reflection of societal paradigms (exposure, culture, religion and prosperity) at that point in time (McInerney, 1991c; Bennett, 1995; Green and Nicol, 2004). Previous to 1995, no economic models that incorporate a measure scale or even a unit of measure for animal welfare (Bennett, 1995). In 2012, an advancement was made in this method of modelling, whereby willingness-to-pay for a welfare-friendly product in the EU, was associated with a welfare assessment scale based upon animal-related measures such as behaviour, cleanliness and body condition (Bennett et al., 2012).

Welfare assessment indices that incorporate animal consequences/outcomes with input measures (such as management skills, genetics and infrastructure) are available. Reportedly these tools may confuse the process of measuring welfare parameters with *'valuing'* welfare. Additionally due to the subjective nature of welfare, these tools are prone to the same biases

(Paton et al., 2010a). Epidemiological studies have also been used as an assessment tool for animal welfare. These studies can be used to identify problems such as management, genetics, infectious causes or environmental risks that act as underlying mechanism for poor welfare. However, they do not measure welfare directly; instead they measure the success of the implementation of better welfare in terms of disease impacts or physical welfare (Green and Nicol, 2004). Risk analysis has also been used to measure the outcomes and impacts of changes to animal welfare. Although this is a flexible tool that can be provide a range of qualitative, semi-quantitative and quantitative outcomes that can be ranked, it still does not provide an absolute welfare value that could be incorporated into economic analysis (Paton et al., 2010a).

Lusk and Norwood (2011), propose that using CBA in agriculture is 'speciest', as policy only considers cost and benefit to people. They propose that in the collection of the cost and benefit data to support a CBA, the human and animal costs and benefits be integrated as a type of net social multi-species benefit. This view is contradictory to that presented by McInerney (2004) who states that animal welfare is a utility value that is relative, not absolute. Neither of these debates aid in the measurement of a stakeholders perception of the value of animal welfare.

3.3.3 Measuring environmental intangibles

Despite methodology available for assessing the physical impacts to the environment, none create a measure of the value of 'biodiversity' or ecosystem function *per se*. Physical resources can certainly be measured. If an element of the ecosystem has a consumptive value we can measure the usage of its components and the associated costs. Fuel-wood, timber and water would be examples of elements with consumptive usage. If we refer back to Zambon's (2003) definition of intangibles, it excludes the physical components of future benefits, so these elements are outside the scope of this discussion. The value of some non-consumable elements can also be measured, such as ecotourism and pharmaceutical genetic benefits.

Environmental elements can be accounted for in terms of the market value that can be assigned to them, as a consumer preference for that good, or the costs of maintaining the environment and preventing degradation (Gowdy and Erickson, 2005). While these costs are simple enough to identify and ascertain, their benefits have a more intangible nature. The measurement of future value potential of these elements or the 'not-yet-quantified' benefits of the environmental are significantly more difficult to determine (Daily et al., 2009).

There is no solution at present for the valuation of this 'natural capital' for inclusion in financial or policy evaluations (Daily et al., 2000; European Commission, 2000; OECD, 2004a). Of what is available, two more commonly used strategies for environmental value are -

1. Valuation techniques based on revealed (observed behaviour) or stated preferences (hypothetical choice situations e.g. willingness-to-pay) and
2. Environmental pricing techniques – associated with market price observations (Limburg et al., 2002; OECD, 2004b; Heberling and Bruins, 2005).

Heberling and Bruins (2005) also describe another valuation technique known as benefit transfer, where the estimated values in previous environmental studies are assigned to new studies. The techniques are not without limitations, such as availability of data, biases and constraints. Gowdy's (2005) ecological economics approach suggests multi-criteria assessment may be a useful tool for evaluation as more diverse indicator criteria can be used. Again this method is based on a preference choice but does assist in incorporating qualitative information into an economic valuation framework. The primary flaw in these measurement techniques is that they measure the commercial value of certain components of the environment, not the 'value' of the environment.

3.4 Summary intangibles

Regardless of whether an intangible has potential commercial value (such as patents and intellectual property) or has social value but cannot be easily given a financial value, there are similar key issues in their measurement. These include (Mortensen, 1999; Canibano et al., 2000; Eustace, 2000; Lev, 2001; MERITUM, 2001; Blair and Wallman, 2003; Eustace, 2003; Zambon, 2003; Pike et al., 2005; Black, 2006):

- The multidimensional nature of intangibles
- Complex and subjective judgements of value for an intangible
- Time lag between investment and benefits
- Lack of methodology available
- Difficulty in trading intangibles
- Lack of full control over intangibles
- Assumptions that economic values can be assigned to some intangibles
- Lack of comparability between countries and cultures
- Reliance on future predictions of market and economy

The commercial intangible assets are considered to be incorporated within the costs and benefits of economic analysis. For the application of the framework presented in this thesis, an alternative definition for intangibles has been created. This definition of intangibles addresses those elements with social/moral value. There is no singular method available to address the variety of intangibles that are covered under the societal and environmental headings. As their value is subjective, what is common to these groupings is an association between consumer preference and **'willingness-to-pay'** for them. A novel method for measurement of the intangibles is described in Chapter 4.

METHODOLOGY

Chapter 4 - Frameworks

4.1 The framework outline

The framework is an underlying conceptual skeleton upon which the analysis is constructed. It is divided into a series of processes or steps which are sequentially related and are shown in Table 17. The framework is designed to aid decision-making in consultative policy development for EADs by providing a tool for the collection of data relating to stakeholder preferences that are impacted by the outcomes of strategies delivered from EAD response policies. These consequences that occur as a result of the implementation EAD response policies will have an impact on both tangible and intangible elements.

The initial component of the analysis is the development of different disease outbreak and intervention scenarios (OIS). This is done by the lead animal health organisation (LAHO). However, input from stakeholders can be invited, depending on the consultative process and time available for development. For a new policy, a longer period of time for the consultation process is generally allowed. In these circumstances, it would be beneficial to invite relevant or most-invested stakeholders to have input into (what they envisage) the most likely outbreak and intervention situations would entail. However, if this process was to revolve around a change in policy in response to an EAD event that was currently underway, time could be saved by the LAHO developing different scenarios to be addressed. At this stage of the analysis, no major information would be lost that could not be further extrapolated in later steps. What would be missed are the benefits that arise from stakeholder interaction and consultation.

Table 17 - Steps involved in the operation of a framework for developing an integrated tangible and intangible assessment of an emergency animal disease outbreak

Operating step	**Description of step**	**Support Tools/Methods**	**Outputs**
Step 1 Process: Scope	Establish the magnitude, severity and potential consequences of disease spread. May include simulation and modelling tools or analysis of prior events to determine outbreak parameters.	Modified Outbreak Risk Ranger Spread models Previous outbreak data	**Case Prediction Load** Number of Cases Number of Farms **Risk Ranking** (if required to establish Priority)
Responsibility	Lead Animal Health Agency (LAHO)		
Step 2 Process: Intervention	Includes the different options for interventions (e.g. vaccination vs. stamping out).	Emergency Animal Disease Response Plans (EADRP)	**Intervention strategies**
Responsibility	LAHO		
Step 3 Process: Scenario development	Develop outbreak scenario from the results of step 1 and 2		**Analysis scenarios**
Responsibility	LAHO or third party		
Step 4 Process: Economic assessment	Cost benefit analysis performed to identify related costs, losses and benefits of the disease incursion under a particular response policy	Cost-benefit analysis	**Benefit-Cost Ratio** **Net Present Value**
Responsibility	LAHO or third party		
Step 5 Process: Intangible analysis	Identification and valuation of intangibles impacted by the disease incursion (done by stakeholders)	Consultation	**Compromise Values** **Trade-off Values** **Predicted Intangible Impact Level**
Responsibility	Stakeholders		
Step 6 Process: Integrative analysis	Calculate integrated economic and intangible outcomes to use as comparative Values	Framework (Table 21)	**Comparative Value Index** **Comparative Value Figure**
Responsibility	LAHO or third party		

To create the OIS, it is vital to know, or predict, what the defining features of the outbreak to be analysed would be. These features give us the ‘scope’ of the outbreak. Consideration is given to the pathogen of concern and its epidemiology, from which the size and severity of the outbreak is determined (by simulation or proposal). Once we know the scope (or key features of the predicted outbreak), we are able to select the most appropriate policies to response to the outbreak. These policies will also offer a guide as to the requirements for resourcing and implementing the intervention strategy. The implementation of these disease response policies will create action to prevent further spread of the disease, implement eradication procedures and help to minimise other deleterious impacts, such as zoonotic disease or impacts on biodiversity, environment or animal welfare. In the case studies in this thesis, the scope is developed using a tool called the MORR (Modified Outbreak Risk Ranger). This is described further in section 4.2.1.

OIS could also be created using previous outbreak data, models or simulations that can generate or predict the size of the outbreak for a certain pathogen including the species and/or enterprises that will be affected and the industry impacts that will likely occur. Some basic examples of outbreak scope descriptions might include - small outbreak, singular farm, singular industry impacts (e.g. small beef enterprise); multi-farm outbreak, single species, singular industry (e.g. medium size pig farm); multi-farm outbreak, mixed enterprise, multiple species (e.g. large beef and sheep area) or small farm, multiple species (e.g. lifestyle or hobby farm).

Once the scope of the outbreak is known, economic costs and benefits are determined or estimated and CBA is used to make an economic analysis of the different OIS for the outbreak. Economic data are gathered from a number of sources that help to estimate both direct and indirect economic consequences of the EAD. Simulation or extrapolation of data can be used in some cases, where no recorded economic data exists.

The outcomes from the steps above are then used as the base for the stakeholder intangible analysis. Stakeholders identify which of the intangible elements (previously described in Table 16) they feel would be impacted under the conditions of OIS. Of these intangible elements selected to be addressed by the stakeholders in the intangible analysis, a scale of worst-case to best-case scenarios for each intangible impact is created. For each intangible in an OIS, the stakeholders identify where they are prepared to 'draw the line' or accept a compromise from their perception of a best-case scenario. Section 4.2.5 describes this process in further details. The final element in this step of intangible analysis is the identification of the predicted intangible impact level (PIIL) for the disease OIS.

The novel feature of the framework is this inclusion of methodology for measuring the stakeholder perspective of the intangible impacts of the EAD outbreak. These intangible-value measures are melded with the outcomes of a CBA. This is done by allowing the participant stakeholders to value-add or value-deduct from a CBA outcome, by incorporating intangible impacts as trade-offs. The adjusted outcomes can be used by decision-makers as a benchmark and a litmus test to gauge reaction to policy from different stakeholder groups. The use of the framework provides for accountable and transparent recognition of stakeholder views and can be used to generate aggregated outcomes if required, to justify net social benefit.

It can also be argued that there is also much benefit to be gained from gathering and recording the insights and discussion generated during the data gathering, to boost the understanding of the underlying stakeholder paradigms. Additionally in the process of gathering data to populate the framework it is possible to identify conflicting stakeholder interpretations and positions. It can also be used to identify animal health or policy concepts that are poorly understood and may highlight anticipated difficulties in the implementation of a particular policy (for example, key industry stakeholders with high compromise thresholds and low trade-off values – a full explanation of these concepts is given in section 4.2.5).

The process allows for some flexibility in assessing policies relating to EADs of different magnitude, priority and impact. The initial steps of the framework involves risk analysis and/or epidemiological analysis to identify the impact variables such as pathogen of concern, magnitude of impact (geographical spread, number of farms affected, number of cases), possible intervention strategies, depth of industry involvement and the cost of responding to the EAD under the different strategies. The different scenarios are then specifically addressed in terms of economic costs and impacts upon intangibles.

The output from the intangible analysis gives the LAHO an indication of where stakeholders are prepared to compromise, in terms of deviation from their best perceived outcome for the scenario (for specific control strategy), namely the Trade-Off Value (ToVal) for an intangible impact. When this trade-off value is used to adjust the outcome of the CBA, it represents an integrated index that combines quantitative economic analysis and subjective individual stakeholder preference. This outcome is commensurable and comparable between stakeholders.

The entire process is designed to engage the stakeholder in a consultative process. It is an opportunity to address the many intangible impacts of EAD and to incorporate them in an accountable way, into a reconcilable analysis. Although the intangible elements are subjective, knowing where the trade-offs lie for different intangibles between stakeholder groups can aid capacity building. It would seem that a further understanding of the nature of the stakeholder perspectives on intangibles could maximise cooperation under the terms of polices that relate to Emergency Animal Disease Response Agreement (EADRA) and aid to direct resources for education, training and surveillance if required.

4.2 The framework input parameters

4.2.1 STEP 1 – Determination of scope

This step uses epidemiological and/or risk assessment methods to establish the scope of the outbreak. The scope aids in determining which emergency animal disease response plan (EADRP) will be the most effective strategy to contain and eradicate the EAD. The information required to give a determination of the scope will be—the agent of concern, the time between likely infection and detection, time taken for a response plan to be implemented, the relevant biosecurity issues and the potential modes of spread of the agent. Consideration must be given to the epidemiology of individual disease agents in terms of their interaction with the environment and the potential hosts that they may infect. The epidemiology of the disease will also be influenced by the attitudes of the stakeholders towards the disease outbreak and the risks that they are prepared to take.

Using a risk assessment or spread model (or dispersal model) for each EAD, enables us to determine the magnitude of the outbreak in terms of infected cases and number of infected farms, with temporal and spatial parameters included. In this first step consideration is given to the following variables of interest -

- Population susceptibility and exposure
- Duration of exposure prior to detection
- Impact of delayed detection
- Likelihood of disease spread
- Implementation of strategies to control disease

When modelling these epidemiological features of an EAD, we must articulate the difference between uncertainty and risk in the parameters. Rushton (2009) describes *risk* as being where the decision-maker knows the possible outcomes and can attach a probability to them. The OIE describes risk more specifically as the '*likelihood of the occurrence and the likely magnitude of the biological and economic consequences of an adverse event or effect to animal or human health' (OIE, 2011a)*. Uncertainty involves a lack of knowledge or lack of information that relates to information such as probabilities, distributions for variability, or regarding the appropriate and adequate inference options to use to structure a model or scenario (Food and Agriculture Authority (FAO) and World Health Organisation (WHO), 1995).

It is postulated that in the use of this framework, both risk and uncertainty are encountered. If risk analysis is based upon '*risk*', the elements of consideration include – the prior history of events happening, comparable situations in other countries and experimental data.

It may be that from previous experiences with outbreaks of this EAD, the scope of the likely scenario is already known or can be estimated. In this case, the economic evaluation is generated from the costs and benefits that were calculated in this EAD experience. These data can also be extrapolated for the purposes of assessing outbreaks of different sizes for this particular EAD. Where prior events are used, the full process of step one (and possibly step 2) to generate a scope for the scenario may not be needed.

If dealing with '*unknowns*' and working under conditions of '*uncertainty'* we can use expert opinion (albeit even this is subjective) and modelling, to simulate events, and build the data needed to create the scenario for analysis (Thrusfield, 2007; Rushton, 2009). Uncertainty can be applied to both epidemiological and economic features of the model. In risk analysis, only the biological uncertainties are addressed. If dealing with a disease of no precedent, then a variety of models can be used to simulate spread of disease under different conditions of detection and different response actions. These simulations can generate the impact in terms of case numbers and industry impacts for further economic and intangible analysis.

There are many models already existing that can perform this task. Limitations in the use of these models are the data required for them to function and the skill requirements of the operator. The spatial modelling process can also be time consuming. For the purpose of this thesis, a simple deterministic model is used to generate the scope of the outbreak under different conditions of disease introduction and spread. The calculations are performed using a modified concept of the program Risk Ranger© developed by the FAO (Ross and Sumner, 2002; Sumner et al., 2004). Risk Ranger© is traditionally used to perform basic food safety risk calculations using Microsoft© Excel spreadsheet software. The parameters of interest have been adjusted accordingly here, to suit the generation of vital information that can be used to create the step one scenarios.

This model has the capacity to generate an estimation of total number of disease cases in a population, and a risk ranking (if required). In this thesis the process is referred to as the modified outbreak Risk Ranger (MORR) analysis. The outcome variable for this analysis is the Case Prediction Load (CPL). It is equal to the predicted number of cases for an outbreak scenario for a particular disease under certain conditions. This is calculated by assigning probabilities to each section of the relevant sections of the risk analysis relating to introduction, exposure and potential for spread within the population at risk. The formula for calculating the CPL can be found in Equation 13 in Appendix 4.

The process is crude and simplistic when compared to some of the advanced disease spread models that are available, but MORR analysis can be performed quickly, without the need for massive data collection. In fact stakeholders could generate a number of different scenarios for analysis without any expert knowledge. A range of probabilities and 'what-if' situations can be included in the model. The key focus is the ability to create outbreaks of different scope under different conditions to match to a suitable EADRA. A further discussion of the use of MORR analysis versus more complicated modeling techniques is covered in Section 7.3.3.

The risk analysis process in the MORR is generally performed by the LAHO, but can also be performed with stakeholder input. The 'shop-front' for the MORR (the user interface) involves the user answering a number of questions relating to the epidemiological features of the disease outbreak. The questions that are used to determine the potential outbreak scope include –

1) How severe is the pathogen?
2) How susceptible is the population of interest?
3) How long has the population been exposed for?
4) How much of the population on the infected premises has had possible exposure?
5) What is the size of the population at risk in the area of concern?
6) What is the probability of the pathogen of concern arriving in the area?
7) What are the effects of quarantine on this pathogen?
8) Does a state of persistent infection occur with this pathogen?
9) What impact does on-farm biosecurity have on the pathogen?
10) How does the risk of spread increase with delayed detection?
11) Does early slaughter of a clinically-infected animal reduce the risk of disease spread?

A final note relating to risk assessment. Although the EAD is considered as a singular event in this framework, it is possible to address the situation of concurrent EAD outbreaks. If the scope of the outbreak is already known, qualitative or semi-quantitative risk matrices can be created to compare likelihood and consequences for the diseases of interest. For some diseases these may already be available as part of an import risk assessment. An example of a risk matrix is shown in Figure 8. Using these matrices, the diseases can be ranked in priority according to the severity of the consequences, and the likelihood of an outbreak event occurring. For example in Figure 8, a ranking of five in the matrix would indicate a low priority incursion of an animal disease, whereas a ranking of one in the matrix would indicate the highest priority incursion of an animal disease.

5x5	Consequence				
Likelihood	Insignificant	Minor	Moderate	Major	Catastrophic
Almost certain	3	2	1	1	1
Likely	4	3	2	1	1
Possible	4	3	3	2	1
Unlikely	5	4	3	3	2
Rare	5	5	4	4	3

Figure 8 - Example of a risk assessment matrix

In the unlikely event of concurrent disease outbreaks, there would definitely be an impact on the resources available and prioritisation for implementation of response plan. This means that further compromises and trade-offs may need to be considered in the analysis. If the scenario scope is generated using the MORR, it enables us able to establish a priority ranking within the analysis that can be used on its own or to support information that is available in other risk matrices.

4.2.2 STEP 2 – Selection of an intervention strategy

Once the scope analysis delivers an estimation of the likely size of the outbreak, the LAHO can establish the method that will be used to control and eradicate the EAD. In Australia, these response plans are well documented in the national EAD response plan called AUSVETPLAN (Animal Health Australia, 2012c). For a given disease agent there may be a number of strategies that can be used for the control of the EAD. The LAHO can select one or a number of different strategies relevant to the EAD of concern to put forward into scenario development for economic and intangible analysis. As in step 1, input from the stakeholders can be accommodated if there is sufficient time in the consultation process to do so.

4.2.3 STEP 3 – Generation of an EAD scenario for economic and intangible analysis

When steps 1 and 2 have been completed, a descriptive scenario can be developed that will be used as the basis for the economic and intangible analysis. The details from the outbreak scope and the actionable strategies from the EAD response policies will create different 'pictures' of the scenarios. Enough detail is to be given in the scenario for a stakeholder to be able to understand the implications and repercussions of the EAD and the response actions.

4.2.4 STEP 4 – Economic analysis

4.2.4.1 Defining costs

As mentioned in Chapter 2, one of the virtues of the cost-benefit methodology is the process of identifying the elements that need to be considered within the analysis. The economic analysis is performed by the LAHO (or a third-party provider), and is relative to the specific outbreak scenario that is generated in the prior steps. Defining costs is a relatively straight forward process (albeit data intensive) of systematically evaluating the response strategy selected for the outbreak. For each element of the response strategy a cost is attributed for the current time period. These costs can be both direct and indirect (consequential). Although a time consuming process, relatively accurate financial values can be assigned to the tangible elements (Power and Harris, 1973; James and Ellis, 1979). Areas of significant cost are shown in Table 18.

It is vital to remember that the 'costs' of responding to an outbreak (such as vaccinations, equipment and labour) also include the losses (production losses, animal deaths and loss of markets) that are accumulated as a result of the EAD. Determining the cost and loss impacts can be a data intensive process but the information is available because the LAHO responsible for implementing the response plan is required to keep financial records under the terms of the EADRA. Gathering this information may require investigation of costs and losses involved in other recent EAD response situations, adjustment of economic data from previous outbreak to the current time period, or simulation of economic data if there is no precedent.

In this thesis a Microsoft Excel™ spread sheet has been used to perform a CBA that incorporates costs incurred in a disease outbreak, such as those listed in Table incorporating the cost estimates listed in Table 18. It is also feasible to use the results of other economic studies, provided there is an accountable process for identifying the costs and benefit of the EADRA. These summaries of costs (and benefits) are provided to the stakeholders as part of the scenario that they will analyse in Step 5.

4.2.4.2 Defining benefits

The benefits are summarised as the costs avoided from not having an incursion of the disease (Power and Harris, 1973). These benefits would include retained disease-free market access and sales, continued tourism, continued production of animal feed and transportation of products. Defining benefits is often more complicated than attributing costs and losses. Consideration needs to be given to the length of time for which the benefits and costs will accrue into the future (and if projections go into the future, which discount rate to use), whether the disease benefits will still apply if the disease becomes endemic and if there are benefits that accrue within directly affected industries, as a result of a cost to another part of the industry.

4.2.4.3 Transfer payments

In some cases transfer payments may create both a cost and a benefit depending on the perspective of a particular industry. Where these cases are presented, given that the primary use of the framework is to facilitate decision-making from a government perspective, then the item is classified as to where the government sees the majority impact (e.g.) in the case of disposal costs – if considering this from a national perspective, it would place the costs in the category of whatever the governing body would consider as the greatest social impact, rather than listing them as industry benefits to those who are benefitting from the additional work related to the outbreak. Similarly, staff overtime is considered a cost, not a benefit to those receiving it. A minor exception to this rule might appear in the case of the benefit to consumers from reduced cost of primary produce in the case of a domestic market glut as a result of export restrictions related to a disease incursion.

Table 18 – Prominent economic impacts in terms of costs, benefits and transfer payments that may occur during emergency animal disease outbreaks

Category	Costs (losses)	Benefits
Technical	Medical intervention costs Vaccination costs Surveillance costs Proof of freedom costs Slaughtering and disposal costs Disinfection costs Mustering and animal containment costs Laboratory services (diagnostic/ surveillance testing)	
Human resources	Staff wages and staff overtime[3] Staff training costs Staff vehicle and kit costs	
Industry	Loss of domestic and export trade Transport industry Processing industry Agricultural workers Feed/nutrition industries	Destruction and disposal industies[3] Processing industry Domestic produce glut – lower prices for consumers[3]
Producer	Loss of income (animal deaths/loss of production/ changes in reproduction) Lower price for produce if market glut occurs[3] Farm idle costs	
Externalities	Tourism industry Racing industry[2]	
Commercial intangibles	Research expenses	Vaccine patents
Government	Compensation payments[3] Destruction and disposal industry[3] Tracing costs Zoning and or movement control costs	

(Garner et al., 2002), (Productivity Commission, 2002)

[2] May be directly affected depending on the disease involved
[3] Indicates potential transfer payment. Caution should be taken not to double count these elements

4.2.5 STEP 5 – A novel framework for intangible analysis

A paper published in Preventive Veterinary Medicine Journal (Wilson et al., 2013).

4.2.5.1 Introduction

The impact of animal diseases can encompass both tangible and "intangible" elements. The tangible impacts are quantifiable financial costs (such as loss of farmer income, vaccination programs, and destruction of and compensation for livestock). The intangible elements however, pose difficulties in both measurement and quantification because these elements are subjective. Based on individual interpretations of value and worth, intangible elements have no physical substance (Canibano et al., 1999; Zambon, 2003) and cannot be easily or precisely measured (Oxford English Dictionary, 2010). The intangible elements of animal disease may refer to impacts in areas such as food security, the environment, public health, lost opportunity, animal welfare, and psychological stress.

Current economic assessment methodologies do not have the frameworks to include an assessment of the intangibles, so the intangibles are often neglected. This is because governments rely heavily on the assessment of economic impacts and try to reduce economic losses and liabilities in the face of a disease outbreak. Public-sector agencies bear the majority of costs associated with EADs, particularly the costs of controlling, eradicating, and compensating for disease outbreaks. Public expenditure must therefore accountably show net social benefits, as well as cost-effective response (Ellis and James, 1979a; McInerney, 1987; Perry et al., 2001).

Although intangibles are not financially included in animal-disease assessments, it would be folly to neglect the intangibles entirely. Examples such as the death of humans through zoonotic disease, large-scale environmental degradation, or diminished biodiversity have great potential to affect decision-making. Intangibles also have the potential to be a strong campaign focus for industry "best practice" (rather than using only least-cost as the focus of campaigns). With the involvement of a diverse and multi-focused field of stakeholders, finding a policy that is publically acceptable and economically sustainable can present a challenge. Additionally, this policy must also be justifiable and scientifically sound.

Our proposed methodology can be used as a tool during consultative policy development, to gauge reaction and act as a litmus test for proposals for policy options when large and diverse stakeholder groups are involved. The tool is designed to gather data on the preference that stakeholders have for particular policy options and what the stakeholders are willing to compromise from their perspective of a "**best-scenario outcome**". Identifying "**willingness to compromise**" is the key contribution of this tool to animal health economics.

An important element to consider in this model is the country involved and its usual practice for the development of animal-health policies. In countries where consultative policy development is undertaken, representatives from a range of stakeholder groups have input. These groups usually include (but are not limited to) grass-roots producers; representatives from scientific, research, and academic organisations; government agencies; secondary industries (such as manufacturing and transport); and advocacy groups for animal welfare, consumers, and the environment.

To posit the example problem for our explanation: consider the impacts of an African Swine Fever (ASF) outbreak (with serious impacts on production) in a piggery. In our theoretical example, the local policy requires that movement restrictions be immediately placed around the area where the disease was suspected to have occurred. This means that pigs cannot be removed from the farm for slaughter and must be held on-farm until slaughtered and disposed of, by the representatives of the lead animal-health agency. This potentially would create overcrowding within the piggery and resource limitations in terms of available space. It is anticipated that these resulting welfare impacts would last approximately for three-to-five days until disease was confirmed and emergency slaughter plans were put into operation.

The financial costs associated with the ASF outbreak are easily distinguishable and include slaughter, compensation, labour, feed costs, disposal, disinfection and so on. A typical way to assess different response options might be with a cost-benefit analysis (CBA). However, a major limitation of CBA in the context of our ASF example is the inability to "value" the intangible benefits and costs (Power and Harris, 1973; Morris, 1999; Rushton et al., 1999; Thrusfield, 2007; Rushton, 2009).

But how then might we include the personal value, cost or worth of the impacts on animal welfare, the environment, and human physical or mental health? Intangibles such as lifestyle, succession, culture, heritage, animal rights and environmental sustainability do not often add financial benefits to an analysis, but are recognized as a source of high value for quality of life and well-being. These intangible impacts will be a high priority for many stakeholders--sometimes more important than the direct financial costs--but conceptually, the intangibles are difficult to measure because the unit of measurement is an arbitrary judgment of value or worth (Ellis and James, 1979a).

Roe (1976) concluded that the valuation and inclusion of intangibles (such as the cost of a human life) at inflated financial terms, had allowed CBA to fall into disrepute. The inclusion of a direct "cost" for an intangible can nullify the usability and repeatability of the outcomes of any CBA (or integrated analysis) that includes them. So rather than try to assign a monetary value to the intangible elements, in our process we gather detail on the level of ***"*****trade-off"** a stakeholder is willing to accept.

What we ascertain is the outcome that stakeholders are willing to accept under the proposed policy options for a certain disease. Necessary (to the process) is that the stakeholder be informed of a specific set of conditions relating to that EAD occurrence (including an estimation of the duration of time for which the likely intangible impacts will occur). For some intangibles (such as animal welfare), the duration of impact will be short (days to a week) as the response policy is implemented. For other intangibles (such as impacts upon human health or the environment), the impacts might last for years. It is important that the durations of the intangible impacts be given consideration *before* stakeholders are asked what they are willing to accept.

If required, we can also assign an ordinal measurement to this willingness-to-accept, in order to determine the stakeholder trade-off. We can do this by ascertaining (through consultation) at what point the stakeholders reach their level of maximal compromise - the stakeholder "**compromise threshold**"; (CT), along a scale of potential intangible impacts.

4.2.5.2. Methodology

The process to determine the CT of each stakeholder follows a sequence of steps. Firstly, we determine which intangibles to address; this can be done in a consultative manner or the lead animal-health organisation alone can identify the intangibles to be addressed. The same intangibles will not necessarily be affected by all diseases or scenarios, which is why flexibility is needed.

The second step in the process is to develop a scale of impacts from worst-case scenario to best-case scenario for each intangible (either in consultation or by the lead animal-health organisation). This step also involves determination of the duration of the relevant impacts that will be considered for each policy. The increments along the scale can be as detailed or simplified as needed to suit either the incremental breakdown of intangible impacts as defined by the stakeholders or the design and process requirements of the end-user(s) (depending on the process used in step 1). The stakeholders then determine their CTs as the end outcomes for that specific intangible along the scale from worst- to best-case. Assigning an ordinal measure to the scale of the CTs allows comparison of CTs among stakeholders and the calculation of a score for an overall **intangible-impact measure** (IntangVal) and a **trade-off value measure** (ToVal).

McPherson and Pike (2001) describe a commensurable value-measurement of an operational variable within a common scale between 0 and 1. We adapted their formula to produce a semi-quantitative measure. $IntangVal_p = (CT_{ix} - min\ CT_{ix}) / (max\ CT_{ix} – min\ CT_{ix})$. This allows the calculation of an intangible-value measure (IntangVal) relating to the stakeholder CT, for a given set of policy conditions (p), for an intangible (i), for stakeholder X (x). We are also able to calculate a trade-off Value (ToVal), which is the deviation from the best-case scenario (1-IntangVal). The max CT_x and min CT_x represent the CTs of the best-case and worst-case scenarios, respectively, for stakeholder x. The formulas for calculating these semi-quantitative outcomes are described in Figure 9.

$$IntangVal_p = (CT_{ix} - \min CT_{ix}) / (\max CT_{ix} - \min CT_{ix})$$

$$ToVal_p = 1 - (CT_{ix} - \min CT_{ix}) / (\max CT_{ix} - \min CT_{ix})$$
$$= [1 - (IntangVal)] \times 100$$

Where:
CT_{ix} is the CT for stakeholder *x,* for the particular policy relating to intangible *i;* and
max CT_{ix} and min CT_{ix} represent the CTs of the best-case and worst-case scenarios respectively for that stakeholder.
These give:
$IntangVal_p$ as the scaled association of the CT_{ix} with best-case scenario for policy *p*; and
$ToVal_p$ as the trade-off percentage from the best case scenario for policy *p*.

Figure 9 - Formulation for the Intangible Value (IntangVal) and the Trade-Off (ToVal)

A stakeholder's preference for what they consider a compromise is neither right nor wrong; it is a subjective and personal assessment. The framework has been designed to collect information from stakeholders regarding their own CT. It is expected that there will be a great variation in results reflecting the personal preferences, biases, backgrounds, ethical considerations, blindspots, and past experiences of stakeholders involved in the consultation.

Stakeholders might then be grouped according to their CT values if reasons for their preferences need to be explored further and understood.

4.2.5.3. Results (demonstration from the ASF example)

Let us consider a theoretical scenario involving ASF, as described above, in which the lead organisation was in the process of developing a new EAD response policy in consultation with leading industry bodies. The framework process begins with determining the key intangibles to be addressed. For this example, we selected animal welfare from the many possible intangibles that could be in the demonstration.

Using the formula above, the intangible-impact variable for this example is “animal welfare” (described as the presence of illness or resource and spatial stress). The max CT and min CT are the maximum and minimum impacts on animal welfare. These values, as well as the arbitrary units along the continuum from the best- to worst-case scenario, are determined in a consultation with stakeholders. These scales of impact will help to determine where the trade-offs for this particular intangible lie. An example of the intangible-value impact scale for the ASF example is given in Table 19.

If we select four potential and diverse stakeholder groups (of many that may be involved in the development of policy during a consultative process), we can demonstrate the operation of the framework. Group AW advocates animal welfare; Group PF is the grass-roots producer group (pig farmers); Group ENV is an environmental organisation concerned about the impact of slaughtering and disposal of pig carcasses within the environment; and group LAHO is the lead animal-health organisation that must implement the strategy selected in an ASF outbreak.

Group AW members personally value maximal animal welfare (only intangible considerations). This might mean Group AW is prepared only to accept minimal-to-no impact on pig welfare in an intensive piggery. In this case, the personal value Group AW would place on a decision to prevent off-farm movements would be much less than allowing the pigs to be moved to another contained area. Group AW might not be prepared to compromise or trade off any negative impacts to animal welfare beyond mild resource or space stress. Group AW would select from the least-impact end of the scale (i.e. a high CT).

Table 19 - An example of a simplified intangible-impact scale for the theoretical ASF outbreak scenario; the intangible impact of this demonstration is "animal welfare of the pigs in the piggery" (numbers are the scores assigned to the levels of the impact).

Impact level	*CT Scale score*	*Impact effects*
Best Case (Least Impact on intangible)	7	No related illness or stress due to welfare issues
	6	Mild resource pressure and stress without illness
	5	Moderate resource limitation and stress with resulting mild illness
↓	4	Resource limitations and stress resulting in illness but no deaths
	3	Occasional animal deaths due to welfare issues and resource pressure
Worst Case (Most impact on intangible)	2	Multiple animal deaths due to welfare issues and resource pressure
	1	Welfare issues requiring emergency slaughter

The Group PF also cares about animal welfare, but needs to balance welfare concerns against the risk of losing farmer livelihoods and the ability to trade (i.e. has a mix of intangible and tangible concerns). Group PF might be prepared to make a compromise on short-term welfare impacts (until the slaughter policy is implemented) for the sake of the sustainability of the industry and future trade. Group PF might selected from somewhere between the medium-impact (i.e. a moderate CT) to least-impact end of the scale.

Group ENV empathises with minimising welfare concerns and wants to reduce the number of deaths (deaths that preventing movements would cause), but Group ENV is prepared to make some compromise (to enable the logistics of large-scale disposal to be done in an environmentally sustainable manner). Group ENV might need further information to make a decision on compromises, but will probably select a CT that is intermediate between those of Groups AW and PF.

Group LAHO must cost-effectively and justifiably minimise the risk of ASF spread. They must balance short-term animal-welfare impacts with the potential for long-term industry impacts and food security under the policies and guidelines for EAD response. Group LAHO are responsible for following policies and legislative requirements that pertain to animal welfare, occupational safety of the workers and field staff and the minimisation of environmental impacts. However, under the conditions of an EAD, Group LAHO subordinates their charge to protect animal welfare to the political and economic necessities of trade and farmer livelihoods. The CT of Group LAHO will reflect the prioritised policies and legislation under which they are operating.

If we were to calculate the IntangVal and the ToVal for the Group PF (for the animal welfare intangible under the prescribed policy conditions for this example), we would firstly take the CT they have selected from the intangible impacts scale (which in this case is chosen as 4: resource limitations and stress resulting in illness but no deaths). The IntangVal is the association between the CT and the best-case outcome for this scale which is determined by the formula to be 0.5. We then calculate the ToVal, which indicated the trade-off from the best-case scenario the Group PF are prepared to make, which in this case is 50% (1-IntangVal). The full working for the PF example is displayed in Figure 10. When we consider Group ENV, they determine their CT as 5 (moderate resource limitation and stress with resulting mild illness), giving us an IntangVal of 0.67 (CT-min CT)/(Max CT-Min CT). This gives us a ToVal of 33%.

$IntangVal_p = (CT_{ix} - \min CT_{ix}) / (\max CT_{ix} - \min CT_{ix})$

$ToVal_p = 1 - (CT_{ix} - \min CT_{ix}) / (\max CT_{ix} - \min CT_{ix})$

$IntangVal = (4-1)/(7-1)$
$= 0.5$

$ToVal = 1 - 0.5$
$= 0.5$ or 50%

Where:
(x) = Group PF,
(i) = Animal Welfare intangible
(p) = policy conditions
$CT_{ix} = 4$, Min $CT_{ix} = 1$, Max $CT_{ix} = 7$ (selected from scale derived in Table 19)

Figure 10 - Calculation of the Intangible Value (IntangVal) and Trade-off Values (ToVal) for the PF stakeholder following the intangible impacts scale in Table 19

The calculations of the semi-quantitative outcomes for the other groups relating to the animal-welfare intangible are demonstrated in Table 20. These outcomes crudely represent the trade-off these groups would be prepared to concede as a proportion of the "welfare distance" between the best-case worst-case situation: Group AW for which no trade-off is acceptable; Group PF prepared to concede a 50% trade-off, Group ENV a 33% trade-off and Group LAHO a 67% trade-off.

Table 20 - Outcomes of compromise thresholds (CT), Intangible Value (IntangVal) scores and Trade-off (ToVal) percentages for stakeholder groups relating the animal-welfare intangible assessment in the theoretical ASF example

Stakeholder Group	Animal welfare impacts		ToVal Trade-off concession %
	CT	IntangVal	
Animal welfare advocates (AW)	7	1	0
Pig farmers (PF)	4	0.5	50
Environmental group (ENV)	5	0.67	33
Leading animal health organisation (LAHO)	3	0.33	67

4.2.5.4 Discussion

Intangible analysis is a neglected element in the economics of animal disease. Intangibles are sometimes "considered" but due to an inability to measure them, they are often left out of analysis. In developing a method to address intangibles in animal health, many of the same issues that we see in qualitative risk analysis arise. The opinions are subjective; there is not always enough evidence to support a finding; and especially relating to intangibles, there is no scientific support.

There is merit in trying to ascertain a measure for the intangible parameter. It is our longer term intent to enable a measurement of value-driven parameters to be incorporated into economic analysis. If risky practices result from economic shortfalls and cost-saving mechanisms, inclusion and promotion of intangible benefits of disease control could be used to promote industry best-practice. Such tools are already used in marketing niche consumer goods such as welfare-friendly meat.

Leading industry bodies, research organisations, co-operative industry organisations, and industry councils could use this tool to collect data and gain insight into the perspectives of their members. This would assist such groups in gaining an awareness of stakeholders' paradigms and needs. It would also allow better mediation between the needs of their members and those of animal-health authorities in preparedness and planning for EAD response. Our method can also be used during an EAD event if unforeseen changes to policy must be made, as happened in the 2007 equine influenza outbreak in Australia (Schemann et al., 2012).

There are differing opinions as to whether the inclusion of animal-health authorities as a stakeholder is justifiable. As an agency that is required to implement on-ground actions, concerns for the health and safety of their field staff or the welfare of the animals during the outbreak are as valid as concerns of other stakeholders. Within one animal-health organisation, there can be 'sub-agencies' that have different and potentially competing focus areas (such as animal welfare or occupational safety). For these reasons, we believe that the lead animal-health organisation (the organisation that will be tasked with implementation of disease-control strategies), should be included as an appropriate stakeholder within the analysis.

As with most methods of analysis, there are limitations and assumptions that are associated with the framework. Some can be addressed in the planning stage prior to the use of the framework. Other limitations provide a challenge and require decisions that the user must make, depending on the intended end-use of the data collected. For example, one of the benefits of the creation of an intangible scale that will be used to gauge impact of a new policy on intangible elements, will almost certainly be the discussion that is generated with different groups of stakeholders. This would include the creation of scales by different stakeholders. However if the intangible scale is to be used for the purpose of gauging the popularity of a policy that has defined intangible impacts, then it may be more efficient for the lead animal-health agency to create the scale, with the value coming from the analysis of the outcomes (CT, IntangVal and ToVal).

The stakeholder groups that could be considered in consultative policy-making are almost endless. This raises the question of how to select which stakeholder groups to involve in the intangible analysis. For most countries that already use consultative policy-making processes for animal-health matters, we suggest that the same stakeholder groups be involved. In the same way that the process of a developing a CBA generates useful discussion, the identification and discussion of intangibles and their values to different stakeholders would be useful. Equal weighting is given to the responses of each stakeholder. The key feature is to gather the information from the stakeholders so that the decision-makers are able to include all relevant intangibles in policy-making. Thus, a diverse group of credible and relevant stakeholders is desirable. For industry or research groups that use our intangible-analysis framework, we suggest that stakeholders include those who are already part of policy-making or decision-making groups, those who have a desire to be involved and those who have a vested interest in the outcome

A major assumption within the framework is that all intangibles are considered to have an equal weighting. For zoonotic and epizootic diseases, the weighting of intangibles raises the subjective question of which intangible has the most importance, highest priority, and greatest value. Even if a particular intangible (for example, the environment) is decomposed into smaller components, it would be difficult to determine whether all the components should have equal weighting. For example, does the aesthetic appeal of a rainforest have as much importance as the ecosystems it supports or the potential it has for providing new pharmaceuticals? We recommend that intangibles be weighted equally, unless there is good reason to do otherwise, as in the case of zoonotic disease, or unless a unanimous prior agreement is reached by stakeholders.

A limitation of intangible analysis is that it requires the collection (albeit discretely or anonymously) of personal and subjective data from stakeholders. This can be done cooperatively and collaboratively because consultative policy-making is voluntary. However, it also means that there is the potential for stakeholders to be missed if they avoid participation. It is also possible that due to previous personal experience, a proposed policy by a certain regulatory or lead industry body might draw antagonism and lack support from certain stakeholders (whose cooperation therefore might be minimal).

The ultimate use of these values will be as an adjunct to economic analysis--particularly when the scenario being analyzed has intangible impacts that will affect policy decision-making. An example of this would be when the potential for human-health impacts secondary to EAD means that higher-cost solutions (rather than the most-economic solutions) must be justified. It can also be used to gather information on the stakeholder reaction to proposed policies for responding to EAD and when industry bodies or research organisations want to gather data on the perceived depth of impacts due to EAD on intangible elements. It can also be used to measure the trade-offs that different stakeholders would be prepared to make to implement a particular set of policy conditions. In the future we hope that we can find a way to enable the incorporation of intangible-value measures to deflate or inflate the parameters used in current economic-analysis methods.

4.2.5.5 Conclusion

We described a framework to assist in the semi-quantitative evaluation of intangible impacts during animal-disease management. Our framework can be used to develop new policies for EADs, to indicate acceptability of new (including altered) policy, and to ensure that consideration is given to intangible impacts. Because intangible-impact analysis is subjective, there are limitations to its inclusion within traditional economic analysis. However, by identifying the level of compromise or trade-off a stakeholder is prepared to make in relation to a particular intangible for a given set of policy conditions, we can make a semi-quantitative measure of intangible impacts that can be an accompaniment to traditional economic analysis. By using both tangible and intangible analysis, we are able to derive a more integrated assessment of the EAD impacts.

4.2.6 STEP 6 – Integrating the formulae

In step 6, there is an integration of all previous steps. To reiterate – step 1 involves the determination of scope using probabilistic risk analysis. From this, our case prediction load (CPL) is generated for the population of concern (y) for a certain disease (d). Once the scope of the outbreak is known, the response strategies (or policies) to be tested in the framework are selected (pol) in step 2. Step 3 is then to make a descriptive scenario upon which the following steps will be based. This is called the outbreak intervention scenario (OIS). In Step 4, the CBA is performed for the OIS described in step 3. The outcomes from the CBA will either be the BCR_{OIS} or the NPV_{OIS} for the OIS. Together the OIS and the CBA results are presented to the stakeholder groups to serve as the data components on which the intangible analysis is performed in Step 5.

Before we complete the integrated analysis, we need to identify if the intangible impact will be a benefit or a cost in terms of the outcomes of this OIS. To do this we generate the predictive intangible impact level (PIIL). The PIIL is generated from the intangible impact scale and identifies what the likely impact of the OIS under the proposed policy will be upon an intangible. It is the responsibility of the LAHO or a third party to estimate the PIIL, but could also be done by generating an average score from stakeholder proposed PIILs. A further discussion of this is found in Chapter 7.

The CT score alone does not give us an indication of whether to value-add or value deduct in the analysis. If the likely outcome of the OIS has the same intangible impact score as the CT, then no net change in value is identifiable for that intangible element. However if there is a great deal of difference between the PIIL and the CT, then there will be value to add or deduct in the analysis. To demonstrate, consider again the example of animal welfare in the ASF scenario in section 4.2.5. In this scenario, the animal welfare advocates state that their CT is a 7 on the intangible impact score. This PIIL in this situation would likely be a 3 (occasional animal deaths and resource pressure). As the PIIL is much lower than the CT, it represents a loss in value (i.e. an intangible cost) for the response strategy. If we consider a stakeholder that had a CT of two, but a PIIL of three, then the response strategy used represents a benefit.

Using the PIIL we make a slight modification to the formula for intangible analysis presented in 4.2.5, so that the minimum CT value that is represented in the numerator is now the PIIL ($CT_{PIIL)}$. This modified formula is displayed in Figure 11. When the IntangVal for the intangible impacts using the PIIL is calculated, the result of the calculation can be a positive IntangVal, in which case the outcome is indeed a cost or a loss to the value of the intangible. In this case the value should be added to the overall cost of the OIS in the integrated analysis. If the outcome of the calculation is a negative IntangVal, then it represents a positive outcome and should be used to value-add to the benefits section of the integrated analysis (a negative IntangVal indicates that the CT of the stakeholder is actually lower than the predicted likely intangible impact and therefore considered a benefit to that OIS).

$IntangVal_p = (CT_{ix} – CT_{PIIL}) / (max\ CT_{IIS} – min\ CT_{IIS})$

Where:
(x) = Stakeholder
(i) = intangible to be addressed under policy condition (p) for disease outbreak
max CT_{IIS} = maximum CT scale score on the intangible impact scale
Min CT_{IIS} = minimum CT scale score on the intangible impact scale
CT_{ix} = Stakeholder (x) CT score for intangible (i) to be addressed under policy condition (p)
CT_{PIIL} = Predictive intangible impact score for policy

Figure 11 - Modifying the intangible analysis formula to account for predictive intangible impact levels (PIIL)

Finally in Step 6, the results of the CBA and the intangible analysis are combined for the OIS described, and the final results presented as an adjusted value. When using NPV as the criterion in the CBA, the value-included outcome becomes adjusted value figure (AVF) and if BCR is used as the criterion of choice, then value-included outcome is the adjusted value ratio (AVR). Table 21 presents the formulae for each of these steps.

Table 21 – Stepwise formulation of the adjusted value figure (AVF) and adjusted value ratio (AVR) for assessing tangible and intangible impacts of emergency animal diseases

Step 1	**$CPL_y = P_{en} \times P_{exp} \times P_{det} \times N_y$** P_{en} = Probability of agent entry into system of concern, P_{exp}= probability of exposure to agent, P_{det}= probability that the agent will remain undetected, N = number of animals in population *y*
Step 2	Selection of Response policy (Pol) for CPL(y)
Step 3	Development of outbreak and intervention scenario related to Step 1 and 2 (OIS) over a specific time period
Step 4	$BCR_{OIS} = \sum_{t=0}^{n} \frac{B_{OIS}}{C_{OIS}}$ and $NPV_{OIS} = \sum_{t=0}^{n} B_{OIS} - \sum_{t=0}^{n} C_{OIS}$ Where: *OIS* is the selected outbreak intervention scenario with a dedicated time period *t* B = Economic benefits that accrue within the time period of the OIS C = Economic costs that accrue within the time period of the OIS *n* = Number of years into the future
Step 5	$IntangVal_{OIS} = (CT_{ix} - CT_{PIIL}) / (\max CT_{IIS} - \min CT_{IIS})$ Where: CT_{ix} is the CT for stakeholder *x,* for the particular policy relating to intangible *I;* max CT_{IIS} and min CT_{IIS} represent the CTs of the best-case and worst-case scenarios respectively in the intangible impact scale; and CT_{PIIL} represents the most-likely case scenario of intangible impact under the conditions of the OIS These give: $IntangVal_{OIS}$ as the difference between the of the CT_{ix} and the CT_{PIIL} as a scaled association for the OIS
Step 6	$\boldsymbol{AVR_{OIS}} = \sum_{t=0}^{n} \frac{[B_{OIS} + (B_{OIS} \times \lvert IntangVal_{AWneg}\rvert) + (B_{OIS} \times \lvert IntangVal_{HHneg}\rvert) + (B_{OIS} \times \lvert IntangVal_{ENVneg}\rvert)]}{[C_{OIS} + (B_{OIS} \times IntangVal_{AWpos}) + (B_{OIS} \times IntangVal_{HHpos}) + (B_{OIS} \times IntangVal_{ENVpos})]}$ $\boldsymbol{AVF_{OIS}} = \sum_{t=0}^{n} [B_{OIS} + (B_{OIS} \times \lvert IntangVal_{AWneg}\rvert) + (B_{OIS} \times \lvert IntangVal_{HHneg}\rvert) + (B_{OIS} \times \lvert IntangVal_{ENVneg}\rvert)] - \sum_{t=0}^{n} [C_{OIS} + (B_{OIS} \times IntangVal_{AWneg}) + (B_{OIS} \times IntangVal_{HHneg}) + (B_{OIS} \times IntangVal_{ENVneg})]$ Where $IntangVal_{(i)pos}$ = Positive valued outcomes and $IntangVal_{(i)neg}$ = negatively valued IntangVal outcomes for intangible (i). Note that the absolute value of the negative IntangVal results are used.

4.3 The framework outcomes - Integrating BCR or NPV

In a typical CBA there is a choice of 3 output criteria – BCR, NPV or IRR as discussed in Chapter 2. When the intangible analysis is incorporated into the economic analysis, we are no longer looking for a 'break-even' rate, so the iterative process of IRR is no longer relevant. Instead, the focus is on adapting the formula for BCR and NPV to incorporate the impact on intangibles as a value to inflate or deflate the financial costs and benefits. The NPV, traditionally a financial measure in dollar terms, becomes the adjusted value figure (AVF). This end output is a non-financial measurement parameter. It is a commensurable index of '*adjusted value'* that can be used to compare or contrast different OIS between stakeholders. When incorporated with the intangible analysis, the traditional BCR outcome becomes the adjusted value ratio (AVR).

Although AVF and AVR are not directly comparable with each other, ideally they are used conjunctively for a more holistic comparison between stakeholders groups. These adjusted output parameters deliver an ordinal value that can be compared and ranked with the highest value being suggestive of the most preferred and the lowest being the least preferred option.

4.4 Summary- Framework Methodology

The framework for calculating the adjusted outcome parameters that incorporate both economic and intangible elements has 6 steps. The early steps help to set the scene, in terms of the size of the disease outbreak and the EADRP that is selected as an intervention. For a particular scenario that is generated, a CBA is performed to ascertain the economic impacts. Stakeholders are then given the scenario and the economic analysis and asked to address the impacts upon the intangible elements from their own perspectives in terms of trade-off from the best-case outcomes. The trade-off is then incorporated into the economic analysis, as a value-deduction from the economic outcomes. The final output of the framework is a value-adjusted figure or value-adjusted ratio (depending on the CBA output) that is commensurable and comparable between stakeholder groups.

RESULTS

Chapter 5 – An industry level model of Porcine Reproductive and Respiratory Syndrome (PRRS) virus in northern Victoria

5.1 Introduction

The impacts of an emergency animal disease can be both tangible and intangible. Traditional economic methods that estimate costs and losses are often portrayed as the key tool to assess the impacts of a disease outbreak. Although economics is a priority consideration for developing policy related to EADs, there are other considerations that must be taken into account. Missing from the more traditional economic approaches is an assessment of the impact of the outbreak on intangible elements. They are often overlooked due to their subjective nature and the challenges that exist in identifying and empirically measuring them. Yet without the inclusion of these intangible elements, a holistic outcome for policy or impact assessment cannot be reached. In this study, in collaboration with Australian Pork Limited (APL), intangible categories relative to the pork industry are identified and a novel method for estimating the impact of EAD intervention strategies is addressed.

Porcine Reproductive and Respiratory Syndrome (PRRS) has been identified as one of the diseases of greatest importance to the Australian Pork Industry (Brookes et al., 2012). For this reason, the disease is used as the paradigm for the case study analysis. Disease outbreak scenarios are developed to generate scope, which allows a CBA to be performed. Major intangible parameters to be addressed are selected and for these, a novel methodology is used to measure the relation of the personal stakeholder value, with the policy options that are being investigated for control and prevention strategies.

5.2 Background

The Australian pork industry contributes almost $8.6 billion in gross domestic product to the Australian economy (Western Research Institute Ltd, 2012). The impact of an emergency animal disease outbreak would have dire direct and indirect consequences that would flow back through the economy. The impact of the EAD would depend on the size and location of the incursion, the speed at which it was detected, the ability to trace the point of introduction and/or biosecurity breach, proximity of neighboring farms, biosecurity practices, dangerous contacts and off-farm movements. Northern Victoria has been selected as it is a representative pork growing area for Australia (the third largest in the country), with both high density pig areas (5,000 plus pigs per local government area) and some very high density pig areas (55,000 plus pigs per local government area). The selected area contains 85% of Victoria's pork production. A map demonstrating the geographic concentrations of pork production in Victoria is found in Figure 12. The pig industry in Victoria consists of approximately 68% establishments with sows, with the remaining establishments operating as contract growers (Australian Pork Limited, 2012). Contract growers purchase piglets after weaning to be grown out to market weight.

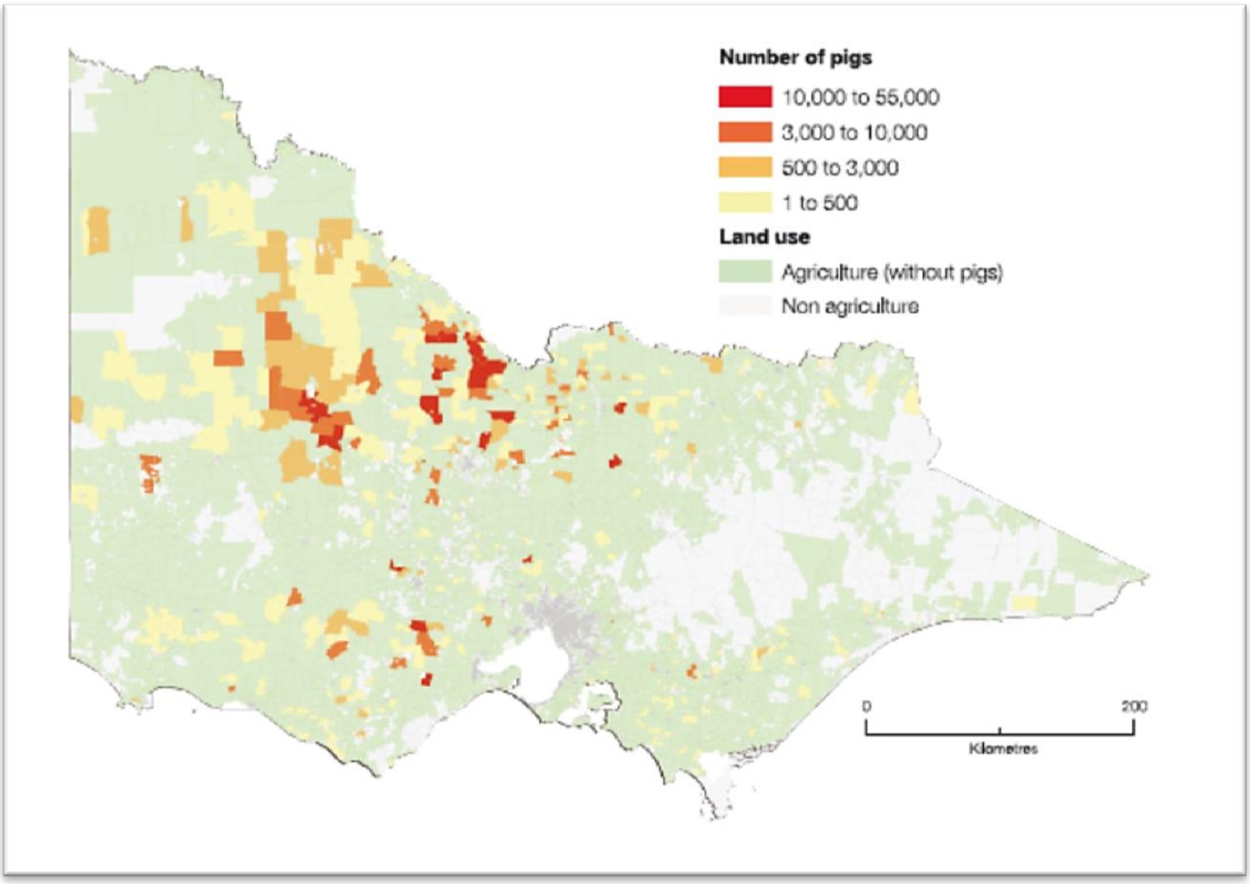

Figure 12 – Map showing the geographic distribution of pig production in Victoria (pigs per statistical land block). Source: (Department of Environment and Primary Industries, 2011)

PRRS is a disease of domestic and feral pigs, caused by an RNA virus of the family *Arteriviridae.* It causes pyrexia, respiratory disease, anorexia, abortion, stillbirths and failure to thrive (Done et al., 1996; Animal Health Australia, 2004b; OIE, 2008; Bingham and Morley, 2010). In 2006 a highly pathogenic strain of the virus also emerged in Vietnam and China (Li et al., 2007; Feng et al., 2008; OIE, 2008; An T-Q et al., 2011; Jian et al., 2012). Australia and New Zealand remain free of PRRS and no antibodies have been detected in national serological surveys in either country (Garner et al., 1997; Motha et al., 1997; Animal Health Australia, 2004b; Stone and Kittelberger, 2004). It is considered to be a Category 4 disease under the EADRA, meaning a disease of industry impact but with insignificant impacts on international trade to affect the national economy (Animal Health Australia, 2012b).

The financial consequences of the introduction of PRRS virus into a naive herd are severe, with high morbidity, mortality (up to 10% in sows and 16-17% in piglets) and production losses (Stevenson et al., 1994; Animal Health Australia, 2004b; OIE, 2008). Further losses can also occur through persistent infection and chronic shedding of PRRS virus and the increased potential for secondary infection with other organisms. The clinical signs of PRRS infection are not pathognomonic. This means the early detection of the disease could be delayed, if it was initially assumed to be another disease and as a result a delay in confirmation by laboratory diagnosis occurred.

The virus can be spread horizontally and also vertically through contaminated veterinary equipment and procedures (artificial insemination, recycled needles). It can also occur through feeding infected animal products or by-products to susceptible pigs, however, it is assumed that transmission will most likely occur through direct contact with infected pigs (Martin and Steverink, 2002; Animal Health Australia, 2004b; Cho and Dee, 2006). According to AUSVETPLAN (Animal Health Australia, 2004b), the most likely route of entry for PRRS virus into Australia, is through infected pigs or semen.

In an Import Risk Assessment (IRA) for pigmeat into Australia, PRRS was considered a disease of highest risk of entry (along with vesicular diseases, swine fever, Aujesky's disease and transmissible gastro-enteritis (TGE)), due to its potential for transmission through the consumption of pigmeat (van der Linden et al., 2003; Department of Agriculture Fisheries and Forestry, 2004b, 2004a; Magar and Larochelle, 2004; Cano et al., 2007). Experimentally, mechanical transmission has been demonstrated via mosquitoes and houseflies and mallard ducks have been shown to be capable of excreting the virus. (Zimmerman et al., 1997; Otake et al., 2002; Otake et al., 2003; Animal Health Australia, 2004b). The risk that these vectors present in terms of introduction of disease into Australia contains a great deal of uncertainty.

It is more probable the introduction of the virus will occur into non-commercial or wild pigs, due to legislative bans of the feeding of swill to domestic pigs and higher levels of biosecurity in commercial piggeries, but this may pose a real threat to commercial industry. It appears that even piggeries with strict biosecurity in place are at risk, with no definitive causation for route of spread yet determined (Cho and Dee, 2006; Rowland, 2007; Holtkamp et al., 2010; Lunney et al., 2010). The experience of the disease in other countries, such as America, is that elimination of the virus (using traditional methods of biosecurity, controlling animal movements and vaccination) has been largely unsuccessful (Cho and Dee, 2006). The recommendations made in Ausvetplan include perimeter fencing to limit spread of the disease from wild pigs and implementation of strict biosecurity to aid control of the disease (Animal Health Australia, 2004b; Morrison, 2011).

5.3 Methodology

5.1.3.1 Case study 5A

The base population data for domestic pigs in Australia, is just over 2.3 million head (Australian Pork Limited, 2012), and the most recent estimates of the feral pig population in

Australia is reported to be between 3.5 million and 23.5 million (Hone, 1990; Choquenot et al., 1996). Although in this study, the introduction of PRRS virus occurs with contaminated semen, a complete analysis of the exposure and release pathways for PRRS in Australia that could be relevant to the introduction and spread PRRS were identified in the process and are recorded in Appendix 6 as a reference. The probabilities relating to the risk of exposure and hazard variables were estimated to generate different scope scenarios are contained in Appendix 7.

Generation of outbreak and intervention scenario (steps 1-3) case study 5A

In this fictitious scenario, an incursion of PRRS begins in commercial piggeries in Northern Victoria with moderate to good biosecurity practices in place. Previous to this incursion, Australia is free of PRRS. The PRRS virus in this scenario has been imported in via semen collected from a sub-clinically infected boar in another country[4] (Garner et al., 2001). It has been shown that PRRS virus is more likely to survive in boars than sows and can survive for up to 43 days in semen. It has been confirmed that infection can be transmitted via artificial insemination (Benfield et al., 1999; Animal Health Australia, 2005; Cho and Dee, 2006). Risk of entry and establishment of infection and the ongoing consequences are considered high in the IRA for pig semen (Department of Agriculture Fisheries and Forestry, 2004b). As a result importation restrictions are in place however in this scenario, a quarantine breakdown is assumed to have occurred allowing importation of semen containing live virus from sub-clinically infected boars.

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[4] This scenario could also apply to the unlikely case of an illegal import of semen or a live animal

The infected semen has been introduced into a naive breeding sow population in a large commercial piggery operation. Garner et al (2001) used stochastic modeling to simulate an outbreak of PRRS from infected semen under delayed conditions of detection. In the 2001 model scenario, eradication was abandoned as the disease was well established and declared endemic. In case study 5A, a 48 hour delay occurs between detection and reporting of clinical signs. The semen began being used approximately 12 days prior to the first noticeable clinical signs. Diagnostic testing has since confirmed disease (Animal Health Australia, 2004b). This property is considered as the first infected premises (IP1).

To generate the scope of the outbreak, the MORR analysis is completed using the variables and weightings contained in Appendix 7 and Appendix 15. The MORR analysis predicts that in this scenario there are now 50 infected cases on the farm of concern. At this stage these cases are all from the dry sow sheds and no positive cases have been detected in the farrowing sheds or amongst the piglets. For this farm, there are three premises that are considered as dangerous contact premises (DCPs) (Garner et al., 2001). One of these farms is a small hobby farm with only three pigs. It has no biosecurity and reportedly there are feral pigs seen on the farm time to time. The second DCP is a finishing operation that often acquires stock from IP1. It has a total of 830 pigs to be finished. The third DCP is a mixed breeding and finishing enterprise with 140 sows and 600 other pigs. None of the DCPs have animals that present with clinical signs.

At this point in time all these farms have been placed under quarantine restrictions and the current policy options for control (given the size of the outbreak) are as follows (Animal Health Australia, 2004b) -

1) Stamping out – all pigs are destroyed and buried or rendered

2) Modified stamping out using salvage and slaughter – marketable pigs are sold and the remainder are destroyed and buried.

Under the modified stamping out salvage and slaughter policy in Ausvetplan, there are different options for the logistics of that process. There are two that will be considered for the outbreak and intervention scenarios (OIS) in this framework. The first is the slaughter of all pregnant sows and the sale of the salvageable pigs, the second option is to delay the slaughtering of the sows until after farrowing, growing out and sale of piglets and sale of other salvageable pigs on the premises. IP1 is using a system of batch farrowing, where farrowing sows are located in the farrowing facilities for approximately three-four weeks before returning to the dry-sow herd. The remaining sows are housed in dry sow sheds. There are good biosecurity practices followed on farm, with additional biosecurity measures taken in the farrowing sheds and nursery. In addition to the sows, there are approximately 650 piglets in the farrowing sheds that will be weaned in the next three-four weeks and the remainder of the herd is grower/finisher pigs. Using these options the OIS can be generated. A summary of the OIS for case study 5A is found in Table 22.

Table 22 – Outbreak and intervention scenario (OIS) summaries for case study 5A showing demographic impacts of affected pig populations under different control strategies

		OIS 1 – requiring all pregnant sows slaughtered, salvage of saleable animals	OIS 2– allowing sows on farm to farrow prior to slaughter, piglets are grown out for sale, salvage of saleable animals
SCOPE DATA	Number of confirmed IPs	1	1
	Total animals testing positive @ day 10 on IP1	50 in dry sow shed Nil in farrowing shed	43 in dry sow shed Nil in farrowing shed
	Total animals on farm	70 wet sows 50 Gilts 430 dry sows 650 nursery piglets	70 wet sows 50 Gilts 430 dry sows 650 nursery piglets
	Dangerous Contact Premises (DCP)	3	3
	Total animals on all DCP	Hobby Farm – 3 pigs Finishing Farm – 830 pigs Mixed breeding – 140 sows, 600 other Total – 1,553	Hobby Farm – 3 pigs Finishing Farm – 830 pigs Mixed breeding – 140 sows, 600 other Total – 1,553
	Number of animals to be destroyed	246 sows	246 (logistically)
	Number of piglets potentially born under IP control	NIL	4,100
	Number of marketable animals potentially salvaged from IP1	650 Piglets to be grown out on farm.	650 nursery piglets Up to 4,100 piglets in upcoming litters

Economic analysis (step 4)

A cost benefit analysis (CBA) is performed to determine economic consequences of the PRRS outbreak, the size of which has been determined in Steps 1-3. Step four considers the direct tangible costs and benefits related to the outbreak. Costs and benefits can be determined through the systematic evaluation of the prevention or response action plan or strategy that is to be implemented. Costs will be considered as the cost of the control and response strategies plus the losses from the disease incursion, where benefits are considered as the costs avoided or new revenues that occur during the outbreak (Power and Harris, 1973; McInerney, 1991a; Tisdell, 2008). The time frame that is considered in this scenario is a 26 week window surrounding the outbreak and clearance of animals off the infected premises and based on production data from 2011. It is assumed that the majority of the in-contact sows will become positive over the weeks following, if they are not slaughtered (Albina, 1997; OIE, 2008). The economic analysis conducted in the CBA compared the baseline situation of normal regional production as provided in the Australia Pig Annual and described below in the pig data (Australian Pork Limited, 2012) with that of the EAD impact.

Pig data

To calculate the cost of the incursions, economic data must be gathered. First we calculate the average price for a saleable pig at slaughter. The assumption is made that the pigs to be sold are at or close to sale weight, which gives us an average carcase weight of 76 kilograms (yearly moving average for Victorian pig production in the 2011-2012 time period). The value of this produce averages $2.80 per kilogram for the same time period (Australian Pork Limited, 2012). This gives an approximate value per slaughtered animal of $212.80. For the animals that are destroyed on farm and are not taken to slaughter, there is no slaughter value. The replacement value of the sows and gilts is calculated to be $319 (Stalder et al., 2003; Australian Pork Limited, 2012; XE, 2013).

The cost of raising these animals to their slaughter weight is calculated by using the feed conversion ratio of kilograms of feed required to produce a kilogram of carcase weight, which in this instance is an average of 3.95 kg (for southern pork production). The feed price in this time period was $225 per Tonne (Australian Pork Limited, 2012). This makes the average cost of feeding to slaughter $67.55. The cost of labour associated with this production must also be included. For each animal raised to slaughter there is an associated labour element of 1.34 hours (Garner et al., 2001). The value of labour for a piggery worker in this period varies depending on experience and responsibility. A new award scheme for agricultural workers began in mid-2011. In this study, using the modern award structure, a median skill and responsibility level was taken (PA4) which has a pay rate of $17.14 per hour (Fair Work Australia, 2011). Feed costs account for 60% of the cost of production and labour on average 12.7% of the cost of production. This leaves the remaining costs of production totaling 37.3%. In this time period the cost of product per kilogram carcass weight is $2.38 per kilogram (Campbell, 2013).

<u>Response data</u>

During the response to an outbreak of PRRS, a number of costs will accrue. A large part of these costs can be attributed to the controlled destocking of the infected piggeries. The median value of the cost of destocking (including labour, equipment hire, slaughter, disposal, decontamination, communications, stores and other) have been estimated to be an average price of approximately $600 per pig in 2001 (Garner et al., 2001). If we adjust this figure to account for inflation, the price per pig in this time period would be $798.20. The price per test for a commercially available serological test is $5/test (Indiana Animal Disease Diagnostic Laboratory, 2010; XE, 2013).

Sows will be slaughtered in both OIS (albeit in OIS 2 in a logistic manner after weaning of piglets). Under the terms of the EADRA, these sows will be valued and compensation paid. Given the yearly turnover of sows in southern Australia (60.2%) and the population of gilts within the herd (23.9%), the average age of sows within this breeding herd is assumed to be 15 months (Australian Pork Limited, 2012). For a sow at this age, the illustrated price under the valuation and compensation agreement in AUSVETPLAN is $400 (Animal Health Australia, 2005). This price is then adjusted for the 2011 time frame and the value per sow is calculated to be $474 (Reserve Bank of Australia, 2013).

During the disease outbreak, the additional costs to be considered apart from direct response costs, are the costs to production. For PRRS, it is estimated that average daily gain of a piglet can be reduced as much as 25% in nursery piglets and 12% in grower pigs (Stevenson et al., 1994; Neumann et al., 2005). This means that there is an associated increase in the amount of feed required to reach finishing weight. The literature reflects a production loss (and therefore an increased feed requirement per kilogram of liveweight to be gained) of between 5 and 20% for PRRS depending on the age of the piglet and (Done et al., 1996; Neumann et al., 2005). In this study, we assume a 12% increase in feeding required to reach slaughter weight.

The acute phase of the outbreak may affect 5-50% of the breeding herd over 7-10 days, but there is great variation depending on the immune status of the herd and the strain of the virus (Done et al., 1996; OIE, 2008). For the non-highly pathogenic strains of PRRS virus, mortality rates can be increased as much as 10% in sows with a mortality of 3.1% – 17.9%

reported in piglets (Done et al., 1996; Animal Health Australia, 2004b; Neumann et al., 2005). It has also been reported that in acute epidemic situations, mortality in piglets would be higher than reported above. For the analysis steps in this case study we assume sow mortality rate in infected animals of 5%. The farrowing rate is reduced by 10.92% and the piglet mortality rate in the farrowing house is increased by 3.3% to an overall mortality of 16.9%, which reduces the average litter size weaned per sow from 9.55 to 7.93. Mortality rate in grower/finisher pigs is reported to increase from 1.53% to 15.9% (Done et al., 1996; Neumann et al., 2005). In this study we assume a further mortality increase in finisher pigs of 4.3%, which means the average number of pigs finished per sow per litter, is 7.59.

For the 650 piglets on farm we assume that under the OIS 1, there are no cases of PRRS that develop due to rapid intervention after diagnosis of the disease and the implementation of very strict biosecurity, including the culling of all sows on the property. Under OIS 2, we assume that that the entire herd becomes exposed to PRRS due to the ongoing virus transmission in the sow group and the eventual spread of disease into the nursery area. Under OIS 2, the piglets that are in the nursery are assumed to be exposed to the PRRS visrus, as well as piglets from the currently pregnant sows. In OIS 2 there are increased mortality rates and reduced production. Where the nursery piglets would normally be removed from the sow farm to a finisher unit, they will be required to stay on farm and be finished until they reach a sale weight. Of the 650 piglet that begin, the expected number surviving to finishing under OIS 2 is 540 (a reduction of 16.9%).

Flow on impacts

Another consideration is the value of the impact that a disease outbreak would have on industries further down the line from primary production. It is estimated that in the pork value chain, processing beyond the farm gate is worth a total of $338 million per year for domestically grown pork for the 2010-2011 financial year (Western Research Institute Ltd, 2012). If a total of 4.6 million pigs were slaughtered in that same time period that gives an estimate of $73.21 per pig flow on within the economy past the farm gate.

The results of the economic analysis are summarised in Table 23 below. The background information for generating the economic data can be found in Appendix 9 and CBA worksheets for case study 5A can be found in Appendix 10. In Case Study 5A, the results of the CBA indicates that although neither option is economically profitable, the economically preferred option would be to implement OIS 2 as the NPV and the BCR are higher for OIS 2.

Table 23 – Cost-benefit analysis outcomes relating to the economic impacts of a PRRS outbreak in northern Victoria for case study 5A

	OIS 1	OIS 2
NPV	-$ 1,347,287.22	-$ 564,098.50
BCR	0.31	0.65

Intangible analysis (step 5)

Using our OIS and the results of the economic analysis for each of the OIS, we can begin the intangible analysis. There are 4 stakeholder groups that are to be considered within the analysis. The first group is industry representation comprising of grass roots pig farmers (Group PF), the second group are the animal welfare advocates (Group AW), the third group are members of the local council (Group LC) and the final group are representatives of the lead animal health organisation (LAHO). Each of these groups have different priorities and experiences with this type of situation, but all feel that they have an interest in achieving the best outcomes under the circumstances. The LAHO have created the intangible impact scales that are used for the intangible analysis. Tables 24-26 demonstrate the intangible impact scales used.

Table 24 - Animal welfare intangible impacts scale for case study 5A

Impact level	*CT Scale score*	*Impact effects*
Best Case (Least Impact on intangible)	7	No related illness or stress due to welfare issues
	6	Mild resource pressure and stress without illness
	5	Moderate resource limitation and stress with resulting mild illness
↓	4	Resource limitations and stress resulting in illness but no deaths
	3	Occasional animal deaths due to welfare issues and resource pressure
Worst Case (Most impact on intangible)	2	Multiple animal deaths due to welfare issues and resource pressure
	1	Welfare issues requiring slaughter

Table 25 - Human health intangible impact scale for case study 5A

Impact level	*CT Scale score*	*Impact effects*
Best Case (Least Impact on intangible)	7	No related illness or stress
	6	Mild stress with no physical symptoms
	5	Moderate increase in stress resulting in mild physical symptoms
↓	4	Physical and or mental health deficits that have a minor impact on quality of life
	3	Physical and or mental health deficits having moderate impacts on quality of life
Worst Case (Most impact on intangible)	2	Physical and or mental health deficits having serious deleterious impacts upon quality of life
	1	Human deaths or severe suffering as a result of direct and indirect disease impacts

Table 26 - Environmental impact intangible scale for case study 5A

Impact level	*CT Scale score*	*Impact effects*
Best Case (Least Impact on intangible)	7	No additional environmental issues (above the usual piggery impacts) created by disease control program
	6	Minimal aesthetic impacts to environmental outlook
	5	Moderate aesthetic impacts
↓	4	Moderate aesthetic and/or pollution issues (waste, noise or smell)
	3	Moderate aesthetic impacts, pollution issues and mild ecosystem impacts
Worst Case (Most impact on intangible)	2	Moderate or severe aesthetic and pollution impacts plus moderate ecosystem impacts
	1	Severe aesthetic impacts, pollution and/or severe ecosystem impacts

The measures of intangible impacts for each stakeholder group are collected through informal interviews with representative stakeholders. Each of the stakeholder groups (or representative for the group) gives consideration to the tables and makes a decision to reflect what they are willing to accept (the compromise threshold) under each of the OIS. It may be that these compromise thresholds (CT) stay the same for each OIS, or it could be that under certain conditions, the groups may be prepared to be more flexible. Following the analysis, data were stored electronically in password protected files and backed up to secure external drives.

Although the OIS 1 is the least economical option according to the CBA, the commercial pig farmers (as a collective) have a preference for this option. It is well documented that even with good biosecurity in place, the spread of PRRS can occur (Rowland, 2007; Holtkamp et al., 2010). From an industry perspective, spread of PRRS beyond the currently infected premises would be detrimental to the pork industry overall. They feel that there would be a greater impact on their health if a PRRS positive herd was to continue to operate for another 6 months, even under strict movement control. They also have concerns regarding the animal welfare conditions that may arise in OIS 2.

The lead animal health organisation supports the PF groups concerns, but needs to balance the concerns of other local industries and the environmental impacts that may occur. If they are able to perform logistic slaughter of the sows in OIS2, then the disposal processes are able to be spread over a longer period of time, reducing environmental impacts. The animal welfare groups support OIS 1, as they have concerns relating to the overcrowding that may occur in OIS 2 and the repercussions of the actual disease such as increased mortality and also an increase morbidity of other secondary diseases.

The local council has been an avid supporter of the pig industry and acknowledges the economic well-being of the community is greatly reliant on the industry. They are firmly in support of OIS 2, as it reduces the flow on impacts into the community as a result of the disease. There are local grain growers, processers and secondary industries that are reliant on the pig numbers going to slaughter. They feel human health impacts will be much greater under OIS 1, due to community impacts. Given these considerations, the intangible analysis is completed and the results are displayed in Table 27 – for the OIS 1 and Table 28 – for the OIS 2 for each of these groups.

Table 27 – Stakeholder intangible analysis outcomes for outbreak intervention scenario 1 (case study 5), showing predicted intangible impact levels for animal welfare, human health and environment

OIS 1	Animal Welfare $CT_{PIILAW} = 5$	Human Health $CT_{PIILHH} = 4$	Environment $CT_{PIILENV} = 3$
	CT	CT	CT
Commercial Pig Farmers (PF)	5	5	4
Lead animal health organisation (LAHO)	4	4	4
Animal Welfare (AW)	7	4	6
Local Council (LC)	5	4	5

Table 28 – Stakeholder intangible analysis outcomes for outbreak intervention scenario 2 (case study 5, showing predicted intangible impact levels for animal welfare, human health and environment

OIS 2	Animal Welfare $CT_{PIILAW} = 3$	Human Health $CT_{PIILHH} = 3$	Environment $CT_{PIILENV} = 3$
	CT	CT	CT
Commercial Pig Farmers (PF)	3	6	6
Lead animal health organisation (LAHO)	5	5	4
Animal Welfare (AW)	7	4	6
Local Council (LC)	3	4	4

Integrated analysis (step 6)

For the completion of step 6, we generate the value-added or integrated CBA. The outcomes of the analysis are shown in Table 29. The integrated analysis demonstrates that the value of the outcomes for both OIS 1 and 2 are deflated by the inclusion of the intangible elements. The AVF and AVR in both scenarios are negatively impacted by the inclusion of the intangible measures.

Table 29 – Integrated analysis outcomes for outbreak and intervention scenarios (OIS) related to the Porcine Reproductive and Respiratory Syndrome (PRRS) outbreak for case study 5A

	OIS1 – Slaughter Sows	*OIS 2 – Farrow and Slaughter*
Economic Analysis Results		
NPV	-$1,347,287.22	-$564,098.50
BCR	0.31	0.65
Integrated Results[5]		
Stakeholder 1 - Pig Farmers		
AVF	-2,149,452.61	-2,396,340.60
AVR	0.20	0.29
Stakeholder 2 – Lead Animal Health Organisation		
AVF	-1,719,226.53	-1,831,386.03
AVR	0.27	0.35
Stakeholder 3 – Animal Welfare Advocates		
AVF	-3,163,197.41	-2,961,295.16
AVR	0.15	0.25
Stakeholder 4 – Local Council		
AVF	-2,149,452.61	-1,266,431.47
AVR	0.20	0.44

5.4A Results

In OIS 1, the mean and median results of all stakeholders calculated from the analysis displayed in Table 29, show us the AVF (-2,295,332.29; -2,149,452.61 respectively) and AVR (0.205; 0.2 respectively) are less than the original CBA outcomes. The same trend appears in OIS 2 with the mean and median for the AVF (-2,113,863.32; -2,113,863.32 respectively) and AVR (0.3325; 0.32 respectively). It must be remembered that AVF is not a measure in dollar terms and a further discussion of this is contained in Chapter 7.

[5] Integrated results in Table 29 relate to the economic analysis data displayed in Table 23 and the intangible analysis data displayed in Table 27 and 28.

In both OIS, the LAHO has a close association with the outcomes that will likely be provided under the OIS, when compared to most other groups. This reflects the terms of net social benefit that the policies aim to achieve. In both OIS the AVR and AVF for LAHO is above the mean and median values. The animal welfare advocates have the least positive association with the outcomes under both OIS, which reflects their strong value associated with intangible impacts that they perceive will occur as a result of the disease and response strategy. Group AW AVR and AVF are below the mean and median outcomes.

The results also show for OIS 2, Group LC has the most closely associated integrated outcome when compared to the economic analysis, reflecting that they favour this outcome more strongly than a group with a less positive association such as the animal welfare advocates and the pig farmers. The AVF and AVR for OIS 2 are well above the mean and median scores, unlike in OIS 1, where Group LC scores sit around the mean and median. This accountably supports the conclusion that for this group the continuation of processing has the greatest economic and intangible benefit when compared to OIS 1.

Group PF scores lie close to the mean and median for the AVF and AVR in OIS 1, and slightly under the mean and median AVF and AVR in OIS 2. Arguably they are the stakeholders bearing the greatest impacts in terms of both the economic and intangible elements. Their results show that they are less supportive of both options when compared to the LAHO group, reflecting the intangible and economic impacts. Group PF is less supportive of OIS 2 than Group LC, which likely reflects their long term commitment to sustainability of the industry, rather than the short term economic gains.

5.1.3.2 Case study 5B

Generation of outbreak and intervention scenario (Steps 1-3) case study 5B

In case study 5B, the scope is far greater. In this fictitious scenario, infected semen was dispersed amongst a number of enterprises in the region. PRRS was not detected for three weeks and therefore the number of farms affected is substantially higher. Consideration is being given to the question of whether to attempt large scale eradication in a modified stamping out (salvage and slaughter) protocol, or if it would be best to allow the disease to become endemic. The analysis for this scenario is staged over a period of time that allows all pregnant sows on farm to farrow and the piglets to be grown out to sale (approximately 36-40 weeks).

Contaminated semen has been used on three farms in the area, and since then another 12 farms have become infected, making a total of 15 infected farms (dissemination rate of 1.4 herds/week) (Garner et al 2001). Two additional grower farms have received infected piglets directly from an IP making a total of 17 IPs. Each of these infected premises has an average number of three DCPs, which makes a total of 51 DCPs (Garner et al, 2001). The DCPs all fall within the restricted area of the IPs, so an extended control area has been established. The DCPs have not been serologically tested at this point; however it is possible that the virus could have been spread onto these premises given their close proximity and the potential for spread via fomites and vehicles.

The Victorian herd is comprised of approximately 35% contract growers, which means that of these 68 quarantined premises, 24 farms would be grower farms and the remaining 44 herds would have sows (Australian Pork Limited, 2012). Based on the demographics of these herds this outbreak would involve 8615 sows on the 44 sow farms (around 15.5% of the total Victorian sow herd) and over 30,000 grower/finished pigs on contract growing farms (16.3% of the Victorian total grower market) (Australian Pork Limited, 2012). The breakdown of the herd demographics are shown in Table 30. Further information regarding the generation of the economic data can be found in Appendix 9.

The MORR indicates that the likely number of infected cases on the IP sow farms after four weeks would be at least 1,120, and on grower farms there could be up to 4,000 cases. The likelihood of the disease being detected on the DCPs is high. The MORR predicts up to 2,000 more cases over the upcoming weeks on the sow farms and up to 12,000 cases on grower/finisher farms. For this reason, and given the proximity of the DCPs and IPs, the DCPs are placed under the same OIS conditions as the IPs. The parameters used for the MORR analysis for case study 5B are described in Appendix 8.

The major difference between the two OIS that are being considered is the slaughter of sows post farrowing in OIS 2. Under this option, logistic de-stocking (de-stocking in a staged process as the sows farrow) of all premises will occur, with a restocking program to commence after the properties have been disinfected. The piglets currently on farm, plus piglets that are born while under quarantine restrictions, will be allowed to grow out and be sold. These piglets cannot be moved out of the restricted area, but as there are grower farms already within the restricted are, limited movement to these farms is allowed. When the piglets reach saleable weight, arrangements can be made with specific slaughterhouses for logistic slaughter for market.

Table 30 - Outbreak and intervention scenario (OIS) summaries for case study showing demographic impacts for affected pig population under different control strategies

		OIS 1 – Disease is allowed to become endemic in population	OIS 2 – Disease is controlled with a modified stamp-out strategy
SCOPE DATA	Farms quarantined	17 IP 2,872 sows, 10,235 grower/finisher pigs	17 IP 2,872 sows, 10,235 grower/finisher pigs
		51 DCP (remainder)	51 DCP (remainder)
	Farm Demographics (IP plus DCP)	With Sows – 32 farms (1-49 sows) 2 farms (50-99 sows) 6 farms (100-499) 2 (500-999) 2 (1,000+) Total sows – 8,615 (including 12% gilts) 6,781 piglets in nursery Contract growers = 30,713 pigs	With Sows – 32 farms (1-49 sows) 2 farms (50-99 sows) 6 farms (100-499) 2 (500-999) 2 (1,000+) Total sows – 8,615 (including 12% gilts) 6,781 piglets in nursery Contract growers = 30,713 pigs
	Total Pigs (IP and DCP)	39,328 pigs 6,781 piglets	39,328 pigs 6,781 piglets
	Predicted positive cases (MORR)	IP Sow farms 1,120 cases IP Grower – 3,992	IP Sow farms 1,120 cases IP Grower – 3,992
	Herds a week slaughtered (capacity)	0	Max 7/week[a] Logistic slaughter
	Number of animals to be destroyed (max)	0	Up to 8,615
	Number of piglets potentially born of infected sows during the time (max)	60,119	60,119

[a] (Garner et al, 2001)

Under the OIS 1 arrangements, all restrictions will be lifted and pigs will be allowed to move freely between farms and to the slaughterhouse as per normal. Piglets can be moved to grower farms and sows will either rejoin the herd post weaning for mating, or be culled and replaced with new breed stock from the gilt pool. Farms will be responsible for implementing their own biosecurity measures to prevent the introduction and spread of PRRS virus.

Economic analysis (Step 4)

The same baseline economic data that was used in case study 5A, is used again for the outbreak analysis in case study 5B (for pigs, disease response and flow-on impacts). More information relating to the generation of this background economic data can be found in Appendix 10 and the CBA worksheets for case study 5B are displayed in Appendix 11.

The costs associated with such a large eradication program mean that for the current time period, the CBA favours OIS 1, allowing the disease to become endemic. If this case study considered a five-ten year benefits window, then the outcomes may be different. Further discussion of these results is found in Chapter 6. Table 31 shows the outcomes of the CBA for Case Study 5B.

Table 31 - Cost-benefit analysis outcomes relating to the economic impacts of a PRRS outbreak in northern Victoria for case study 5B

	OIS 1	OIS 2
NPV	$ 22,174,686.85	-$ 251,908.72
BCR	3.70	0.99

Intangible analysis (Step 5)

The same stakeholder groups are considered in case study 5B and the same intangible impact scales (as described in Tables 24-26) are used. In this case study, despite the economic analysis for the short-term greatly favouring the OIS 1, the PF group are adamant that it is not the best long term strategy, so their willingness-to-accept a compromise on the intangible impact is low for OIS 1, but much more flexible for OIS 2. They are strongly committed to retaining a PRRS-free pig population in Australia and are willing to compromise the short-to-medium term implications of an eradication program to protect the industry.

The LAHO is also prepared to compromise a little on their willingness-to-accept intangible impacts under OIS 2, if it means the industry remains PRRS free. However, under the conditions of OIS 1, they are more flexible than the PG group. The AW group is particularly concerned about the impacts on animal welfare under the OIS 2, and environmental impacts that may occur as a result of the destruction and disposal processes. They feel that these impacts would be less under OIS 1, although they are still concerned about the ongoing impacts the virus may have on pigs. The LC group have concerns with community capacity and the job impacts under OIS 2. Although the flow-on effects of processing will still be present, the impact of de-stocking and restocking will have short-term impacts on the prosperity of the community. They are only willing to compromise if the outcome supports the net benefit of the community. Tables 32-33 contain the predicted intangible impact level (PIIL) and the compromise thresholds (CT) for each of the stakeholders, under the OIS 1 and OIS 2 respectively.

Table 32 – Stakeholder intangible analysis outcomes for outbreak intervention scenario 1 (case study 5B), showing predicted intangible impact levels for animal welfare, human health and environment

	Animal Welfare CT_{PIILAW} = 6	Human Health CT_{PIILHH} = 6	Environment $CT_{PIILENV}$= 7
	CT	CT	CT
Commercial Pig Farmers (PF)	7	7	7
Lead animal health organisation (LAHO)	7	6	6
Animal Welfare (AW)	7	5	7
Local Council (LC)	6	6	7

Table 33 - Stakeholder intangible analysis outcomes for outbreak intervention scenario 2 (case study 5B), showing predicted intangible impact levels for animal welfare, human health and environment

	Animal Welfare CT_{PIILAW} = 3	Human Health CT_{PIILHH} = 4	Environment $CT_{PIILENV}$= 5
	CT	CT	CT
Commercial Pig Farmers (PF)	3	4	4
Lead animal health organisation (LAHO)	4	4	4
Animal Welfare (AW)	7	5	7
Local Council (LC)	6	6	6

Integrated analysis (Step 6)

When the intangible analysis and CBA are integrated, the analysis demonstrates the impact the intangibles have upon the results of the integrated analysis (Table 34).

Table 34 - Integrated analysis outcomes for outbreak and intervention scenarios (OIS) related to the porcine reproductive and respiratory syndrome outbreak described in case study 5B

	OIS 1 – Endemic Disease	***OIS 2- Salvage and Slaughter***
Economic Analysis Results		
NPV	$ 22,174,686.85	-$ 251,908.72
BCR	3.70	0.99
Integrated Analysis Results[6]		
Stakeholder 1 - Pig Farmers		
AVF	19,438,484.31	2,943,090.72
AVR	2.78	1.15
Stakeholder 2 – Lead Animal Health Organisation		
AVF	25,870,467.99	-293,893.51
AVR	3.70	0.99
Stakeholder 3 – Animal Welfare Advocates		
AVF	24,502,366.72	-22,910,798.34
AVR	3.24	0.46
Stakeholder 4 – Local Council		
AVF	22,174,686.85	-19,673,814.11
AVR	3.70	0.49

5.4B Results

The mean and median scores for all stakeholders involved in the analysis displayed in table 34 for OIS 1 are AVF (22,996,501.47; 23,338,526.79 respectively) and AVR (3.355; 3.47 respectively) and for OIS 2 are – AVF (-9,983,853.81; -9,983,853.81 respectively) and AVR (0.7725; 0.74 respectively). Group PF can be seen to strongly favour the outcome of OIS 2 (which is inflated in the integrated analysis), compared to OIS 1 (which is deflated in the

[6] The integrated results displayed in Table 34 relate to the economic analysis data displayed in Table 31 and the intangible analysis data gathered in Tables 32 and 33.

integrated analysis). Also supporting this are the above average scores for Group PF in OIS 2, and the below average scores in OIS 1.

The AW group favour neither option, although the OIS 1 scores are much closer to the mean and median results than the OIS 2 scores. Group LC are in favour of the OIS 1 rather than OIS 2, which is demonstrated in the above mean and median results for OIS 1 and below mean and median results for OIS 2.

These results indicate that industry stakeholders (Group PF) strongly support that Australia remain free of PRRS, despite the impact of an EAD response campaign involving slaughter of sows on infected premises. Group LC and Group AW are not as supportive of a salvage and slaughter campaign (OIS 2) due to the intangible impacts that would occur. The LAHO integrated analysis reflects the neutral stand supporting the actions of the OIS in terms of net social benefit.

Chapter 6 – A regional level model of Hendra Virus in Southeast Queensland

6.1 Background

Hendra Virus (HeV) is a member of the family Paramyxoviridae (Halpin et al., 1999; Field et al., 2011). It is classified as an EADRA category two disease. This categorisation denotes a disease of national socio-economic consequences and/or significant public health and environmental impacts (Animal Health Australia, 2012). The virus has zoonotic capacity with a transmission pathway that begins with pteroptid bats (fruit bats from the family *Pteropodidae* – more commonly known as flying-foxes) as a reservoir host, flying-fox to horse transmission occurs and horses become the spillover host. Horse to horse transmission can occur, through contact with infectious bodily fluids such as respiratory or nasal secretions, blood or urine from horses. The virus undergoes amplification in the horse and humans exposed to large amounts of virally contaminated blood and secretions from these infected horses can become infected (Young et al., 2011). Natural infection in a dog has occurred in one known instance and experimentally other mammalian species (cats, monkeys, pigs and laboratory animals) have developed infection after exposure. To date, no human to human transmission has been recorded (Halpin et al., 2000; Young et al., 2011; Field et al., 2012; Mahalingam et al., 2012; Degeling and Kerridge, 2013).

HeV is endemic in pteroptid bats, but the epidemiology of the disease makes prediction of when outbreaks (or in this case clusters) will occur difficult. The spatial and temporal patterns of disease clusters are likely to be related to environmental factors. Therefore ecosystem changes that occur as a result of urbanisation, tree clearing in preferred roosting areas and changes in migratory patterns might impact the patterns of disease outbreaks (Plowright et al., 2011). Further complicating the prediction of outbreaks is the inconsistent and periodic excretion of HeV by flying-foxes (Field et al., 2011). Preventive measures revolve around hygiene, education and avoidance of horse activities in flying-fox roosting areas (Mahalingam et al., 2012; Department of Agriculture Fisheries and Forestry (Queensland), 2013). A HeV vaccine for horses was released in 2013 and is available under a minor use permit issued by the Australian Pesticides and Veterinary Medicine Authority (APVMA, 2013; Department of Agriculture Fisheries and Forestry (Queensland), 2013; Health4Horses, 2013).

In this case study, rather than evaluating the OIS in terms of a response strategy, the focus is on disease prevention strategies. To prevent or limit the number of cases of HeV, it can be postulated that removal of all flying-foxes from the horses' environment would be prudent. However for certain stakeholder groups, it could be anticipated that the preferred option would be the removal of all horses from the flying-fox's ecosystem. Given the likely intersection of the two environments in which these animals live, and the continuation of urban sprawl, the dynamic remains that exposure to the virus is an ongoing risk that must be managed. In Queensland flying-foxes cannot be culled (except under extenuating circumstances by mitigation permit for crop protection). Roosts cannot be destroyed without an approved management plan guided by a code of practice. Only non-lethal dispersal methods are allowed to be used for roost management (Department of Environment and Heritage Protection, 2012, 2013b, 2013a). Flying-foxes have a 'protected' status under the Nature Conservation Act (Queensland Government, 2012).

6.2 Introduction

The horse population in Southeast Queensland is estimated to be around 100,000 horses (Anonymous, 2008). This population is made up of competition horses, leisure-riding horses, 'pet' horses and race horses. The thoroughbred racing population represents around 10% of the total horse population in Australia (Ryan, 2010). The overall contribution of the horse industry to the Australian economy was estimated to be $6.2 billion in 2001 (Gordon, 2001).

There are more than 100 known flying-fox roosts within Southeast Queensland (Department of Environment and Heritage Protection, 2011). A map detailing these sites can be found in Appendix 12. Of these roosts, 25 are considered to be within 'urban areas' (Roberts et al., 2006). Figure 13 shows the urban flying-fox camp areas of Southeast Queensland where proposed roost site removal will occur (there may be multiple roosts within one 'camp'). Under proposed changes to the legislation, the Queensland Government intends to give local councils the power to disperse, remove or manage flying-fox roosts in a non-lethal manner without a permit in urban areas (Department of Environment and Heritage Protection, 2013b). There are concerns that the greater rights of councils to control flying-fox issues will lead to problems with the conservation of these species. A possible alternative to removal or dispersal of flying-foxes from their roosts is to vaccinate horses that are located within the flying-fox areas.

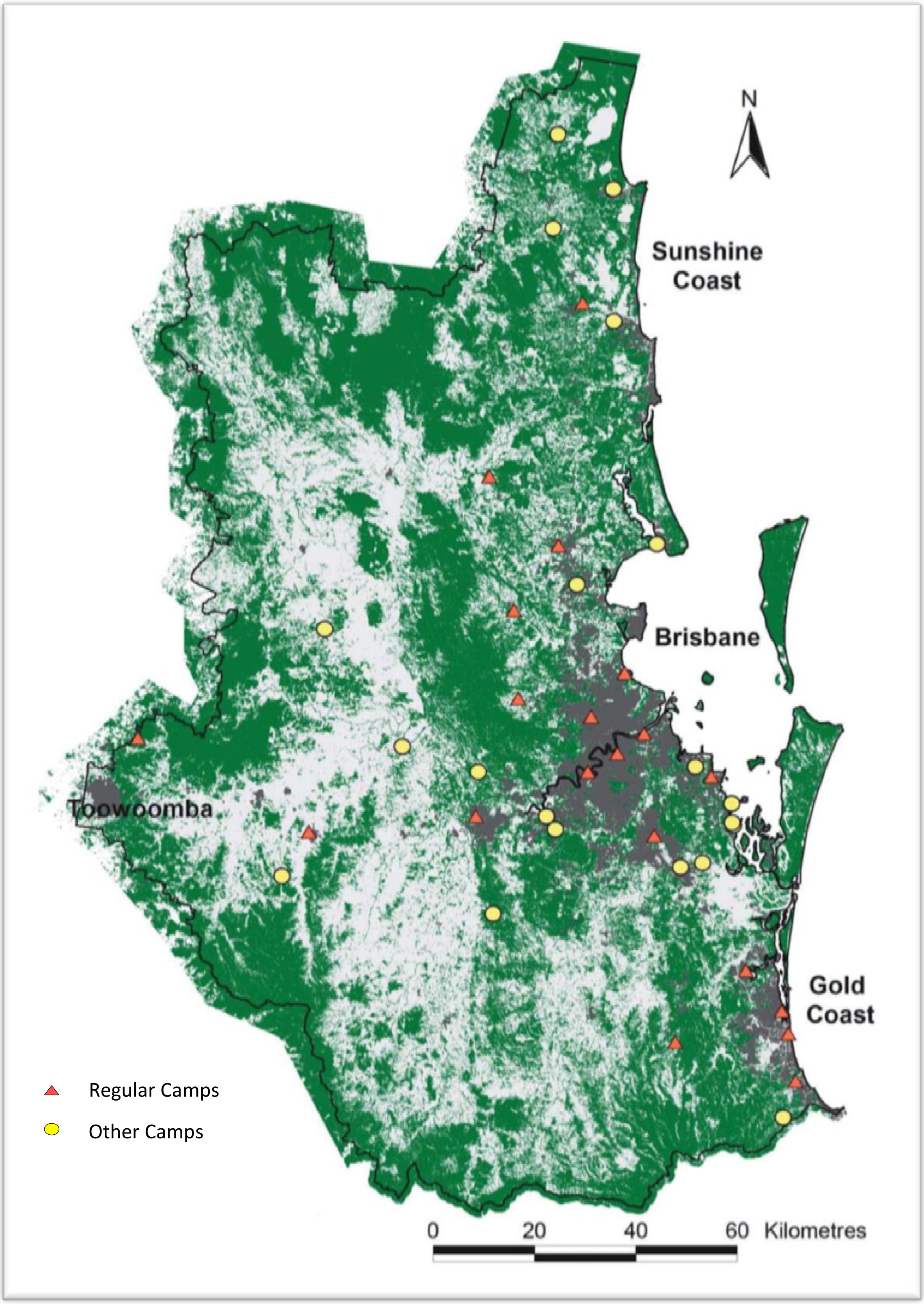


Figure 13 – Commonly used flying-fox camps in urban areas in Southeast Queensland where proposed roost removal will occur in case study 6. Source: Roberts et al (2006) Page 4. (Camps in grey shaded areas are considered to be 'urban' camps).

In case study 6, the proposal is made to weigh up the tangible and intangible costs and benefits of the removal of flying-fox roosts from within the Queensland south-eastern urban area versus the vaccination of all horses within these areas with the newly available commercial vaccination. The stakeholders considered within this study are the race horse competition and leisure horse owners (Group CLHO), combined local council management group (Group LC), veterinary representatives (VR) and wildlife advocates (Group WA). The cost of removal of one flying-fox roost has been reported to be between $30,000 and $150,000 in Queensland (ABC News, 2013; Anonymous, 2013), $42,000 (averaging approximately $57,00 per year per roost) in northern NSW (GeoLink, 2010) and for a single large colony relocation attempt in Melbourne around $3 million dollars in 2003 (Roberts, 1990; GeoLink, 2010; Department of Sustainability Environment Water Population and Communities, 2013). A median figure of $57,000 was used in this case study.

The cost of vaccination for HeV excludes the veterinary fees and micro-chipping required with vaccination. The protocol requires an initial course of two vaccinations three weeks apart and a follow up booster vaccination every six to twelve months (Health4Horses, 2013). The total cost of each treatment can from $100 to $270 per dose depending on the veterinary call-out fee and the need for micro-chipping (Geiger, 2012; Walker, 2013b). In this scenario a combined local council management group is considering employing an accredited veterinarian (with HeV training), part-time to perform subsidised HeV vaccination as an alternative to roost management. The total cost of the initial vaccination protocol (including two vaccinations, veterinary fees and micro-chipping) will cost the horse owner $220 at ‘vaccination clinics’. There is an advertising budget of $5,000 for these clinics.

Group VR (whilst supportive of the move towards increasing the uptake of the vaccination) feels that the council is unnecessarily competing with their services. They also feel that this approach breaks the link between the clients and veterinarians for other services and increases the risk of the spread of other contagious diseases between horses. This approach does nothing to address the risk of other zoonotic diseases that may be prevented by removing the flying-fox habitats. Group VR has discussed the implications of visiting unvaccinated horses with clinical signs that could differentially indicate HeV. They consider that to reduce risk to themselves, an overall increase in the uptake of HeV vaccination would be better for the profession in the longer term.

The group LC defends their options, given the polarity of the public opinion on moving the flying-fox colonies. They feel there is no greater risk of transmissible disease spread between horses during a vaccination clinic at a local show grounds, than there would be in hosting a local equestrian event. Group LC has suggested that if Group WA is vehemently opposed to the removal of flying-fox roosts, then support and possible financial contribution to a vaccination clinic would be proactive and for the greater good of the communities. Group LC is aware of the limited success of other attempts to relocate flying-fox roosts, and feels that removal of the flying-fox roosts altogether would destroy some of the aesthetic appeal of the public areas in the community. This is balanced by the already reduced amenity of public areas because of flying-fox colonies roosting in the area (with faecal contamination, noise, smell and public concern over spread of disease). Overall the group LC concern is for the best public health outcome, which needs to be balanced with education, proactive intervention and community consultation.

Group WA are supportive of the proposal to vaccinate horses. They have major concerns about the negative impacts of moving or destroying flying-fox roosts. They feel that if the flying-fox habitats were to be removed then compensatory habitats would need to be found. Their argument is supported by the precedent of other unsuccessful flying-fox roost mitigation measures. Group WA also have concerns relating to the disturbance of reproductive patterns in the flying-fox populations. Group WA feels that removing roosts may encourage illegal vigilante actions towards flying-foxes and as a result, an increase in unnecessary animal welfare issues will arise. Group WA feels that group LC should be planting ecosystems that help in nurturing these colonies, which could provide an option for eco-tourism for nature lovers (GeoLink, 2010).

Group CLHO strongly advocates removal of flying-fox roosts. They feel that even with their horses vaccinated, the measures that they still have to take in terms of cleaning up after the flying-foxes and protecting themselves from other zoonotic diseases, mitigates the environmental disturbance. Despite group WA claiming that removing roosts may actually increase flying-fox numbers in singular or small clumps of trees in backyards with horses (where the occupant has no powers to remove the roosts), group CLHO are adamant that having to pay for horse vaccinations is unfair, when there is an alternative. Vaccinating horses also does not protect their other animals such as dogs and stable cats that may be at risk. There is a feeling within the competition horse community that vaccination may soon become compulsory (Anonymous, 2012). In this situation, the subsidised vaccination would be more economical for the horse owners in most cases.

The uptake of the HeV vaccination to date has been reportedly so poor that there is manufacturer concern that the vaccine may not be commercially viable (Walker, 2013b). It is estimated that only 13-20% of horses in high risk areas have been vaccinated to date (Walker, 2013a). This is postulated to be due to a number of factors (such as concerns regarding safety, efficiency and ability to travel the horse internationally after vaccination) but primarily due to cost of the vaccination (Zoetis, 2012; Walker, 2013b).

6.3 Methodology

Generation of the outbreak intervention strategy (step 1-3)

In this case study we consider an Outbreak and Intervention Scenario (OIS) relating to HeV. The geographical area to be considered is Southeast Queensland, with a horse population of approximately 100,000 horses (Anonymous, 2008). If we consider that 20% of horses in the area have already been vaccinated against HeV and the overall uptake of HeV vaccination will be 50% of the overall horse population in the area, that leaves 30,000 naïve horses to be vaccinated under the first option of the strategy (OIS 1). There are 25 flying-fox roosts that are considered to be eligible for removal under the urban flying-fox roost mitigation proposal for local government under the second strategy (OIS 2). In both scenarios, it is assumed that 75% of the horse population is at risk of exposure (vaccinated or unvaccinated). These two OISs are considered as singular strategies (either/or), with the investment by Group LC to be put either into OIS 1 or 2, depending on the outcomes of the analysis.

Using the MORR, we can calculate the difference in predicted numbers of horse cases when using the vaccination strategy compared to the roost removal strategy (Table 35). An assumption that needs to be made under each strategy to generate the scope is the prevalence of virus in the flying-fox population. In this case study prevalence was assumed to be 10% based on sero-prevalence findings in prior studies of between 9 – 56% (Young et al., 1996; Halpin et al., 1999; Breed et al., 2011) and pooled urine sample prevalence of 2.5% (Field et al., 2011). The expected number of human cases is based on the findings by Field et al (2012). The background data for case study 6 is displayed in Appendix 13 and the probabilities for the MORR calculations can be found in Appendix 15.

Table 35 – Epidemiological impacts of prevention strategies for Hendra virus used in case study 6

		OIS 1 – Vaccination	OIS 2 – Roost Removal
SCOPE DATA	Unvaccinated horses at the end of the Strategy (at risk of disease)	50,000	80,000
	Predicted cases (MORR)	**7**	**22**
	Assumed prevalence in flying-foxes	10%	10%
	Anticipated potential number of human cases	**3-4**	**11**
	Flying-fox roosts removed	0	25

Economic analysis (step 4)

Horse maintenance costs were worth approximately $1.9 billion to the Australian economy in 2001. At this time the estimated number of horses in Australia (excluding feral horses) was 715,820 (Gordon, 2001). This produces an average contribution to the economy per horse of $2,564. If this figure is adjusted for inflation to current prices, then the contribution is $3,471

(Reserve Bank of Australia, 2013). The average economic loss due to a horse death is considered to be $12,625 (adjusted for inflation from the average economic loss due to horse mortality during the 2007 Equine Influenza outbreak) (Smyth et al., 2011; Reserve Bank of Australia, 2013). HeV is a category two disease under the EADRA, which means that 80% of response costs are covered by Government and the other 20% by industry (Animal Health Australia, 2012c).

Costs involved in responding to a case of Hendra virus include staff time, diagnostic testing, destruction and disposal costs, disinfection of immediate surroundings and surveillance testing of in-contact animals. The average response and support costs per horse for HeV are $18,032 (total of $200,000 for 12 horse cases in 2008-2009 financial year, adjusted for inflation) (Queensland Ombusman, 2011; Field et al., 2012; Reserve Bank of Australia, 2013).

The wholesale cost of a HeV vaccination is $54.80 per vaccination (with a two vaccination initial protocol) and the cost of a microchip is $10.41 (Provet customer hotline - personal comms 4/6/2013). The cost of employing an experienced veterinarian on a casual rate to perform the vaccination clinics is $54.49/hour (UQ, 2013). It is estimated that 4,200 hours of veterinary work will be utilised (average 50 horses per day over 600 clinics) in the vaccination campaign. Each veterinarian will require a kit that includes a car fridge, disposables such as gloves, disinfectants, thermometers, alcohol swabs as well as the vaccinations and microchips. The cost of these kits for the 4,200 hours of work is estimated to be approximately $22,000 (itemised details in Appendix 14).

The most recent outbreak of HeV had no associated human cases of disease. This is reportedly likely due to the low intensity of contact between the horses and the owners. It could also indicate an increased awareness and positive response to education for HeV in both horse owners and attending Veterinarians (Field et al., 2012). The economic costs of human medical treatments for any positive human cases are considered to be out of scope for this study, although the associated intangible impacts are considered in the following section. The cost of a human case of HeV was considered out of scope because with only a small proposed improvement in vaccine uptake proposed, the risk of human exposure to HeV is reduced but not mitigated. Further to this, there are still other zoonotic diseases that can be transmitted to humans from flying-foxes which are not reduced by the use of HeV vaccination protocols. As the epidemiological and ecological aspects of HeV are still largely unknown, the ability to predict the number of human cases is difficult.

The full working of the CBA is given in Appendix 14, with the results summarised in Table 36. Although the ratio of costs to benefits is slightly better in OIS 2, the overall NPV for the vaccination strategy in OIS 1 is higher.

Table 36 - Cost-benefit analysis outcomes relating to the economic impacts of Hendra virus control in Southeast Queensland

	OIS 1 (Vaccination)		OIS 2 (Roost Removal)	
NPV	$	3,019,789.00	$	1,677,419.00
BCR		1.74		1.77

Intangible analysis (step 5)

The intangible elements that are considered in this case study are – environmental amenity value, human health and risk of zoonotic disease, flying-fox welfare impacts and horse welfare impacts. The intangible impact scales that are used for analysis are shown in Tables 37-40 below.

Table 37 - Environmental amenity impact scale for presence of flying-fox colonies and roost removal

Impact level	*CT Scale score*	*Impact effects*
Best Case (Least Impact on intangible)	5	Minimal environmental disturbance, amenity very low in roost areas due to noise, odour, faecal contamination and colonisation. Tree damage due to roosting
	4	Minimal aesthetic impacts to environmental outlook – canopy thinning. Slight improvement to amenity in general area (reduced odour, faeces and noise), reduction in tree damage due to lower levels of roosting
	3	Moderate aesthetic impacts – canopy thinning and tree trimming, colony disruption and improvements to amenity and usability in most tree zones for short periods of time while colony is disrupted. Neutral tree damage from roosting due to trimming.
↓	2	Selective removal of singular trees from within clumps, trimming of other trees and canopy thinning. Moderate-high aesthetic impact. Great improvement to amenity and only occasional temporary colonisation with minor impacts from noise, odour and faecal contamination.
Worst Case (Most impact on intangible)	1	Severe aesthetic impacts, removal of large clumps of trees, localised removal of flying-fox habitat, large improvement in amenity and useability in tree zones at all times. No colonisation present so negligible faecal contamination, odour or noise.

Table 38 - Human health impact scale for presence of flying-fox colonies and roost removal

Impact level	*CT Scale score*	*Impact effects*
Best Case (Least Impact on intangible)	7	No related illness or stress, no impact of odour, noise or faecal contamination, negligible - very low risk of zoonotic disease from flying-fox colonies
	6	Mild stress with no physical symptoms, low impact of odour, noise or faecal contamination, very low risk of zoonotic disease from flying-fox colonies
	5	Moderate increase in stress resulting in mild physical symptoms, and/or mild sleep deprivation as a result of flying-fox colonies, low – moderate impact of odour, noise or faecal contamination, very low-low risk of zoonotic disease from flying-fox colonies
↓	4	Physical and or mental health deficits that have a minor impact on quality of life, mild-moderate sleep deprivation, moderate impact of odour, noise or faecal contamination, low risk of zoonotic disease from flying-fox colonies
	3	Physical and or mental health deficits having moderate impacts on quality of life, moderate sleep deprivation, moderate – high impact of odour, noise or faecal contamination, low-moderate risk of zoonotic disease
	2	Physical and or mental health deficits having serious deleterious impacts upon quality of life, high level of sleep deprivation, high impact or odour, noise or faecal contamination, moderate risk of zoonotic disease from flying-fox colonies
Worst Case (Most impact on intangible)	1	Human deaths or severe suffering as a result of direct and indirect impacts, severe impact of odour, noise or faecal contamination, high – severe levels of sleep deprivation, moderate – high risk of zoonotic disease from flying-fox colonies

Table 39 - Animal welfare impact scale for horses located in proximity to flying-fox habitats

Impact level	*CT Scale score*	*Impact effects*
Best Case (Least Impact on intangible)	5	No related illness or stress due, no additional treatment or intervention required
	4	Mild routine changes or reduction in freedom, minor non-invasive biosecurity interventions required to prevent disease (e.g. change feeding routines or places)
↓	3	Moderate changes in routine or biosecurity with resulting mild stress or limitation to freedom (e.g. locking up at night, reduced access to free grazing)
Worst Case (Most impact on intangible)	2	High level changes to routine or freedom such as no paddock grazing access, moderated feeding times
	1	Complete restriction of horse to enclosed stable only. Minimal opportunity for socialisation

Table 40 – Animal welfare impact scale for flying foxes in habitats where roosts are removed

Impact level	*CT Scale score*	*Impact effects*
Best Case (Least Impact on intangible)	5	No related illness, physiological changes, stress of fatigue or due to welfare issues or resource limitations
	4	Mild resource pressure in roosts and stress without illness from fatigue
↓	3	Moderate resource limitations in roosts, stress and fatigue resulting in illness, increased predation, juvenile separation and or abortions and exposure to the elements
Worst Case (Most impact on intangible)	2	High levels of resource limitation in roost sites and stress, resulting in illness, abortion, juvenile separation, predation, exposure to the elements and mortality increase of 5-15%
	1	Severe resource limitations in roost sites causing mortalities greater that 15%, plus juvenile separation, illness, abortion and starvation. Predation and exposure to the elements frequent events causing mortalities.

There is much diversity between the stakeholder groups. For some groups, both horse and flying-fox welfare are important. For other groups, one animal is more important than the other. In the case of other stakeholders, human health is the over-riding concern that drives their assessment of the intangible elements. Economically, both OIS are justifiable but come with intangible pros and cons. The LC group delivers the PIIL for each intangible element under the OIS being considered. Following this, each stakeholder group delivers what they consider to be their compromise threshold for each intangible element. The outcomes of the intangible analysis are shown in Tables 41 and 42.

Table 41 – Outcomes of the intangible impact analysis for Hendra virus case study using intervention strategy 1 – horse vaccination

OIS 1 Vaccination	Env Amenity $CT_{PIILENAM}$= 5	Human Health CT_{PIILHH} = 4	Horse Welfare CT_{PIILHW}= 4	Flying-fox Welfare CT_{PIILBw}= 4
	CT	CT	CT	CT
Group CLHO	2	6	4	2
Group LC	3	6	4	4
Group VR	3	6	4	3
Group WA	6	5	1	5

Table 42 - Outcomes of the intangible impact analysis for Hendra virus case study using intervention strategy 2 – flying-fox roost removal

OIS 2 Roost Removal	Env Amenity $CT_{PIILENAM}$= 1	Human Health CT_{PIILHH} = 6	Horse Welfare CT_{PIILHW}= 2	Flying-fox Welfare CT_{PIILBw}= 2
	CT	CT	CT	CT
Group CLHO	2	6	4	2
Group LC	1	6	3	2
Group VR	4	6	3	3
Group WA	6	3	1	5

From the results, we can see that Group CLHO want consistent conditions for their own health and the welfare of their horses and are prepared to compromise on the welfare of the flying-fox colonies. Group LC appreciates the impacts on both environmental amenity and the flying-fox welfare that will have to be sacrificed under OIS 2, but see that some impact to environmental amenity will still need to be considered under the OIS 1. Group VR want consistent welfare for both animals, but sees that OIS 1 will prevent the impact upon the horse welfare that may have to be endured in OIS 2. Of great concern to groups CLHO, LC and VR, is limiting the impact upon human lives.

Group WA is determined that flying-fox welfare should not be impacted and that humans and flying-foxes should be able to co-exist with the correct education (GeoLink, 2010). This means humans accepting the impacts that come with flying-foxes to maintain the ecosystem with only minimal environmental impacts. They feel that the horse population is invading the traditional flying-fox ecosystem and that if any animal was to be moved, then the horses should move or be prepared to take precautionary measures that prevent contact with flying-foxes.

Integrated analysis (step 6)

When the result of the economic and intangible analysis are integrated, it becomes evident OIS 1 is the most favoured option by all groups (Table 43).

Table 43 – Results of the economic and integrated analysis of disease control strategy impacts for the Hendra Virus case study

	OIS 1 - Vaccination	OIS 2 – Roost Removal
Economic Analysis Results		
NPV	$3,019,789.00	$ 1,677,419.00
BCR	1.74	1.77
Integrated Analysis Results[7]		
Stakeholder 1 – Competition and Leisure Horse Owners		
AVF	10,545,645.33	589,511.00
AVR	2.93	1.18
Stakeholder 2 –Local Council		
AVF	5,211,705.33	1,314,783.00
AVR	1.96	1.52
Stakeholder 3 –Veterinary Fraternity		
AVF	6,989,685.33	317,079.00
AVR	2.28	0.92
Stakeholder 4 – Wildlife Advocates		
AVF	5,625,641.67	801,200.33
AVR	1.82	1.14

6.4 Results

The option to vaccinate horses unanimously adds value to the economic results, whilst the option for roost removal unanimously detracts from economic analysis value. Both the mean and median stakeholder AVF (7,093,169.42; 6,307,663.50 respectively) and AVR (2.2475; 2.12 respectively) for OIS 1 are inflated when compared to the economic analysis, indicating a more positive outcome for the integrated results. In OIS 2, the mean and median AVF (755,643.33; 695,355.67 respectively) and AVR (1.19; 1.16 respectively) are deflated when

[7] The integrated analysis uses the data gathered from economic analysis displayed in Table 36 and the intangible analysis data displayed in Tables 41 and 41.

compared to the outcomes of the economic analysis. This indicates that with the inclusion of intangible values, all stakeholders think that OIS 1 is creating greater value, while OIS 2 is creating greater cost in terms of intangible value.

DISCUSSION

Chapter 7 – Assessment of operation and overall utility of the framework

7.1 Results - Case study 5A and 5B (PRRS in northern Victoria)

There are two factors that would have a major impact on the economic and intangible impacts of the PRRS case studies. One is the size of the disease incursion (in terms of the number of cases) and the other is the time period during which the benefits of the OIS are considered. In case study 5A, the outbreak is relatively small and contained and controlled at an early stage. In this case study the eradication strategies are implemented in a discrete and relatively short time period and the recovery phase can begin quickly without major industry impacts. This is assuming that the disease is able to be successfully eradicated and freedom from disease status can be regained.

The overseas experience indicates that the reality is the ability to prevent and/or eliminate PRRS on farm, even with good biosecurity, is a challenge (Cho and Dee, 2006). Case study 5B presents the scenario where a larger outbreak is sustained over a longer period of time, and therefore the results are more dramatic in terms of economic and intangible impacts. The reality of a large scale and widespread outbreak is that there is a possibility that eradication attempts may be abandoned. This would mean that the onus for control and prevention would be placed upon the producer. The producer would also bear the losses sustained with endemic PPRS and additional costs in the production of pork. It is likely that eventually these costs would be at least partially passed on to the consumer, until such a time that supply and demand was impacted.

If we were to consider the PRRS situation over a much longer timeframe, such as 10-15 years, the expenditure required for eradication would likely return much greater benefits (such as a reduction in costs and losses associated with PRRS). PRRS is a category four disease under the EADRA, so industry is responsible for 80% of the response costs and government 20% of the costs. Overall, the pork industry is the stakeholder with the greatest investment and must carefully weigh up the expenditure on eradication with long-term industry benefits.

PRRS is not a zoonotic disease, it is species-specific affecting only pigs, and it has no direct environmental impact (Albina, 1997). Compared to some other swine diseases with zoonotic impacts or impacts on native animals, the intangible impacts of PRRS are considerably less. However there is no doubt that the impact of a PRRS outbreak would affect human mental health and anxiety (which could lead to physical health effects), succession and livelihood (for primary and secondary industries), animal welfare and at least some indirect and short-term environmental impacts during large scale carcase disposal. It is primarily a disease of economic impact. Intangible impacts (particularly animal welfare) would be a subjective and yet highly emotive consideration in responding to a disease incursion.

While the inclusion of intangible impacts served to inflate or deflate the economic analysis results, in neither of the PRRS case studies, did the overall outcome preference change when compared to the economic analysis. The results provided a gauge as to acceptability of the different OIS for different stakeholder groups, reflecting and recording the compromise thresholds for each intangible considered under different OIS.

7.2 Results - Case Study 6 (HeV in Southeast Queensland)

The results of the HeV case study are interesting due to the polarity in the outcomes. It is evident that all stakeholders indicate through intangible analysis that one strategy is more highly regarded than the other. Unlike the PRRS case studies, the inclusion of intangibles changed the ranking of the OIS being examined in terms of the AVR (or combined economic and intangible cost to benefit ratio). It would seem prudent to follow the guidance that this analysis provides. The economic analysis alone indicates that both strategies are economically feasible, although the organisation and initial outlay costs are larger for OIS 1 and the benefit to cost ratio of OIS 2 is slightly larger. An ideal approach would possibly involve a combination of both strategies such as minor canopy trimming and increasing vaccination of horses through provision of subsidised vaccination.

Some groups, such as the CLHO and VF have a much stronger positive association with the outcomes of the OIS 1 than other groups (such as group LC). This perhaps reflects the burden of responsibility for the organisation and implementation of the strategy, albeit with positive economic and intangible outcome. The opportunity to invest and make revenue on the OIS 1 could present a business opportunity for group LC. Of course the revenue is largely dependent on the uptake of the vaccinations at the 'vaccination clinics' and for this a greater advertising budget may be needed. It also assumes that a proactive and integrated local government management group would agree to the initial investment.

An additional consideration in the decision to implement one of these strategies, is the developing knowledge of the impact of stress upon viral shedding in flying-foxes, particularly during pregnancy (Breed et al., 2011; McFarlane et al., 2011; Plowright et al., 2011; Field et al., 2012). Given the stress and resource limitations that would likely be associated with roost removal, it is possible that an increase in viral shedding could occur in local flying-fox colonies. If there are no roost sites available at the usual documented spots, then flying-fox colonies could move into backyard areas, where local governments have no powers to address the issue of colony removal and any backyard horses may be placed at higher risk. This development in turn places humans at higher risk, a risk that could be mitigated by vaccination of horses with the HeV vaccine.

Despite Group VF being reserved about the impact of OIS 1 on their business, the outcome from this option still serves their best interests in the longer term. There has been dialogue regarding the right of a veterinarian to refuse to visit an unvaccinated horse showing clinical signs consistent with HeV infection (Clarke, 2013). Veterinarians and people working in the horse industry are over-represented in the mortalities from human HeV infection, so a reduction in occupational hazards and human mortality relating to HeV in humans, provides net social benefit (Young et al., 2011; Field et al., 2012). The value of this 'safety' element is lost in finance-only evaluations of these strategies, as is the value of a human life saved.

The understanding of HeV is still evolving. This disease presents a unique set of legislative, practical, environmental and emotive issues for which no simple solution can be derived. With the technological advancement of vaccine production and availability, we have an opportunity to break the transmission pathway. It is disappointing the uptake of the vaccination has been low, given the intangible elements that are potentially affected. It may be that the cost of vaccination needs to be subsidised or the capacity for accessing the vaccination (such as vaccination clinics) needs to be addressed so as to improve uptake. However the fact remains that the responsibility for preventing loss of human life, preserving environmental integrity and maintaining animal welfare is a joint effort between all stakeholders.

7.3 Assessment of operational parameters

7.3.1 Assessment of outcomes of analysis

Output parameters:

In this framework, two output parameters are used. The AVF is a value adjusted figure that incorporates both economic and intangible elements. It represents the integrated costs minus the integrated benefits. The AVR is the ratio of integrated benefits to integrated costs. The components of both are derived by inflating or deflating the economic costs and benefits, according to the compromise that the stakeholder is willing to consider, for the impacts upon a specified intangible element, under certain disease outbreak or response conditions.

Because NPV in a CBA is interpreted directly in monetary units, there is always the risk that AVF will also be assumed to be a monetary measure. This is not the case and the point of creating an intangible measure scale is to avoid the scenario whereby subjective elements that are undefinable in monetary terms are given a dollar value. It can still be considered that an overall AVF of greater than zero will provide benefit. In the situation that the NPV for a case study is less than zero, but the AVF is greater than zero, it would mean that the project is feasible when intangible elements are considered for that stakeholder. This outcome was demonstrated in case study 5B for the PF group. So for this group, when the intangible impacts were considered in addition to the economic impacts, the value of implementing eradication strategies rather than allowing PRRS become endemic had a positive AVF therefore providing benefit (where all other stakeholder groups had a negative AVF – indicating that the outcome did not provide benefit to that group). AVF is useful for ranking the integrate economic and utility values from lowest to highest and for comparing AVF between the LAHO groups (which are seen to reflect net social benefit) and other stakeholder groups.

The AVR seems to provide the most comprehensible information in terms of the value of the benefits provided for the costs sustained for that scenario. The BCR and AVR are never considered in dollar terms but as a ratio. Under conditions where the NPV/AVF shows great variation between the options, the use of BCR or AVR may provide more meaningful information to the decision-maker. Using the BCR criterion in traditional CBA, it is stated that a higher BCR does not make a more worthwhile project as intangibles are not considered. The use of AVR integrates the intangible impacts for each stakeholder group, which means that the higher the AVR, the higher the value of the project. The AVR therefore delivers commensurability. As was demonstrated in Case Study 6, when the intangible impact of two different prevention strategies for HeV are considered, the ratio of integrated costs to benefits (AVR) changed the ranking of the output criteria for all groups when compared to the economic outcome of the BCR.

The problems that have been ascribed to the use of BCR in Chapter 2.5.2, are somewhat irrelevant to the use of the AVR. Social consequences are considered (as are environmental and animal welfare issues) and have been incorporated into the economic assessment. The ability to '*rank'* the outcome according the AVR is a key goal, to allow identification of the acceptability of the outcome of the analysis for different stakeholder groups. The ranking of the outcomes do not indicate which option the lead organisation should select, but it demonstrated where the most favourable outcome lies according the perspectives of the stakeholders. In cases where there is a large discrepancy between the AVF for different OIS, the AVR can be used to demonstrate the best outcome in terms of benefits scaled to costs according to the stakeholders.

These two output criteria considered together, provide the decision-maker with a comparative ranking of stakeholder reflections on overall impact to integrated utility that would occur in an EAD situation. The two integrated output parameters (AVF and AVR), when compared with the economic outcome parameters (NPV, BCR), provides a great deal of information for the decision-maker. It provides a method to measure and record the impact of different situations (of disease outbreak and prevention) upon different stakeholders. The lead organisation, who will ultimately take responsibility for implementing the most socially beneficial strategy, can use this information to guide and support their decision-making. In essence this method allows a 'ground-truthing' of anticipated or expected stakeholder reaction to proposed policy strategies for EADs.

7.3.2 Assessment of framework variables and their operational performance

Time scale

A CBA is generally conducted over a prescribed period of time (a project length, a financial year, 5 years) and includes discounting to adjust the costs and benefits to reflect future values. No definitive timeframe for a CBA could be found in research and some authors caution that estimating the length of accrual for future benefits and costs can be difficult (Power and Harris, 1973). A short analysis timeframe has been chosen for the PRRS and HeV case studies. The timeframe includes the time from detection of disease, until the farm is destocked, disinfected and in farm-idle state. The reason for this shorter time frame was to assess the immediate impacts of emergency animal disease. With the nature of EAD requiring immediate response and decision-making to performed under critical conditions, the analysis was designed to collect the stakeholder perspectives to support such conditions. The goal in the analysis was not to assess long term impacts, but the immediate impacts of the incursion upon the stakeholders.

CBA was selected as the preferred methodology as enabled flexibility for the inclusion of intangible analysis that other economic assessment methodologies lacked. As the timeframe considered was short, no discounting was required in the analysis. If the analysis had been considered over a long timeframe, then discounting would have applied to the CBA to adjust the economic parameters to reflective values for that time period.

Some intangible benefits may not be realised until much further into the future than economic benefits. Examples of such benefits include the benefits of biodiversity, legacy and sustainability. It is therefore difficult in an analysis framework to set a time limit on benefits that may not yet be quantified, or may not be generated within the analysis window. In fact the end limit to benefits within economic and intangible analysis is difficult to quantify (Power and Harris, 1973; Daily et al., 2009). For this reason, a prescribed time limit for the integrated analysis is given, generally the length of time for the implementation of the intervention or prevention strategy being considered. There is no reason why future (or prior) benefits could not be considered in the analysis. If the economic analysis (either prospectively or retrospectively) is adjusted for the time frame that is considered, then the integrated analysis will reflect this. For example in the endemic disease situation, benefits and costs of different intervention programs may change with changes in the economy, but the value a stakeholder places on animal welfare or human health is unlikely to change.

The concept of personal 'value' (related to an intangible) is not subject to inflation and deflation by the economy. Intangibles help to add fulfilment to human life, and the intensity of that desire towards that intangible element is what gives it subjective value. Like supply and demand markets, it is possible to consider some intangibles in terms of availability and opportunity (such as environmental amenity, health and welfare) and this is what creates part of the spectrum of intangible value. It is possible that due to the subjective nature of personal value, the intangible impacts (as judged by the stakeholders) may have been impacted by the experience of the EAD itself in the longer term. This would have an impact on the SPIIL and therefor the overall intangible analysis. Shifts in culture may impact the value of intangibles, as will evolving societal acceptability. It is possible that in the future, trends of urbanisation, technological advancement and intensification of food production to meet consumer needs may have impacts upon the intangible values of some stakeholders relating to emergency animal diseases. These longer term impacts would have to be considered to also impact the SPIIL over a longer term analysis of the intangible elements.

Intangible weighting

A major assumption within the framework is that all intangibles have equal weighting. The complexities and interrelation of different intangibles (for example - environment and human health, animal welfare and sustainability of food production, legacy and lifestyle) make it difficult to value one intangible above another. Like the nature of the intangibles themselves, the weighting of their importance is very subjective. Human health would be considered a priority to most stakeholders, but would this be priority enough to rank it above sustaining the environment for net societal benefit? Does the aesthetic appeal of a rainforest have as much importance as the ecosystems it supports or the potential it has for creating pharmacological advancements?

The moral and philosophical debate relating to the weighting of intangibles is endless. For the purposes of measuring the impacts of EADs, the process of deciding which intangibles should be included in the analysis delivers some indication of which intangibles are a priority for each situation. Each intangible element is given the same weighting in this framework. A case-by-case basis consultation with stakeholders could perhaps ascribe weighting to different intangibles. The most likely situation, in which this would happen, is in the case of a highly pathogenic zoonotic disease.

Additivity of costs and benefits

The formula indicates that there is additivity within the integrated costs and/or benefits and that these costs and benefits are a result of independent or non-related intangibles. As previously mentioned intangibles are often inter-related, so inflation of one may cause deflation of another. Or inflation of one intangible may also inflate another intangible. These linkages between intangibles are not the same for each stakeholder. Yet again the subjectivity of intangibles means that no hard and fast rules can be applied to where there are areas of interconnectedness and areas where a variable may lack independence.

In this thesis each intangible is considered on its own, with the impact upon it for each stakeholder considered as a stand-alone component. The inclusion of each intangible impact measure as either a cost or a benefit, will incorporate the value scores regardless of any interaction that may occur as a result of linkages between the intangible elements.

Stakeholder weighting

In this thesis it is suggested that there is likely already a process for stakeholder selection in place in countries where consultative policy-making is used. It would seem prudent to use the same stakeholders for the integrated analysis, with the addition of any other stakeholder group that wanted to take part. As this is a voluntary and democratic process of policy-making that is used, then stakeholder participation is encouraged but cannot be made compulsory. All stakeholders are given equal weighting. If within one stakeholder group there are polarised opinions (as there are bound to be in some cases), then stakeholder sub-groups can be created for the analysis. In fact, the analysis can be done at the individual level if there is no consensus within a group. The key benefits of the process include the gathering of data relating to the intangibles, as well as the end outcomes. It is expected that anyone can express an opinion within the forum and take part within a group, or on their own if they feel that they do not align with their stakeholder group. The tool is flexible enough to adapt to this situation.

Animal industries in Australia are becoming less family-owned and more corporatised and commercially-oriented. This will not only change the outlook of the impact of disease, but the risk that the company is willing to take. MacDiarmid (1991), suggests that the risk that a more entrepreneurial company owner may be prepared to take from a business perspective would be considered unacceptable to the representatives of the established livestock industries. For the generation of stakeholder data, this potentially creates a lot of variability between the members of one industry. If the situation arises that many individuals prefer to participate on their own rather than as a representative group, then consideration can be given to weighting the stakeholder groups, dependant on the number of members in the group that the response collectively represents. This is a decision that the lead agency can make during or after the data-gathering process, before the analysis of the results begins.

The inclusion of the lead animal health agency as a stakeholder has been criticised. In defence of keeping the lead animal health organisation as a stakeholder, consider the many roles that the lead agency has in a disease response. Policy, implementation, regulation and compliance are some of these roles. It is fair to expect implementation teams to have concerns relating to human health or animal welfare if they are operating in the field. These views may differ from those in the roles of policy-making or regulation, particularly when different business groups are involved. There may also be different government departments with conflicting outcome requirements (wildlife preservation versus disease control). They can all be considered to have valid input in the development of policy and the data collected would benefit decision-making.

Intangible impact scales

The intangible impact scales, from which the CTs are derived, depict linearity in the consequences of the impact. While it is true that there generally is a graduation in the severity of the impact, the reality is that the graduation of the scale is much less parochial than is demonstrated in the case studies. It is also difficult to predict exactly what will be considered as the best and worst outcomes for each intangible, for different stakeholder groups. If we take human health as an example, some stakeholders may consider a human death to be the worst outcome possible. Other stakeholders may consider that permanent severe mental or physical disability, or chronic disabling pain, is a worse outcome than death.

This subjectivity applied to other intangibles as well as human health (is it worse to interfere with an ecosystem to prevent the invasion of a foreign species or to allow a foreign species to invade and then destroy another species – such as the case of noxious invading plant species). It may also be that the inter-relation of the intangibles creates an impact (such as the case of extinction of a non-human species versus the ability to sustain growing human populations, or the pharmaceutical benefit of rainforest plants versus sustaining food for human populations). There is no clear-cut spectrum of impacts that universally meets the needs of all stakeholders.

One method that could perhaps be utilised as a more flexible tool to suit the needs of the stakeholders is the creation of intangible impact matrices. Like a risk matrix, the intangible impact matrix would demonstrate both the consequence and severity of the intangible impacts. The impacts could be grouped into a semi-quantitative system of ranking that stakeholders select from. The development of these matrices could also employ some of the techniques that are already used to measure animal welfare, human health or environment covered in Chapter 3. The matrices could provide an increased capacity to more reflectively capture the stakeholders' considerations in the intangible impact scales, by identifying key variables within the disaggregated intangible and basing the measurement scale on other observable criteria relative to the variable.

If no observable criteria for that intangible are available (such as the value of 'livelihood') or the criteria are too vague to observe (for example beauty or peacefulness of environmental amenity), then the intangible may not yield effective results when disaggregated and the recommendation would be to aggregate the intangible until an observable criterion is reached.

<u>Using the predicted intangible impact level (PIIL)</u>

It is the responsibility of either the lead agency or a third party to determine the PIIL for each outbreak and intervention scenario (OIS). In some instances, the OIS will give a fairly clear indication of what the impact will be (for example in the HeV case, the roost removal will require trees be completely removed and any remaining trees be trimmed to prevent flying-fox roosting). In other scenarios the outcome may be less defined and subject to levels of uncertainty that are difficult to predict (for example the level of impact upon human health as a result of a disease outbreak). While previous experience may well give an indication of what the likely PIIL will be, some subjectivity in this will remain.

If we are dealing with intangibles that have PIIL that are difficult to predict, an alternative approach is to use a stakeholder predicted impact level (SPIIL). This allows the stakeholder to indicate what they think the likely impact upon the intangible variable will be, rather than be guided by a third party. This may be particularly useful where intangible impact is hard to predict due to the individuality of human nature (such as human mental health) or in other intangibles where observable criteria are difficult to assess. It is also a useful strategy to use if particularly fractious stakeholders are involved, particularly if these stakeholders feel that generalisations and assumptions about their concerns are being made, without a deeper understanding of their reasoning behind these concerns.

The variability in the results when using SPIIL rather than PIIL will further differentiate the value of intangible impacts as perceived by the stakeholders. These results are still comparable between stakeholder groups within the OIS. It is likely that each group will have its own bias towards different intangibles and may exaggerate (positively or negatively) the likely impacts as a result. The results for that stakeholder will reflect the strong or weak attachment to that particular intangible, which provides valuable information for the decision-makers.

Disaggregation of intangibles

The intangibles covered in this thesis are highly aggregated. Most intangibles are able to be disaggregated into many smaller components, each of which have their own component value. For example human health could be disaggregated into mental and physical health or environment disaggregated into sustainability, biodiversity, ecosystem health and environmental amenity.

It is possible to accommodate the disaggregation of intangibles within the framework. For each disaggregated intangible component, an intangible impact scale is created. The analysis proceeds as described. There will be greater levels of inflation or deflation contained in the AVF and AVR as a result. The higher the number of intangible components included, the greater the adjustment to the AVF and AVR due to their additive nature. There is no issue with this happening, as long as the results of the analysis are only compared within the scenario being identified for those intangibles and not compared to another scenario, or the same scenario with different intangible inclusions.

As mentioned above, disaggregation of intangibles into many small components may end up detracting from the overall goal of the framework. It is important that intangible components with their own inherent value are addressed, particularly if stakeholders are concerned that these values may be lost. The process of breaking down intangibles and identifying component parts may also help us define more specifically what we are placing value on. However, care must be taken that in doing so, we do not lose sight of the big picture or the analogy of not being able to see the forest for the trees (Andriessen, 2001).

7.3.3 Assessment of scenario development models

MORR versus other modeling methods

There are many tools available for disease modelling that could be used to generate the scope for the EAD scenario. The MORR was chosen because it is adaptable and user-friendly tool. The deterministic results that the MORR delivers are comprehensive enough for use in this framework. The major limitation of the MORR is that it does not perform spread modelling or give us geographical disease spread data, meaning that assumptions about the spread of disease are inferred from the number of predicted cases. The MORR does not provide measures of variability and uncertainty that could be provided if a stochastic model were used. Overall the greatest concern in this thesis was to generate the number of cases of disease, so that economic analysis could be performed.

The descriptors for the risk parameters and the probabilities that are used within the MORR are available in Appendix 15. These probabilities are subjective. A problem with the use of probabilities in any EAD analysis is the lack of objective estimation of probabilities for risk events. Individual 'experts' in the field may give opinion as to the likelihood of events, but the reality is that subjectivity remains (Kasper, 1980; Redmill, 2002; James, 2009). This does potentially present an issue in terms of the possibility of the compounded under or over-estimation of risk (James, 2009). The use of a stochastic modelling tool would reduce issues in this respect.

7.4 Benefits addressed through utilising integrated analysis in the framework

7.4.1 Net social benefit

The challenge for decision-makers EAD management will always be to deliver a control or prevention strategy that will be most societally beneficial. In the process of delivering net social benefit, intuitively areas of compromise must be reached during consultative policy development. Whilst economic justification of many of these compromises is the norm, certain decisions are '*value*'-based, particularly those with human elements such as health and livelihood. As value is complex and individually oriented, consensus will rarely be reached. In fact compromise may not even be possible. These are the cases in which expert opinion and scientific knowledge will need to play a guiding role.

So where does net social benefit lie in the framework outcomes? Generally the policies that are developed (or postulated) by the lead animal health agencies are reflective of net social benefit. Public expenditure to implement these policies must be economically justifiable (and accountable) and reflect the greatest benefit to society. The results within the case study also reflect this (AVF and AVR lie close to the outcome for NPV and BCR). But what happens when we start considering policies that either have little or no-public expenditure? These would be policies such as industry-funded policy or research organisation policy (consider animal ethics committees). Do these policies still need to strive for net social benefit or can they be biased towards their own policy goals?

If we first consider the PRRS case study, under the EADRA industry bears the majority of costs associated with an outbreak (80%), with the remainder government funded. Should the policy for combatting an outbreak therefore be supportive of the bias towards the industry-only benefits given that they are the majority funder? It is likely that this is the case if the scientific evidence supports their policy. This alignment of industry and government policy can be better managed by the inclusion of the intangible impacts.

In a different scenario that does not relate to disease directly, consider the trend towards sow-stall free pork production. In this case the majority expenditure stakeholder (the pork producer) has had to proactively adapt policy in response to consumer demands. If we considered the economic analysis for this move, then it is unlikely the returns from providing niche product would make up for the required expenditure and losses associated with the implementation of sow-stall free pork production. If we include the intangible benefits of improving animal welfare (for all stakeholders), the integrated analysis would likely reflect that the ratio of benefits to costs (AVR) would be much higher than the BCR. But is this a net social benefit? Will the increased cost of pork due to implementation of changes provide a net social benefit?

While net social benefit is a highly aggregated concept of what outcome is best for society, it is still derived from an economic paradigm. As with CBA, consideration may be given to intangible elements but there is no inclusion of them within the analysis methodology. This does avoid the subjectivity of intangible analysis and provides a clear economic outcome that can be used to justify expenditure, however does it really provide an adequate justification of what is best for society? More often than not, it provides a guide for the decision-makers to work from, but leaves the intangible impacts to be addressed from a single stakeholder view (the decision-maker).

7.4.2 The value of integrated outputs for decision-making

What then do we use as the equivalent for integrated net social benefit? And how is this derived? The use of both a CBA and integrated analysis will deliver more information for decision-making. CBA will indicate the most economically beneficial strategy. The integrated analysis builds upon the information provided by economic analysis. Using the AVF and AVR we can analyse the median or mean integrated value outcomes. Provided a representative and broad selection of stakeholders are available, these results can be used to explore where and for whom the intangible impacts occur. With these results, consideration could be given to small adjustments to policy that may not add a great additional extra cost to the CBA, but may provide much greater intangible returns.

<u>How do we measure the integrated ‘net’</u>

The decision must be made regarding what to use as the representative integrated net social benefit score. Will the outliers and extreme views skew the results from societally beneficial preferences? The mean and median are two choices. The mean will be impacted more by the outlier groups than the median, so it is not as robust. Perhaps the user would have to consider the distribution of the results as well. For skewed distributions perhaps the use of the median, and for normal distributions the mean. These parameters represent the average or middle of the integrated social benefits, balancing the outliers. The net social benefit is a way of determining the best economic outcome for the most people, so by taking either the mean or median (depending on the distribution curve) we maximise the integrated net social benefit for the majority of the stakeholders. As part of a democratic government's stewardship of a nation, it becomes imperative that the stand they take is that which will be beneficial to most people. There is rarely a solution where all stakeholders will reach complete consensus or be in agreement that there is one ideal approach that suits everyone.

Consideration of outlier groups

Outlier groups – or those that lie at the polar ends of the distribution curve represent the diverse range of opinions from extreme activist to excessively conservative. When there are intangible impacts the complexities of the stakeholder opinions are endless. Each stakeholder has involvement because they either have investment or concern with the policy or they perceive there is a risk that some component of their lives will be impacted (and usually negatively). Not every stakeholder will have livelihoods at risk, but for many stakeholders the indirect impacts are perceived to affect their lives. Examples include the loss of freedom (as was the case in the UK when footpaths and hiking trails were closed during the 2001 FMD outbreak), environmental destruction, animal welfare issues or human health impacts (particularly in the case of zoonotic diseases).

The ability to identify outlier groups does not indicate a hidden agenda on behalf of the lead agency. The application of the framework is designed to be benevolent and aid the incorporation of the diverse views of stakeholders into the considerations that must be taken during policy-making. It is also beneficial to identify outlier groups in the case that perhaps they do not have a good understanding of the pathogenicity or epidemiology of a disease. In this case they may inadvertently place themselves, others or an industry at risk. It may be that these groups, due to their lack of understanding, perhaps do need further education or surveillance – for example on the prevention of swill feeding, or where the risk of a zoonotic disease may occur as a result of their practices (for example Hendra Virus).

Identification of outlier groups may also indicate a split in the stakeholder membership of an organisation. In order for a peak industry body or lead agency to build working relationships through consultative policy development, understanding of all stakeholder alliances would be beneficial. This understanding would also enable the lead organisations to effectively and strategically align policies to gain better support and achieve higher compliance with regulation when required. Identification of outliers may provide a 'red-flag' that could represent a risk (in terms of disease, public health or non-compliance), or could potentially indicate policy that appears illogical or impractical when viewed from the stakeholder perspective.

There is also the potential for this methodology to be used in other industry-level applications such as identifying and addressing niche market consumers, gauging approvability of changes and concepts within an industry and capacity building. Identifying key intangible concerns of the broader group of industry stakeholders will help enable diversification and expansion. Development of relationships with stakeholder groups benefits education and liaison, and acts to build community and industry capacity to respond to animal diseases. Stakeholder and public opinion and political astuteness have to be a consideration in many animal health situations – for example sow-stall-free pork production or the use of pyres for carcass disposal during the 2001 FMD outbreak in the United Kingdom (which were unpopular and eventually changed as a disposal method due to public opinion and impact on intangible values).

The value of 'value'

'Axiology is the branch of philosophy that considers the nature of value and what kinds of things have value' (Arneson, 2009). In the process of the framework presented in this thesis, an axiological study is completed. This is followed by a method to measure the impacts upon the intangibles that are identified by stakeholders as important within the axiological study. This means the concept of axiology can be extrapolated within this defined context, to give a measure of an intangible that is intrinsically valuable or worthwhile (M'Pherson and Pike, 2001; Arneson, 2009). The context in this case is the willingness-to-accept a certain level of outcome (for an intangible impact), along a continuum or scale of intangible impacts. In perspective, it gives context to the notion that for a stakeholder a policy is only as good as its alignment to their value of benefit or cost to intangible impacts.

Value is both a noun and a verb. It can represent worth, significance or price, and the act of valuing (or valuation) will give us an estimate of what is the value. The criteria for valuation of an intangible generally makes the assumption that there will be a disturbance to the intangible involved. The value is then determined by what it represents to the stakeholders' well-being, to remain undisturbed (Limburg et al., 2002). Placing value on the complex systems involved in emergency animal disease outbreaks is multi-focused. Determining the intangible impact of the outbreak will be effected by the scale (temporal and spatial) of the outbreak and the resistance and resilience (the time to recover) of the system to respond to the impact. Addressing the economic and intangible impacts as separate has mainly occurred due to the limitations of an encompassing methodology.

7.4.3 The benefit of measurement for decision-makers

Why do we want to measure any of these elements (tangible or intangible)? This is best answered by a quote from Mouritsen (2004) who states that *'measurement captures the value(s) or inherent dimensions of …. a phenomenon and its expression…and helps us establish a relation between phenomenon and our perception of it'.* This is particularly true of the intangible elements in this analysis that not only present unique challenges in identification, classification and measurement but are also greatly impacted by individual perception and value. Even the value of financial benefit to some people is dependent on perception. Classical economic theory does not provide us with the tools to assess the concept of "value" in the methodology. Within economic analysis these incommensurable elements do not have the ability to be expressed in terms of each other (Robinson, 2004).

For the purposes of this analysis, measurement is able to provide insight and assistance to aid the decision-making process. The steps that are utilised within the process help to build the baseline knowledge and identify gaps that exist within that knowledge so the most effective and beneficial decision can be made. This process - as described by Hubbard (2010) - includes

1. Define a decision problem and the relevant uncertainties
2. Determine what you know now

3. Compute the value of additional information
4. Apply the relevant measurement instruments to high-value measurements
5. Make a decision and act upon it.

In the final step (5) of the process above, acting on the end *'decision'* can involve a variety of opportunities depending on what is required from the process. The decision opportunity can be a strategy which helps with formulation and execution of a task. The decision opportunity can relate to the data gathered and include validation, evaluation of strategies, opportunities for diversification and expansion or reporting on outputs or outcomes. This decision-making data can also be used for reporting and planning, improving management and other regulatory motives. In some cases the decision opportunity may be about the opportunity to influence behaviour or in some circumstance to deliver an intervention (Marr et al., 2003; Andriessen, 2004; Grasenick and Low, 2004; Marr and Chatzkel, 2004; Mouritsen, 2004; Sveiby, 2010). Sometimes these tools are predictive, and at other times prescriptive (Upton 1996).

All of these opportunities represent different tactics that decision-makers must deploy at different times and for different reasons. They are the key to delivering the results of the liaison and consultation that occurs with different stakeholders during policy-making. The decision-makers and the policy-makers involved in animal health emergencies hold many diverse roles and responsibilities. They are tasked with representing the needs and desires of the stakeholders in their deliverables.

These requirements are a heavy burden that should not be taken lightly and include (but are not limited to) the following -

- Protect and preserve human health and human life,
- Moderate and mitigate public health issues
- Protect and preserve industry capacity and sustainability,
- Protect and preserve investment, infrastructure and ability to trade
- Ensure continuation of safe food supply,
- Protect and preserve animal health,
- Protect and support animal welfare,
- Reflect multi-agency legislation,
- Monitor and regulate compliance,
- Support stewardship of the environment, culture and heritage.

The process of decision-making involves consideration of a great number of variables and uncertainties. Some of these elements are tangible and measurable, producing data that is available for interpretation. Often policy decisions are based on the provision of an outcome to provide net social benefit according to economic assessment. The intangible elements must be considered within this process. The inclusion of a variable that allows a scale of measurement for 'value' driven parameters assists in justifying decisions, by providing a tool to generate data on intangible impacts.

7.5 Limitations of the framework

7.5.1 Data requirements

The creation of the OIS can be laborious. They are required to be quite specific and include a lot of data. These data may or may not be available, a point reiterated by Thrusfield (2007) (page 501), who comments that there is a general lack of quantitative data with which to assess the probability and magnitude of animal disease risks. If unavailable, probabilities can be used with modelling or simulation tools to fill the gaps in the creation of OIS or in some cases qualitative information may be required. Previous outbreaks can be used as the model or experiences borrowed from a similar outbreak. Outbreaks in other countries can also be used as the base data to create the OIS. The creation of such data also requires the skill and experience of the person doing the modelling, but also an expert in animal health to interpret These data as a scenario. The scenario and the impacts sustained are required as a precursor to all following steps within the analysis.

As pointed out in previous chapters, data requirements are a major limitation of any economic analysis. This is particularly true of cost-benefit analysis; however the process of determining costs and benefits can often help identify intangible elements that may be impacted. The use of the cost-benefit framework is therefore a good choice for economic analysis and may help reduce the time spent in identifying the intangible elements.

The process of identifying intangible impacts and developing and delivering intangible impact scales is time and labour intensive. To make the process as stakeholder-engaging as possible, it is advisable to include the stakeholders through all of these steps in the intangible analysis.

The reality is that it may not be time-effective to do so and the process of consultation is often limited by the urgency of the policy that is to be developed or changed. Preliminary work can be performed using surveys to help gather data and develop generic intangible impact scales, but often response to surveys is quite low.

The use of generic intangible impact scales does not present a problem, unless a particular and specific intangible impact arises that presents unique challenges. In this case the modification of an already existing intangible-impact scale can be performed, or given a short amount of a time, a new intangible impact scale can be created. There is no limit to the number of increments upon the intangible impact scale, so adjustments and modifications can easily be performed.

The collation and data entry of the elements of the analysis is another rate-limiting step. For each stakeholder, the intangible scores need to be entered into the spreadsheet for calculation of the integrated results. From there these results can be analysed by the end user. The time required to perform these tasks is dependent upon the number of stakeholders that participate.

7.5.2 Cooperation from stakeholders, generating stakeholder support

As mentioned in Section 4.2.5, the operation of the framework depends on the cooperation of the stakeholders. To get a full spectrum of results it would require that all stakeholders participate within the process. This is unlikely to occur. It is unfair to assume that because a stakeholder does not participate as an active voice in their industry or group, that they do not have concerns relating to intangible impacts. To encourage commitment and ownership of the process, it is important that the process remain voluntary and stakeholder focused. It might mean that to improve collection of data, other survey methodology is required.

7.5.3 Problems with economic analysis

It is possible that economic analysis can become biased towards the requirements of the decision-maker (the same could also be said for the generation of the OIS being biased towards the needs of the end-user). The economic analysis is not a description of the issue, but a representation of the problem through the lens of those that create the analysis (Mouritsen, 2004). This means that the results of the economic analysis need to be understood by those that read them. It is likely that many stakeholders will not have experience with highly aggregated CBA, therefore preventing them from being able to interpret the information they contain (although the output criteria of CBA are more interpretable than some other methodologies). For this reason again, CBA was the economic analysis tool of choice. With some explanation, most stakeholders will understand the concept of what the NPV and BCR represent.

A weakness of CBA when assessing animal diseases is that generally there is a lack of information available on what it costs to avoid the impact of the disease. Often the information that is used is historical average costs, which are impacted by changes in technology and veterinary intervention (Rushton, 2009). Baseline costs in animal production are dynamic and the extrapolation of economic or epidemiological data from individual to national flock level does not always put the problem in context (Howe, 1992; Rushton, 2009).

There are social, political, scientific and economic considerations that must be given to the outcomes of the economic analysis. One of the challenges for the policy-maker is to make the determination of who will end up better off and who is worse off. Who has the resourcing capacity to cope with the impacts of the policy interventions? This is the net social benefit debate again. If the problem is viewed via economic measures, then it is framed in terms of the risk of losses that can be tolerated for the benefits of trade (Thrusfield, 2007). But perceptions and reactions will impact this, meaning that intangibles must be included.

7.5.4 Using Sensitivity analysis with intangibles

Sensitivity analysis of economic methodologies was discussed in Section 2.6.2. If a sensitivity analysis was completed for the intangibles, would it indicate the significance of each attribute in the value generation given that it has already been stated that each intangible is considered to have equal weighting? If weighting were to be added to the intangible, then perhaps sensitivity analysis could help to provide decision-makers with early indications of critical processes. For example, if a decision relating to an EAD policy that potentially resulted in changes to weighted intangibles such as impacts upon human health or a change in the environmental status. At this time, sensitivity analysis has not been performed on the intangible elements based on the assumption that all intangibles are equally weighted and considered within the analysis.

7.6 Future directions for the framework

It is anticipated that the model would also be applicable in the analysis of EAD impacts over longer timeframes and for the analysis of endemic diseases over longer timeframes. In these situations discounting would be applied to the economic analysis. It is envisaged that in the future, the framework could be modified to enable different types of economic analysis methodologies to be used – such as mathematical programming, for when optimising decisions also includes the impacts that will occur upon intangible elements. It could also provide valuable information if incorporated into decision analysis.

Different types of modelling programs could be used for generating the OIS. With the advent of spatial modelling tools that generate visual and comprehendible spread patterns, the OIS would likely present with a greater impact to the stakeholder. If the framework goes on to be a product that is used by decision-makers, a second version interface will incorporate such changes. The product would be designed to be a step-by-step process that could be displayed through audio-visual equipment explaining the process to the stakeholders with visual cues, maps and stimulating formatting.

Intangibles are a neglected and yet vitally important element of decision-making. These case studies have been based on EADs and their impacts, however, the framework is equally applicable to endemic or emerging local diseases. The ability to generate a 'score' for the impact upon an intangible is a step forward in creating accountability and justification for animal health policy. Further research into equitable measurement techniques and commensurability for intangible elements impacted by EADs would benefit the longer term application of consultative policy development.

CONCLUSION

Chapter 8 – Conclusions on the use of the framework methodology

This study presents a conceptual framework that incorporates both the economic and intangible impacts of managing an emergency animal disease. The challenge in placing a value score upon an intangible is hindered by the difficulty in measuring the intangible, but also because there is a paradigm that relates to the nature of intangibles meaning they are unmeasurable. The concept may seem abstract and will require a paradigm shift for those trained to deal with economic methodologies. The reasoning is sound, but the abstraction into the process of measuring intangibles is challenging. It has been implied that different professions see economics through different perspectives and this is even more true of intangibles (McInerney, 1987). Intangibles are abstract, subjective, personal, difficult to measure and yet a part of life for all stakeholders.

Using this methodology to create an integrated value score delivers an output that provides an accountable, justifiable and transparent means of incorporating value based parameters into decisions. It can be used to detect the acceptability levels of policies (or policy changes) for different stakeholders and can be used to gauge policy reaction under different analytical conditions such as demographic, spatial, temporal or representativeness. Using this methodology to compare different control strategies in the face of an outbreak (for example stamp-out versus vaccination) could also be used to identify the more socially-acceptable intervention methods in terms of consumer preference or public reaction.

There is also the potential for this methodology to be used in other industry-level applications. These uses could involve identifying and addressing niche market consumers, gauging approvability of changes and concepts within an industry and capacity building, by identifying key intangible concerns of the broader group of industry stakeholders. It could also be used to signal key areas that would favour diversification and expansion.

In Australia the development of policy for controlling emergency animal disease is a consultative process, involving not only experts in the field of veterinary medicine, epidemiology, public health and policy-making, but also peak industry bodies, non-government organisations, animal welfare organisations and representatives from relevant secondary and supporting industries. The aims of national policy is to generate net social benefit, protecting our industries and ability to trade and to continue the sustainable provision of food for domestic consumption during an emergency animal disease response.

Cost-benefit analysis may indicate what is best in terms of net social benefit from an economic point of view and policy-making must accountably provide justification for the use of public expenditure for the case of emergency animal disease intervention. However, often policy will not reflect the most economically sound intervention if there is great intangible impact. The most common example of this is in the case of pathogenic zoonotic disease. The intangibles of concern are considered within the analysis, but are unable to be included within the economic measurement justification. For these situations, it is also unlikely that market mechanisms will make an impact upon the outcome of policy (unless supply and demand is affected by a food-borne disease).

To create an understanding of what the integrated net social benefit looks like, both cost-benefit analysis and intangible analysis are used. Decision-making processes are supported by filling the intangible void with information that assists in delivering policy that addresses the intangible impacts as well as the economic impacts. Even the value of knowing where the compromises and willing-to-accept levels are for different stakeholders aids in making reflective and accountable decisions. This process helps stakeholders to feel some ownership of the decisions and policies that are made, by allowing the input of the personal impacts that cannot be measured by economic methodology.

The approach has great potential to aid decision-makers at all levels and for any issues in which intangibles are impacted. The technique has evolved through many phases to create the framework that is presented here. At the end of the day, the issue of putting a 'price' on an intangible was still avoided and the value of a decision for a stakeholder has been guided by the benefits and costs without resorting to finances-only analysis. The methodology offers many exciting opportunities to further investigate the compounding effects of impact of intangible elements upon costs and benefits of EAD control and prevention strategies.

REFERENCES

ABC News, 2013. Government stands firm on new bat removal rules. http://www.abc.net.au/news/2013-05-02/government-stands-firm-on-new-bat-removal-rules/4664410. Accessed 7 May 2013. Australian Broadcasting Commission. Brisbane.

Acs, S., Berentsen, P.B.M., Huirne, R.B.M., 2007. Conversion to organic arable farming in The Netherlands: a dynamic linear programming analysis. Agricultural Systems. 94(2), p 405-415.

Ahuja, V., 2009. Animal health policy in South Asia: What can economic analysis contribute. In: Rushton, J. (Ed.), The economics of animal health and production. CABI, Wallingford, UK.

Albina, E., 1997. Epidemiology of porcine reproductive and respiratory syndrome (PRRS): An overview. Veterinary Microbiology. 55(1-4), p 309-316.

Alexander, P. and Baden, S., 2000. Glossary on macroeconomics from a gender perspective. Institute of Development Studies, University of Sussex .

An T-Q, Tian Z-J, Leng C-L, Peng J-M, G-Z, T., 2011. Highly pathogenic porcine reproductive and respiratory syndrome virus, Asia [letter]. Emerging Infectious Diseases. 17(9), p 1782-1784.

Andriessen, D. 2001. Weightless wealth: Four modifications to standard IC theory. Journal of Intellectual Capital. 2(3), p 204-214.

Andriessen, D. 2004. IC valuation and measurement: classifying the state of the art. Journal of Intellectual Capital. 5(2), p 230-242.

Animal Health Australia, 2004a. Ausvetplan Disease Strategy: Porcine reproductive and respiratory syndrome. Animal Health Australia. http://www.animalhealthaustralia.com.au/wp-content/uploads/2011/04/prrs3final.pdf. Canberra.

Animal Health Australia, 2004b. Disease strategy: Porcine reproductive and respiratory syndrome (Version 3.0). Australian Veterinary Emergency Plan (AUSVETPLAN), Edition 3. Council, P.I.M. Canberra, ACT.

Animal Health Australia, 2005. Operational procedures manual: Valuation and compensation (Version 3.0). Australian Veterinary Emergency Plan (AUSVETPLAN), Edition 3. http://www.animalhealthaustralia.com.au/wp-content/uploads/2011/04/vac11final.pdf. Accessed 13 April 2013. Primary Industries Ministerial Council. Canberra ACT.

Animal Health Australia, 2009. Animal Health in Australia. http://www.animalhealthaustralia.com.au/shadomx/apps/fms/fmsdownload.cfm?file_uuid=862738CE-E851-8F68-A8F0-A784D60D5D63&siteName=aahc. Accessed 6 February 2012. Animal Health Australia. Canberra.

Animal Health Australia, 2012a. EADRA - Frequently asked questions. http://www.animalhealthaustralia.com.au/wp-content/uploads/2011/04/Emergency-Animal-Disease-Response-Agreement-FAQs-rev3-28-Aug-2012.pdf. Accessed 2 January 2013. Animal Health Australia. Canberra.

Animal Health Australia, 2012b. Emergency Animal Disease Response Agreement. http://www.animalhealthaustralia.com.au/wp-content/uploads/2011/04/EADRA-Version-12-01-25-05-2012.pdf. Accessed 2 January 2013. Animal Health Australia. Canberra.

Animal Health Australia, 2012c. Response policy briefs (Version 3.4). Australian Veterinary Emergency Plan (AUSVETPLAN). Standing Council on Primary Industries. http://www.animalhealthaustralia.com.au/programs/emergency-animal-disease-preparedness/ausvetplan/response-policy-briefs/. Canberra.

Anonymous, 2008. Report to support the reclassificaiton of the Queensland Equine Influenza green zone to white. http://www.qld.equestrian.org.au/site/equestrian/qld/downloads/Influenza/Report_for_QLD_Green_to_White_230608.pdf. Accessed 30 May 2013. Queensland Government.

Anonymous, 2010. Economic Models: Input-Output Modeling (with IMPLAN). http://unfccc.int/files/adaptation/methodologies_for/vulnerability_and_adaptation/application/pdf/economic_models_-_input-output_modeling__with_implan_.pdf. Accessed 14th Septmeber. United Nations Framework Convention on Climate Change.

Anonymous, 2012. Hendra Virus vaccine. Horseyard forums. http://www.horseyard.com.au/forum/1-general-horse-topics/60808-hendra-virus-vaccine. Accessed 4 June 2013. horseyard.com.au.

Anonymous, 2013. Flying-fox funding fails. http://www.freetimes.com.au/wordpress/index.php/2013/05/flying-fox-funding-fails/. Accessed 3 June 2013. Southern Free Times.

Apland, J., Jonasson, L., Ohlmer, B., 1994. Sector modelling for prediction and evaluation. Swedish Journal of Agricultural Research. 24, p 119-130.

APVMA, 2013. EQUIVAC HeV Hendra virus vaccine for horses. Permit to allow supply and minor use of a veterinary chemical product. Permit Number PER13510. http://permits.apvma.gov.au/PER13510.PDF. Accessed 15 May 2013. Australian Pesticides and Veterinary Medicines Authority. Canberra.

Arneson, P., 2009. Axiology. Encyclopedia of communication theory. SAGE Publications Thousand Oaks, USA.

Aulaqi, N.A., Sundquist, W.B., 1978. Simulation Analysis to estimate the economic impact of Foot-and-Mouth Disease in the United States. University of Minnesota. St Paul.

Australian Bureau of Statistics, 2010. Number of pigs sourced from the 2006 Agricultural Census. This map was produced using coordinate system: Lat/Long GDA94, Based on 2006 Mesh Block Boundaries. Accessed 7 May 2013. Australian Bureau of Statistics. Canberra.

Australian Bureau of Statistics, 2012. Agricultural Commodities Australia 2010-2011. http://www.ausstats.abs.gov.au/ausstats/subscriber.nsf/0/53A90A6B9B8AA465CA257A2B00

17A9DE/$File/71210_2010-11.pdf. Accessed 7 May 2013. Australia Bureau of Statistics. Canberra.

Australian Pork Limited, 2012. Australian Pig Annual 2011-2012. http://www.australianpork.com.au/pages/images/Australian%20Pig%20Annual%202011-12%20LR.pdf. Accessed 29 September 2012. Australian Pork Limited. Canberra.

Baourakis, G., Lakatos, C., Xepapadeas, A., 2008. Economic implications of the EU accession of Bulgaria and Romania: a CGE approach. TradeAG Working Paper.(08/1), p 16 pp.

Barasa, M., Catley, A., Machuchu, D., Laqua, H., Puot, E., Kot, D.T., Ikiror, D., 2008. Foot-and-mouth disease vaccination in South Sudan: benefit-cost analysis and livelihoods impact. Transboundary and Emerging Diseases. 55(8), p 339-351.

Barclay, E., 2005. Local community preparedness for an emergency animal disease outbreak. Rural Industries Research and Development Corporation. Canberra.

Benfield, D.A., Collins, J.E., Dee, S.A., Halbur, P.G., Joo, H.S., Lager, K.M., Mengeling, W.L., Murtaugh, M.P., Rossow, K.D., Stevenson, G.W., Zimmerman, J.J., 1999. Porcine reproductive and respiratory syndrome. Diseases of Swine 18, p 201-232.

Bennett, R., 1995. The value of farm animal welfare. Journal of Agricultural Economics. 46(1), p 46-60.

Bennett, R., Christiansen, K., Clifton-Hadley, R., 1999. Preliminary estimates of the direct costs associated with endemic diseases of livestock in Great Britain. Economic assessment of livestock disease problems. Proceedings of a conference and workshops organised by the Department of Agricultural and Food Economics and the Centre for Agricultural Strategy, The University of Reading, held at The Town Hall, Reading, UK, on 2 March 1999., p 13-24.

Bennett, R., Kehlbacher, A., Balcombe, K., 2012. A method for the economic valuation of animal welfare benefits using a single welfare score. Animal Welfare. 21(S1), p 125-130.

Bennett, R.M., 1992. The use of 'economic' quantitative modelling techniques in livestock health and disease-control decision making: a review. Preventive Veterinary Medicine. 13(1), p 63-76.

Bennett, R.M., 1997. Farm animal welfare and food policy. Food Policy. 22(4), p 281-288.

Berentsen, P.B.M., Dijkhuizen, A.A., Oskam, A.J., 1992a. A critique of published cost-benefit analyses of foot-and-mouth disease. Preventive Veterinary Medicine. 12(3-4), p 217-227.

Berentsen, P.B.M., Dijkhuizen, A.A., Oskam, A.J., 1992b. A dynamic model for cost-benefit analyses of foot-and-mouth disease control strategy. Preventive Veterinary Medicine. 12(3-4), p 229-243.

Bernués, A., Manrique, E., Maza, M.T., 1997. Economic evaluation of bovine brucellosis and tuberculosis eradication programmes in a mountain area of Spain. Preventive Veterinary Medicine. 30(2), p 137-149.

Bingham, P., Morley, C., 2010. Exotic disease focus: porcine reproductive and respiratory syndrome. Surveillance (Wellington). 37(3), p 5-7.

Black, P.F., 2006. Veterinary science and economics: What next? In, 11th International Symposium on Veterinary Epidemiology and Economics, Cairns.

Blair, M.M., Wallman, S.M.H., 2003. The growing intangibles reporting discrepancy. In: Hand, J.R.M., Lev, B. (Eds.), Intangible Assets. Oxford University Press, New York.

Blake, A., Sinclair, M.T., Sugiyarto, G., 2003. Quantifying the impact of foot and mouth disease on tourism and the UK economy. Tourism Economics. 9(4), p 449-465.

Blancou, J., 1999. Preface - The economics of animal disease control. Revue Scientifique Et Technique-Office International Des Epizooties. 18(2), p 295.

Blokhuis, H.J., Jones, R.B., Geers, R., Miele, M., Veissier, I., 2003. Measuring and monitoring animal welfare: transparency in the food product quality chain. Animal Welfare. 12(4), p 445-455.

Bounfour, A., 2003. The management of intangibles [electronic resource] : the organisation's most valuable assets. Routledge. London ; New York

Breed, A.C., Breed, M.F., Meers, J., Field, H.E., 2011. Evidence of Endemic Hendra Virus infection in flying-foxes (*Pteropus conspicillatus*) - Implications for disease risk management. Plos One. 6(12).

Breierova, L., Choudhari, M., 1996. An introduction to sensitivity analysis. MIT System Dynamics in Education Project. Massachusetts Institute of Technology, Massachusetts.

Breisinger, C., Thomas, M., Thurlow, J., 2010. Social accounting matrices and multiplier analysis: An introduction with exercises. Food Security in Practice technical guide 5. International Food Policy Research Institute. Washington, D.C.

Brookes, V.J., Hernandez-Jover, M., Cowled, B.D., Holyoake, P.K., Ward, M.P., 2012. Multi-criteria decision analysis to prioritise exotic disease investigation for the Australian pig industry. 13th International Symposium on Veterinary Epidemiology and Economics. Maastricht, Holland.

Brown, D., Dillard, J., Marshall, R.S., 2006. Triple bottom line: A business metaphor for a social construct. http://www.recercat.net/bitstream/handle/2072/2223/UABDT06-2.pdf;jsessionid=60998CF40137C6B1803C198FB28E559D.recercat1?sequence=1. Accessed 20 February 2013.

Campbell, R., 2013. Aussie pork producers coming off the bench. Australian Pork Newspaper. 17(2), p 3-4.

Canadian Government, 2007. Understanding the factors influencing animal health and the process leading to a national animal health strategy for Canada. http://animauxsains.gc.ca/english/doc/discussion/a/s4_e.shtml. Accessed 17 May 2011. Canadian Government. Ottowa.

Canibano, L., Garcia-Ayuso, M., Sanchez, P., 1999. The value relevance and managerial implications of intangibles: A literature review International Symposium: Measuring and reporting intellectual capital: Experiences, issues and prospects. OECD, Amsterdam.

Canibano, L., Garcia-Ayuso, M., Sanchez, P., 2000. Accounting for intangibles: A literature review. Journal of Accounting Literature. 19, p 102-130.

Cano, J.P., Murtaugh, M.P., Dee, S.A., 2007. Evaluation of the survival of porcine reproductive and respiratory syndrome virus in non-processed pig meat. Veterinary Record. 160(26), p 907.

Carpenter, T.E., 1976. The application of benefit-cost analysis to compare alternative approaches to the Brucellosis problem in California. In, New Techniques in Veterinary Epidemiology and Economics (ISVEE 1), Reading.

Carpenter, T.E., Dilgard, P., 1982. An application of computerized decision analysis in animal health economics. International Symposia on Veterinary Epidemiology and Economics (ISVEE) proceedings. ISVEE 3: Veterinary Epidemiology and Economics, Proceedings of the 3rd International Symposium, Arlington, Virginia, USA(Modelling & decision analysis session), p 408-414.

Carpenter, T.E., O'Brien, J.M., Hagerman, A.D., McCarl, B.A., 2011. Epidemic and economic impacts of delayed detection of foot-and-mouth disease: a case study of a simulated outbreak in California. Journal of Veterinary Diagnostic Investigation. 23(1), p 26-33.

Carpenter, T.E., Thieme Jr, A., 1980. A simulation approach to measuring the economic effects of foot-and-mouth disease in beef and dairy cattle. In, Second International Symposium on Veterinary Epidemiology and Economics,, Canberra, Australia, May 7-11, 1979, , pp. 511-516.

Caskie, P., Davis, J., Moss, J.E., 1999. The economic impact of BSE: a regional perspective. Applied Economics. 31(12), p 1623-1630.

CCEAD, 2008. Consultative Committee on Emergency Animal Disease, . www.daff.gov.au/animal-plant-health/animal/committee/ccead. Accessed 17 July 2010. Australian Government. Canberra.

Cho, J.G., Dee, S.A., 2006. Porcine reproductive and respiratory syndrome virus. Theriogenology. 66(3), p 655-662.

Choquenot, D., McIlroy, J., Korn, T., 1996. Managing vertebrate pests: Feral pigs. Bureau of Resource Sciences. Canberra.

Christiansen, K.H., 1985. The use of decision analysis to determine the value of laboratory services to farmers. International Symposia on Veterinary Epidemiology and Economics (ISVEE) proceedings. ISVEE 4: Proceedings of the 4th International Symposium on Veterinary Epidemiology and Economics, Singapore(Modelling in veterinary epidemiology & economics session), p 272-274.

Clarke, L., 2013. Horse Sense. Veterinary practise staff & the Hendra virus vaccine. Vet Answers. http://www.vetanswers.com.au/blog/post/veterinary-practise-staff-the-hendra-virus-vaccine/109. Australia.

Codex Ailimentarius, 2011. Codex Ailimentarius: international food standards. http://www.codexalimentarius.net/web/index_en.jsp. Accessed 3 June 2011. Food and Agriculture Organisation of the United Nations. Rome.

Colebatch, H.K. (Ed.), 2006. Beyond the policy cycle - The policy process in Australia. Allen & Unwin Crows Nest NSW.

Colebatch, H.K., 2009. (Third), Policy. McGraw-Hill. Berkshire UK.

Council of Australian Governments' Standing Council on Primary Industries, 2012a. Background to the Councils. www.mincos.gov.au/background. Accessed 13 February 2013. Australian Government. Canberra.

Council of Australian Governments' Standing Council on Primary Industries, 2012b. Primary Industries Standing Committee. www.mincos.gov.au/pi_standing_committee. Accessed 24 February 2013. Australian Government. Canberra.

Council of Australian Governments, 2012. About COAG. www.coag.gov.au/about_coag. Accessed 12 February 2013. Australian Government. Canberra.

Croes, M.M., 2000. Data for intangibles in selected OECD countries. A report commissioned by the OECD and the Dutch Ministry of Economic Affairs. OECD.

Currie, J.M., Murphy, J.A., Schmitz, A., 1971. The Concept of economic surplus and its use in economic analysis. The Economic Journal. 81(324), p 741-799.

Cutler, R., Holyoake, P.K., 2007. The Structure and dynamics of the pig meat industry. http://www.daff.gov.au/__data/assets/pdf_file/0004/723829/pig-movement-ead.pdf. Accessed 12 May 2013. Department of Agriculture, Fisheries and Forestry. Canberra.

Dagupta, A.K., Pearce, D.W., 1972. Cost-Benefit Analysis. The Macmillan Press LTD. London.

Daily, G.C., Polasky, S., Goldstein, J., Kareiva, P.M., Mooney, H.A., Pejchar, L., Ricketts, T.H., Salzman, J., Shallenberger, R., 2009. Ecosystem services in decision making: time to deliver. Front Ecol Environ. 7(1), p 21-28.

Daily, G.C., Söderqvist, T., Aniyar, S., Arrow, K., Dasgupta, P., Ehrlich, P.R., Folke, C., Jansson, A., Jansson, B.-O., Kautsky, N., Levin, S., Lubchenco, J., Mäler, K.G., Simpson, D., Starrett, D., Tilman, D., Walker, B., 2000. The value of nature and the nature of value. Science 289(5478), p 395-396.

Davies, G., 1996. The role of the public sector in controlling the epidemic diseases of livestock. In: Thrusfield, M.V., Goodall, E.A. (Eds.), Society for Veterinary Epidemiology and Preventative Medicine (SVEPM), Glasgow.

Degeling, C., Kerridge, I., 2013. Hendra in the news: Public policy meets public morality in times of zoonotic uncertainty. Social Science & Medicine. 82, p 156-163.

Del Rio Vilas, V.J., Culver, F., Gibbens, J.C., 2009. T4-2.3.4 - A tool for the job: a simplified multi-criteria decision analysis of emerging threats to UK's animal health. International Symposia on Veterinary Epidemiology and Economics (ISVEE) proceedings. ISVEE 12: Proceedings of the 12th Symposium of the International Society for Veterinary Epidemiology and Economics, Durban, South Africa(Theme 4 - Risk and decision analysis: Risk assessment,Decision making,Epidemiological methods,Risk analysis), p 175-175.

Department of Agriculture Fisheries and Forestry, 2004a. Executive summary and quarantine requirements for importation of pigmeat. Accessed 17 April 2013. Department of Agriculture, Fisheries and Forestry. Canberra.

Department of Agriculture Fisheries and Forestry, 2004b. Generic import risk analysis (IRA) for pig meat - Final Risk Analysis Report Annexes. Department of Agrculture, Fisheries and Forestry. Canberra, ACT.

Department of Agriculture Fisheries and Forestry, 2011. National list of notifiable animal diseases. Animal Pests and Diseases. http://www.daff.gov.au/animal-plant-health/pests-diseases-weeds/animal/notifiable. Accessed 6 May 2013. Department of Agriculture, Fisheris and Forestry. Canberra.

Department of Agriculture Fisheries and Forestry, 2012. Establishing a piggery. http://www.daff.qld.gov.au/27_4085.htm. Accessed 15 May 2013. Queensland Government. Brisbane.

Department of Agriculture Fisheries and Forestry (Queensland), 2013. Hendra Virus - Information for horse owners, handlers, competitors and event organisers. www.daff.qld.gov.au/4790_20718.htm. Accessed 13 May 2013. Depatment of Agiculture, Fisheries and Foresty Queensland. Brisbane.

Department of Environment and Heritage Protection, 2011. Flying-fox roost locations - Southern Queensland. http://www.ehp.qld.gov.au/wildlife/livingwith/flyingfoxes/pdf/seq-roosts.pdf. Accessed 30 May 2013. Queensland Government,. Brisbane.

Department of Environment and Heritage Protection, 2012. Code of Practice - Ecologically sustainable lethal take of flying-foxes for crop protection. Nature Conservation Act 1992. http://www.ehp.qld.gov.au/wildlife/livingwith/flyingfoxes/pdf/cp-wl-dmp-lethal-flying-fox.pdf. Accessed 16 June 2013. Queensland Government. Brisbane.

Department of Environment and Heritage Protection, 2013a. Damage Mitigation Permit. Native Animal Management. Accessed 25 May 2013. Queensland Government. Brisbane.

Department of Environment and Heritage Protection, 2013b. Flying-fox roost management. Living with wildlife. www.ehp.qld.gov.au/wildlife/livingwith/roost-management.html. Accessed 23 May 2013. QUeensland Government. Brisbane.

Department of Environment and Primary Industries, 2011. Victoria's pig, goat and deer industry - Winter 2012. http://www.dpi.vic.gov.au/agriculture/animals-and-livestock/victorias-pig-goat-and-deer-industry. Accessed 7 May 2013. State Government of Victoria. Melbourne.

Department of Sustainability, Environment, Water, Population and Communities, 2013. Flying-foxes. Flying-foxes and national environmental law. http://www.environment.gov.au/biodiversity/threatened/species/flying-foxes.html. Accessed 3 June 2013. Australian Government. Canberra.

Dicks, M.R., 1996. How agricultural policy affects you. John Deere Publishing. Moline, IL.

Dijkhuizen, A., Huirne, R., Jalvingh, A., 1995a. Modeling the economics of animal health control. American Journal of Agricultural Economics. 77(5), p 1386-1386.

Dijkhuizen, A.A., Horst, H.S., Jalvingh, A.W., 1997a. A new approach to integrate risk analysis and economics. In, International Symposia on Veterinary Epidemiology and Economics (ISVEE) proceedings, Paris, 6-6.

Dijkhuizen, A.A., Huirne, R.B.M., Jalvingh, A.W., 1995b. Economic analysis of animal diseases and their control. Preventive Veterinary Medicine. 25, p 135-149.

Dijkhuizen, A.A., Huirne, R.B.M., Morris, R.S., 1997b. Economic decision making in animal health management. In: Dijkhuizen, A.A., Morris, R.S. (Eds.), Animal Health Economics. University of Sydney, Sydney. 13-23.

Dijkhuizen, A.A., Jalvingh, A.W., Huirne, R.B.M., 1997c. Critical steps in systems simulation. In: Dijkhuizen, A.A., Morris, R.S. (Eds.), Animal Health Economics:Principles and Applications. University of Sydney, Sydney. 59 - 67.

Dijkhuizen, A.A., Morris, R.S., 1997. Framework and basic methods of economic analysis. In: Dijkhuizen, A.A., Morris, R.S. (Eds.), Animal health economics: principles and applications. Unversity of Sydney, Sydney. 1-58.

Disney, W.T., Green, J.W., Forsythe, K.W., Weimers, J.F., Weber, S., 2001. Benefit-cost analysis of animal identification for disease prevention and control Revue Scientifique Et Technique De L Office International Des Epizooties. 20(2), p 385-405.

Done, S.H., Paton, D.J., White, M.E.C., 1996. Porcine reproductive and respiratory syndrome (PRRS): A review, with emphasis on pathological, virological and diagnostic aspects. British Veterinary Journal. 152(2), p 153-174.

Duchin, F., Steenge, A.E., 2007. Mathematical models in input-output economics. Working Papers in Economics. Department of Economics, Rensselaer Polytechnic Institute. Troy, NY.

Edvinsson, L., 1997. Developing intellectual capital at Skandia. Long Range Planning. 30(3), p 320-321, 366-373.

Ekboir, J.M., 1999. The role of the public sector in the development and implementation of animal health policies. Preventive Veterinary Medicine. 40(2), p 101-115.

Elbakidze, L., Highfield, L., Ward, M., McCarl, B.A., Norby, B., 2009. Economics analysis of mitigation strategies for FMD introduction in highly concentrated animal feeding regions. Applied Economic Perspectives and Policy. 31(4), p 931-950.

Ellis, P.R., 1981. Animal health--information, planning and economics. Bulletin de l'Office International des Epizooties. 93(5/6), p 775-782.

Ellis, P.R., James, A.D., 1979a. The economics of animal health - (1) Major disease control programmes. Vet. Rec. 105(22), p 504-506.

Ellis, P.R., James, A.D., 1979b. The economics of animal health - (2) Economics in farm practice. Veterinary Record.(105), p 523-526.

Ellis, P.R., Shaw, A.P.M., Stephens, A.J., 1976. Editors' introduction : Evaluation of alternative strategies : B. Economic evaluation. In, ISVEE 1: New Techniques in Veterinary Epidemiology and Economics, Proceedings of a Symposium, University of Reading

Encyclopedia of Public Health, 2008. DALY (Disability Adjusted Life Years). In: Kirch, W. (Ed.), Encyclopedia of Public Health. Springer Netherlands. 191-191.

European Commission, 2000. Organisation for Economic Co-operation and Development Activities on Intangibles. http://www.ll-a.fr/intangibles/oecd.htm. Accessed 2 June 2011 European Observatory on Intangible Assets Intangible Assets - A European Commission initiative. Lusemburg.

European Commission, 2007. A new animal health strategy for the European Union (2007-2013) where “prevention is better than cure”. Office for Official Publications of the European Communities, Luxembourg.

Eustace, C.G., 2000. The intangible economy: Impact and policy issues. Report of the European high level expert group on the intangible economy. European Commission. http://www.edis.sk/ekes/intagible.pdf. Luxemburg.

Eustace, C.G., 2003. The PRISM Report 2003: Research findings and policy recommendations. European Commission Information Society Technologies Programme. http://www.intangability.com/wp-content/uploads/2009/03/prism-project-report-of-research-findings-and-policy-recommendations.pdf. London.

Fair Work Australia, 2011. Pastoral Award 2010. Fair Work Act 2009. http://www.fwc.gov.au/awardsandorders/html/PR509066.htm. Accessed 20 May 2013. Fair Work Australia. Melbourne, Victoria.

Feng, Y., Zhao, T., Tung, N., Inui, K., Ma, Y., Thi Hoa, N., Van Cam, N., Liu, D., Quang Anh, B., Long Thanh, T., Wang, C., Tian, K., Gao, G.F., 2008. Porcine respiratory and reproductive syndrome virus variants, Vietnam and China, 2007. Emerging Infectious Diseases. 14(11), p 1774-1776.

Field, H., Crameri. G., Kung, N., Wang, L.F., 2012. Ecological aspects of Hendra Virus. Current Topics in Microbiology and Immunology. 359, p 11-23.

Field, H., de Jong, C., Melville, D., Smith, C., Smith, I., Broos, A., Kung, Y.H., McLaughlin, A., Zeddeman, A., 2011. Hendra Virus infection dynamics in Australian fruit bats. Plos One. 6(12).

Food and Agriculture Authority (FAO), World Health Organisation (WHO), 1995. Application of risk analysis to food standards issues, Report of the Joint FAO/WHO Expert Consultation. World Health Organisation, Geneva, Switzerland,.

Frakt, A., Carroll, A., 2010. Why consumer surplus is negative. The integral of the demand function. The Incidental Economist. http://theincidentaleconomist.com/wordpress/why-consumer-surplus-negative-the-integral-of-the-demand-function/.

Garner, M.G., Fisher, B.S., Murray, J.G., 2002. Economic aspects of foot and mouth disease: perspectives of a free country, Australia. Revue Scientifique Et Technique De L Office International Des Epizooties. 21(3), p 625-635.

Garner, M.G., Gleeson, L.J., Holyoake, P.K., Cannon, R.M., Doughty, W.J., 1997. A national serological survey to verify Australia's freedom from porcine reproductive and respiratory syndrome. Australian Veterinary Journal. 75(8), p 596-600.

Garner, M.G., Lack, M.B., 1995. An evaluation of alternative control strategies for foot-and-mouth disease in Australia: a regional approach. Preventive Veterinary Medicine. 23(1-2), p 9-32.

Garner, M.G., Whan, I.F., Gard, G.P., Phillips, D., 2001. The expected economic impact of selected exotic diseases on the pig industry of Australia. Revue Scientifique Et Technique De L Office International Des Epizooties. 20(3), p 671-685.

Geiger, D., 2012. Relief as hendra virus vaccine is announced. Daily Mercury. http://www.dailymercury.com.au/news/relief-as-hendra-virus-vaccine-is-announced/1606381/. Accessed 20 May 2013. Australian Regional Media. Mackay.

GeoLink, 2010. Maclean flying-fox management strategy. http://www.geolink.net.au/index.php?row=622&field=05_FileList_document. Accessed 4 June 2013. GeoLink Environmental Mangement and Design. Lennox Head.

Gittinger, J.P., 1982. (Second Edition), Economic analysis of agricultural projects. John Hopkins University Press. Baltimore.

Gordon, J., 2001. The horse industry - contributing to the Australian economy. Accessed Rural Industries Research and Development Corporation. Canberra.

Gowdy, J., 2005. Toward a new welfare economics for sustainability. Ecological Economics. 53(2), p 211-222.

Gowdy, J., Erickson, J.D., 2005. The approach of ecological economics. Cambridge Journal of Economics. 29(2), p 207-222.

Grasenick, K., Low, J., 2004. Shaken, not stirred: Defining and connecting indicators for the measurement and valuation of intangibles. Journal of Intellectual Capital. 5(2), p 268-281.

Green, B.L., 2007. The missing calculation: the human cost. Veterinaria Italiana. 43(2), p 299-301.

Green, L., Nicol, C., 2004. Use of epidemiology to assess animal welfare – advantages and disadvantages. Proceedings of the food safety and biosecurity branch New Zealand Veterinary Association

Grindle, R.J., 1985. The use and abuse of economics methods, as applied to veterinary problems. 4th Conference of the International Society for Veterinary Economics and Epidemiology. Singapore.

Guilding, C., Pike, R., 1990. Intangible marketing assets: A managerial accounting perspective. Accounting & Business Research. Croner.CCH Group Limited.

Guitian, J., Pfeiffer, D., 2006. Should we use models to inform policy development? The Veterinary Journal. 172(3), p 393-395.

Habtemariam, T., Howitt, R., Ruppanner, R., Riemann, H.P., 1984. Application of a linear programming model to the control of African trypanosomiasis. Preventive Veterinary Medicine. 3(1), p 1-14.

Hall, D.C., Kaiser, H.M., Blake, R.W., 1998. Modelling the economics of animal health control programs using dynamic programming. Agricultural Systems. 56(1), p 125-144.

Halpin, K., Young, P.L., Field, H., Mackenzie, J.S., 1999. Newly discovered viruses of flying foxes. Veterinary Microbiology. 68(1-2), p 83-87.

Halpin, K., Young, P.L., Field, H.E., Mackenzie, J.S., 2000. Isolation of Hendra virus from pteropid bats: a natural reservoir of Hendra virus. Journal of General Virology. 81, p 1927-1932.

Hardaker, J.B., Huirne, R.B.M., Anderson, J.R., Lien, G., 2004. Decision analysis: outline and basic assumptions. CABI Publishing. Wallingford UK.

Health4Horses, 2013. Hendra Vaccine. www.health4horses.com.au. Accessed 23 May 2013. Zoetis Australia Pty Ltd,.

Heberling, M.T., Bruins, R.J.T., 2005. Introduction to economic analysis in watersheds. In: Bruins, R.J.T., Heberling, M.T. (Eds.), Economics and Ecological Risk Assessment. CRC Press, Boca Raton.

Hilton, A., 2002. Model Validation - A regulator's perspective. http://www.moodyskmv.com/cpc06/pres/02_Hilton.pdf. Accessed 26 Jan 2011. Food Safety Authority Risk Review Department.

Holtkamp, D.J., Yeske, P.E., Polson, D.D., Melody, J.L., Philips, R.C., 2010. A prospective study evaluating duration of swine breeding herd PRRS virus-free status and its relationship with measured risk. Preventive Veterinary Medicine. 96(3–4), p 186-193.

Hone, J., 1990. How many feral pigs in Australia. Wildlife Research. 17(6), p 571-572.

Howe, K.S., 1985. An economist's view of animal disease. Proceedings of the Society for Veterinary Epidemiology and Preventive Medicine, 27th-29th March 1985., p 122-129.

Howe, K.S., 1988a. Conceptual affinities in veterinary epidemiology and economics. Acta Veterinaria Scandinavica. p 347-349.

Howe, K.S., 1988b. Livetock economics - the economics of veterinary services - A perspective. British Veterinary Journal. 144(4), p 343-350.

Howe, K.S., 1992. Epidemiologists' views of economics - an economist's reply. Society for Veterinary Epidemiology and Preventive Medicine: Tenth-anniversary Proceedings 1st-3rd April 1992, University of Edinburgh., p 157-167.

Hubbard, D.W., 2010. (2nd Edition), How to measure anything. John Wiley & Sons. New Jersey.

Huirne, R.B.M., Dijkhuizen, A.A., 1997. Basic methods of economic analysis. In: Dijkhuizen, A.A., Morris, R.S. (Eds.), Animal Health Economics. University of Sydney, Sydney. 25 - 39.

Hurd, H.S., Kaneene, J.B., Lloyd, J.W., 1993. A stochasitc distributed-delay model of disease processes in dynamic populations. Preventive Veterinary Medicine. 16(1), p 21-29.

Indiana Animal Disease Diagnostic Laboratory, 2010. New PRRS serology test. https://www.addl.purdue.edu/Newsletters/2010/Summer/PRRS.aspx. Accessed 5 May 2013. Purdue University,. West LaFayette.

Intriligator, M.D., 1983. Economic and econometric models. In: Griliches, Z., Intriligator, M.D. (Eds.), Handbook of Econometrics. North-Holland Publishing Company, Los Angeles.

Jalvingh, A.W., Dijkhuizen, A.A., Renkema, J.A., 1997. Linear programming to meet management targets and restrictions. In: Dijkhuizen, A.A., Morris, R.S. (Eds.), Animal Health Economics. University of Sydney, Sydney. 69 - 84.

James, A.D., 1987. Principles and problems of benefit-cost analysis for disease control schemes. In: Howe, K.S., McInerney, J.P. (Eds.), Proceedings of a symposium in the Community programme for coordination of agricultural research, Exeter.

James, A.D., 2009. Modelling and the generation of information. In: Rushton, J. (Ed.), The Economics of Animal Health and Production. CABI, Wallingford.

James, A.D., Ellis, P.R., 1979. The evaluation of production and economic effects of disease. In, International Symposium on Veterinary Epidemiology and Economics, Canberra, Australia, 363 - 372.

Jian, N., Shi, Y., Bounlom, D., Xiu, Y., Zhi, Z., Jian, S., Khamphouth, V., Vatthana, T., Ke, T., 2012. Emergence and pathogenicity of highly pathogenic porcine reproductive and respiratory syndrome virus in Vientiane, Lao People's Democratic Republic. Journal of Veterinary Diagnostic Investigation. 24(2), p 349-354.

Johanson, U., 1999. Mobiising Change: Characteristics of intangibles proposed by 11 swedish firms. Measuring and reporting intellectual capital: Experiences, issues and Prospects. OECD, Amsterdam.

Jonasson, L., 1996. Mathematical programming for sector analysis. Swedish University of Agricultural Sciences. Uppsala.

Jurczak, J., 2008. Intellectual capital measurement methods. Economics and Organization of Enterprise. 1(1), p 37-45.

Just, R.E., Hueth, D.L., Schmitz, A., 2004. The welfare economics of public policy Edward Elgar Publishing Ltd. Cheltenham.

Kahrs, R.F., 2004. Global livestock health policy. Iowa State Press. Iowa.

Kasper, R.G., 1980. Perceptions of risk and their effects on decision making. In: Schwing, R.C., Albers, A. (Eds.), Societal Risk Assessment: How Safe is Enough? Plenum Press, New York.

Kennedy, R.C., Xiang, X., Madey, G.R., Cosimano, T.F., 2008. Verification and validation of scientific and economic models.

Kirkwood, C.W., 1992. An overview of methods for applied decision analysis. Interfaces. 22(6), p 28-39.

Krystynak, R., 1985. The economics of controlling foreign animal diseases. Food Market Commentary.(1), p 40-43.

Lessley, B.V., Johnson, D.M., Hanson, J.C., 1991. Using the partial budget to analyze farm change. Maryland Cooperative Extension, University of Maryland, College Park MD.

Lev, B.I., 2001. Intangibles: Management, measurement and reporting. Bookings Institution Press. Washington DC.

Li, Y., Wang, X., Bo, K., Wang, X., Tang, B., Yang, B., Jiang, W., Jiang, P., 2007. Emergence of a highly pathogenic porcine reproductive and respiratory syndrome virus in the Mid-Eastern region of China. Veterinary Journal. 174(3), p 577-584.

Liew, C., 2005. Dynamic variable input-output (VIO) model and price-sensitive dynamic multipliers. The Annals of Regional Science. 39(3), p 607-627.

Limburg, K.E., O'Neill, R.V., Costanza, R., Farber, S., 2002. Complex systems and valuation. Ecological Economics. 41(3), p 409-420.

Lowe, P., Edwards, S., Ward, N., 2001. The Foot-and-mouth crisis: Issues for public policy and research. Centre for Rural Economy Working Paper Series. University of Newcastle.

Lunney, J.K., Benfield, D.A., Rowland, R.R.R., 2010. Porcine reproductive and respiratory syndrome virus: An update on an emerging and re-emerging viral disease of swine. Virus Research. 154(1-2), p 1-6.

Lusk, J.L., Norwood, F.B., 2011. Animal Welfare Economics. Appl. Econ. Perspect. Pol. 33(4), p 1463-1483.

Luthy, D.H., 1998. Intellectual capital and its measurement. In, Asian Pacific Interdisciplinary Research in Accounting Conference (APIRA), Osaka, Japan.

M'Pherson, P.K., Pike, S., 2001. Accounting, empirical measurement and intellectual capital. J. Intellect. Cap. 2(3), p 246-260.

Macquarie Dictionary, 2009. Macquarie Dictionary. Macquarie Dictionary. Macmillan Publishing Sydney.

Magar, R., Larochelle, R., 2004. Evaluation of the presence of porcine reproductive and respiratory syndrome virus in pig meat and experimental transmission following oral exposure. Canadian Journal of Veterinary Research. 68(4), p 259–266.

Mahalingam, S., Herrero, L.J., Playford, E.G., Spann, K., Herring, B., Rolph, M.S., Middleton, D., McCall, B., Field, H., Wang, L.F., 2012. Hendra virus: an emerging paramyxovirus in Australia. Lancet Infectious Diseases. 12(10), p 799-807.

Mahul, O., Durand, B., 2000. Simulated economic consequences of foot-and-mouth disease epidemics and their public control in France. Preventive Veterinary Medicine. 47(1-2), p 23-38.

Mansur, A., Whalley, J., 1984. Numerical specification of applied general equilibrium models: Estimation, calibration, and data. In: Scarf, H.E., Shoven, J.B. (Eds.), Applied General Equilibrium analysis. Cambridge University Press, Cambridge, UK.

Marr, B., Chatzkel, J., 2004. Intellectual capital at the crossroads: managing, measuring, and reporting of IC. Journal of Intellectual Capital. 5(2), p 224-229.

Marr, B., Gray, D., Neely, A., 2003. Why do firms measure their intellectual capital? Journal of Intellectual Capital. 4(4), p 441-464.

Martin, R.G., Steverink, P.J.G.M., 2002. Oral transmission of PRRS virus via the feeding of infected muscle to pigs. Proc Am Assoc Swine Vet. 45.

Mason, G., Mendl, M., 1993. Why is there no simple way of measuring animal welfare? Animal Welfare. 2, p 301-319.

Masters, W.A., 1996. The economic impact of agricultural research: A practical guide. http://www.agecon.purdue.edu/staff/masters/ImpactCD/Manuel/EconSurplusManual-English.pdf. Accessed 30 September 2010. Department of Agiculturel Economics, Purdue University.

McCarl, B.A., Apland, J., 1986. Validation of linear programming models Southern Journal of Agricultural Economics.(December), p 155 -164.

McCarl, B.A., Spreen, T.H., 1980. Price endogenous mathematical programming as a tool for sector analysis. American Journal of Agricultural Economics. 62, p 87-102.

McFarlane, R., Becker, N., Field, H., 2011. Investigation of the climatic and environmental context of Hendra virus spillover events 1994-2010. Plos One. 6(12).

McGlone, J.J., 2001. Farm animal welfare in the context of other society issues: toward sustainable systems. Livestock Production Science. 72(1–2), p 75-81.

McInerney, J., 1991a. A socio-economic perspective on animal welfare. Outlook on Agriculture. 20(1), p 51-56.

McInerney, J., 2004. Animal welfare, economics and policy. Report on a study undertaken for the Farm & Animal Health Economics Division of Defra. http://archive.defra.gov.uk/evidence/economics/foodfarm/reports/documents/animalwelfare.pdf. DEFRA. London.

McInerney, J.P., 1987. An economist's approach to estimating disease losses. In: Howe, K.S., McInerney, J.P. (Eds.), Diseases in Farm Livestock: Economics and Policy. Commission of the EEC, Luxembourg. 25-60.

McInerney, J.P., 1991b. Cost benefit analysis of livestock disease: A simplified look at its economic foundations. In, Proceedings of the 6th International Symposium on Veterinary Epidemiology and Economics.

McInerney, J.P., 1991c. Economic aspects of the animal welfare Issue. In: Thrusfield, M.V. (Ed.), Proceedings of a Meeting of the Society for Veterinary Epidemiology and Preventive Medicine, Edinburgh.

Meat and Livestock Australia, 2009. Overseas Markets. http://www.mla.com.au/Prices-and-markets/Overseas-markets. Accessed 16 May 2011. Meat and Livestock Australia. Sydney.

Mehrez, A., Gafni, A., 1989. Quality-adjusted Life Years, utility theory, and Healthy-years Equivalents. Med Decis Making. 9, p 142-149.

Mellor, D.J., Stafford, K.J., 2001. Integrating practical, regulatory and ethical strategies for enhancing farm animal welfare. Australian Veterinary Journal. 79(11), p 762-768.

MERITUM, 2001. Guidelines for managing and reporting on intangibles: Final report. European Community: Targeted Socio-economic Research.

Meuwissen, M.P.M., Horst, S.H., Huirne, R.B.M., Dijkhuizen, A.A., 1999. A model to estimate the financial consequences of classical swine fever outbreaks: principles and outcomes. Preventive Veterinary Medicine. 42(3-4), p 249-270.

Miernyk, W.H., 1965. The elements of Input-Output. Random House. New York, NY.

Miller, G.Y., Tsai, J.S., Forster, D.L., 1996. Benefit-cost analysis of the national pseudorabies virus eradication program. Journal of the American Veterinary Medical Association. 208(2), p 208-213.

Morris, R.S., 1999. The application of economics in animal health programmes: a practical guide. Revue Scientifique Et Technique De L Office International Des Epizooties. 18(2), p 305-314.

Morrison, R.B., 2011. Control and elimination of PRRS virus. Advances in Pork Production. 22, p 137-145.

Morrow, R.H., Bryant, J.H., 1995. Health policy approaches to measuring and valuing human life: Conceptual and ethical Issues. American Journal of Public Health. 85(10), p 1356-1360.

Mortensen, J., 1999. Measuring and reporting intellectual capital: Experiences, issues and prospects - Programme notes and background. Measuring and Reporting Intellectual Capital. OECD, Amsterdam.

Motha, J., Stark, K., Thompson, J., 1997. New Zealand is free from PRRS porcine reproductive and respiratory syndrome , TGE transmissible gastroenteritis and PRCV porcine respiratory coronavirus. Surveillance (Wellington). 24(1), p 10-11.

Mourits, M.C.M., van Asseldonk, M., Huirne, R.B.M., 2010. Multi-criteria decision making to evaluate control strategies of contagious animal diseases. Preventive Veterinary Medicine. 96(3-4), p 201-210.

Mourits, M.C.M., van Asseldonk, M.A.P.M., 2006. Multi criteria analysis of anternative strategies to control contagious animal disease. In, SVEMP, Oxford, UK, 255.

Mouritsen, J., 2004. Measuring and intervening: how do we theorise intellectual capital management? Journal of Intellectual Capital. 5(2), p 257-267.

Mukhebi, A.W., Wathanga, J., Perry, B.D., Irvin, A.D., Morzaria, S.P., 1989. Financial analysis of east coast fever control strategies on beef-production under farm conditions. Veterinary Record. 125(18), p 456-459.

Murray, C.J.L., 1994. Quantifying the burden of disease: the technical basis for disability-adjusted life years. Bull World Health Organ. 72(3), p 429–445.

Ndiritu, C.G., McLeod, A., 1995. Institutionalisation of veterinary epidemiology and economics: The Kenyan experience. Preventive Veterinary Medicine. 25(2), p 93-106.

Neumann, E.J., Kliebenstein, J.B., Johnson, C.D., Mabry, J.W., Bush, E.J., Seitzinger, A.H., Green, A.L., Zimmerman, J.J., 2005. Assessment of the economic impact of porcine reproductive and respiratory syndrome on swine production in the United States. Javma-Journal of the American Veterinary Medical Association. 227(3), p 385-392.

Newman, P., 2009. Applied Econometrics. In: Mills, T.C., Patterson, K. (Eds.), Palgrave Handbook of Econometrics. Palgrave-Macmillan, Basingstoke. 8-22.

Ngategize, P.K., Kaneene, J.B., Harsh, S.B., Bartlett, P.C., Mather, E.L., 1986. Decision-Anlaysis in animal health programs - merits and limitations. Preventive Veterinary Medicine. 4(3), p 187-197.

Nokkala, M., 2002. Social accounting matrices and CGE models in policy analysis: Data needs and future developments. In, 14th International Conference on Input-Output Techniques, Montreal, Canada.

Nwafor, M., Diao, X., Alpuerto, V., 2006. A 2006 Social Accounting Matrix (SAM) for Nigeria: Methodology and Results. http://www.ifpri.org/dataset/2006-social-accounting-matrix-nigeria-methodology-and-results. Accessed 15 July 2010. International Food Policy Research Institute (IFPRI). Washington, DC.

OECD, 1992. Technology and the Economy. The key relationships. Organisation for economic co-operation and development. Paris, France.

OECD, 2004a. Economic value of biodiversity. Handbook of market creation for biodiversity: Issues in implementation. OECD Publishing, Paris, France.

OECD, 2004b. Handbook of market creation for biodiversity: Issues in implementation. www.oecd.org/environment/resources/34088095.pdf. Accessed Organisation for Economic Co-operation and Development. Paris, France.

OIE, 2008. PRRS: the disease, its diagnosis, prevention and control. OIE AD HOC group on Porcine Reproductive and Respiratory Syndrome.

http://www.oie.int/fileadmin/Home/eng/Our_scientific_expertise/docs/pdf/PRRS_guide_web_bulletin.pdf. Accessed 13 May 2013. OIE. Paris.

OIE, 2011a. Glossary. Terrestrial animal health code. http://www.oie.int/index.php?id=169&L=0&htmfile=glossaire.htm. Accessed 15 October 2013.

OIE, 2011b. The World Organisation for Animal Health (OIE). http://www.oie.int/about-us/. Accessed 18 May 2011. Paris.

Ostergaard, S., Chagunda, M.G.G., Friggens, N.C., Bennedsgaard, T.W., Klaas, I.C., 2005. A stochastic model simulating pathogen-specific mastitis control in a dairy herd. Journal of Dairy Science. 88(12), p 4243-4257.

Otake, S., Dee, S.A., Rossow, K.D., Moon, R.D., Pijoan, C., 2002. Mechanical transmission of porcine reproductive and respiratory syndrome virus by mosquitos, *Aedes vexans* (Meiga). Canadian Journal of Veterinary Research. 66(3), p 191-195.

Otake, S., Dee, S.A., Rossow, K.D., Moon, R.D., Trincado, C., Pijoan, C., 2003. Transmission of porcine reproductive and respiratory syndrome virus by houseflies (*Musca domestica*). Veterinary Record. 152(3), p 73-76.

Otte, M.J., Chilonda, P., 2000. Animal health economics: An introduction. http://www.fao.org/ag/againfo/resources/en/publications/agapubs/pproc01.pdf. Accessed Food and Agriculture Organisation. Rome.

Otte, M.J., Nugent, R., MacLeod, A., 2004. Transboundary animal diseases: Assessment of socio-economic impacts and institutional response. Livestock Policy Discussion Papers Series 9. Food and Agriculture Organisation. Rome.

Oxford English Dictionary. 2010. Oxford English Dictionary. Oxford University Press. Oxford.

Paarlberg, P.L., Lee, J.G., Seitzinger, A.H., 2003. Measuring welfare impacts of an FMD outbreak in the United States. Journal of Agricultural and Applied Economics. 35(1), p 53-66.

Pang, Meaher, Lim, 2006. An aggregated Social Accounting Matrix for the Australian economy: data sources and methods. Paper presented to the International Conference on "Growth, Distribution and Social Accounting Matrices". Daejeon, Korea.

Pannell, D.J., 1997. Sensitivity analysis of normative economic models: theoretical framework and practical strategies. Agricultural Economics. 16(2), p 139-152.

Paton, M., Fisher, A., Martin, T., Giraudo, A., 2010a. Practical uses of risk assessment method in animal welfare DAFF. http://www.daff.gov.au/__data/assets/pdf_file/0004/1046497/37-michael-paton.pdf. Canberra.

Paton, M., Fisher, A., Martin, T., Giraudo, A., 2010b. Risk analysis to measure animal welfare. http://www.daff.gov.au/animal-plant-health/welfare/aaws/aaws_international_animal_welfare_conference/risk_analysis_to_measure_animal_welfare. Accessed 21st March 2013. Department of Agriculture, Fisheries and Forestry. Canberra.

Perkins, N.R., Pfeiffer, D.U., 1999. An introduction to decision analysis In: Decision trees. Proceedings of the Society of Dairy Cattle Veterinarians of the NZVA Annual Conference. Proceedings of the Society of Dairy Cattle Veterinarians of the NZVA Annual Conference, p 163-174.

Perry, B., McDermott, J., Randolph, T., 2001. Can epidemiology and economics make a meaningful contribution to national animal-disease control? Prev. Vet. Med. 48(4), p 231-260.

Perry, B.D., Randolph, T.F., 1999. Improving the assessment of the economic impact of parasitic diseases and of their control in production animals. Veterinary Parasitology. 84(3-4), p 145-168.

Peters, M.A.J., van Sluijs, F.J., 2002. Decision analysis tree for deciding whether to remove an undescended testis from a young dog Veterinary Record. 150, p 408-411.

Pike, R.W., 2001. Optimization for Engineering Systems (http://www.mpri.lsu.edu/bookindex.html). Minerals Processing Research Institute. Baton Rouge, LA.

Pike, S., Fernström, L., Roos, G., 2005. Intellectual capital: Management approach in ICS Ltd. Journal of Intellectual Capital. 6(4), p 489 - 509.

Plowright, R.K., Foley, P., Field, H.E., Dobson, A.P., Foley, J.E., Eby, P., Daszak, P., 2011. Urban habituation, ecological connectivity and epidemic dampening: the emergence of Hendra virus from flying foxes (Pteropus spp.). Proceedings of the Royal Society B-Biological Sciences. 278(1725), p 3703-3712.

Poulton, C., Morrison, J.A., Randolph, T.F., Stevens, C., Perry, B.D., 2003. Using economic analysis to assess the equity impacts of foot and mouth disease and its control on the poor in Zimbabwe.

Power, A.P., Harris, S.A., 1973. Cost-benefit evaluation of alterative control policies for foot-and-mouth disease in Great Britain. J. Agr. Econ. 24(3), p 573-600.

Preslar, D.B., 2010. Lessening the Impact of Animal Disease on Developing Country Agriculture: A Proposed Program Using Developed Country Technologies. Federation of American Scientists. http://www.fas.org/ahead/ukart2.htm. Washington DC.

Pritchett, J., Thilmany, D., Johnson, K., 2005. Animal disease economic impacts: A survey of literature and typology of research approaches. International Food and Agribusiness Management Review. 8(1), p 23-45.

Productivity Commission, 2002. Impact of a foot-and-mouth disease outbreak on Australia. Ausinfo. Canberra.

Queensland Government, 2012. Nature Conservation (Wildlife) Regulation 2006. Nature Conservation Act 1992. Queensland Government. Brisbane.

Queensland Ombusman, 2011. The Hendra virus report. http://www.ombudsman.qld.gov.au/Portals/0/docs/Publications/Inv_reports/Hendra/Hendra_Virus_Report_web_V1.pdf. Accessed 5 June 2013. Queensland Ombudsman. Brisbane.

Ramsay, G.C., Philip, P., Riethmuller, P., 1999. The economic implications of animal diseases and disease control at the national level. Revue Scientifique et Technique de L'Office International Des Epizooties. 18(2), p 343-356.

Redmill, F., 2002. Risk Analysis - a subjective Process. Engineering Management Journal. 12, p 91-96.

Reserve Bank of Australia, 2013. Inflation Calculator. http://www.rba.gov.au/calculator/. Accessed 9 May 2013. Reserve Bank of Australia. Sydney.

Rich, K.M., Miller, G.Y., Winter-Nelson, A., 2005. A review of economic tools for the assessment of animal disease outbreaks. Rev Sci Tech. 24(3), p 833-845.

Roberts, B., Kanowski, J., Catterall, C., 2006. Ecology and management of flying fox camps in an urbanising Region. Issues in Tropical Forest Landscapes. http://www.rainforest-crc.jcu.edu.au/issues/ITFL_flyingfox.pdf. Accessed 3 June 2013. Rainforest CRC.

Roberts, D., 1990. A comparison of input-output and social accounting methods for analysis in agricultural economics. Department of Agricultural Economics, Faculty of Economic and Social Studies, University of Manchester. Manchester.

Robinson, J., 2004. Squaring the circle? Some thoughts on the idea of sustainable development. Ecological Economics. 48(4), p 369-384.

Roe, R.T., 1976. Summary of the workshop session on economic evaluation and planning. In, ISVEE 1:New Techniques in Veterinary Epidemiology and Economics, Proceedings of a Symposium, University of Reading, 211-213.

Roland-Holst, D., Otte, J., Nguyen Do, A.T., 2010. Integrated poverty assessment of livestock promotion: An example from Viet Nam. A Living from Livestock. FAO - Pro-poor Livestock Policy Initiative. FAO.

Ross, T., Sumner, J., 2002. A simple, spreadsheet-based, food safety risk assessment tool. International Journal of Food Microbiology. 77(1-2), p 39-53.

Rougoor, C.W., Dijkhuizen, A.A., Barkema, H.W., Schukken, Y.H., 1994. The economics of caesarian-section in dairy cows. Preventive Veterinary Medicine. 19(1), p 27-37.

Rougoor, C.W., Dijkhuizen, A.A., Huirne, R.B.M., Marsh, W.E., 1996. Impact of different approaches to calculate the economics of disease in pig farming. Preventive Veterinary Medicine. 26(3-4), p 315-328.

Round, J., 2003. Social accounting matrices and SAM-based multiplier analysis. In: Bourguignon, F., Pereira da Silva, L.A. (Eds.), The Impact of Economic Policies on Poverty and Income Distribution: Evaluation Techniques and Tools. Oxford University Press for the World Bank, New York.

Rowland, R.R.R., 2007. The stealthy nature of PRRSV infection: The dangers posed by ever-changing mystery swine disease. The Veterinary Journal. 174, p 451.

Rushton, J., 2009. The economics of animal health and production. CABI. Wallingford UK.

Rushton, J., Thornton, P.K., Otte, M.J., 1999. Methods of economic impact assessment. Rev. sci. tech. Off. Int. Epiz. 18(2), p 315-342.

Ryan, H., 2010. The "leisure" sector of the horse industry. http://www.ryanshorses.com.au/article/tonyburkeletter. Accessed 20 May 2013. Newcastle.

Schemann, K.A., Firestone, S.M., Taylor, M.R., Toribio, J.-A., Ward, M.P., Dhand, N.K., 2012. From the horse’s mouth: Perceptions of the management of the 2007 equine influenza outbreak in Australia. Transboundary Emerging Dis. 59(6), p 503-516.

Schwabe, C., 1982. The current epidemiological revolution in veterinary medicine. Part I. Preventive Veterinary Medicine. 1(1), p 5-15.

Schwabe, C.W., 1994. The current epidemiological revolution in veterinary medicine. Part II. Preventive Veterinary Medicine. 18(1), p 3-16.

Shields, P.M., Tajalli, H., 2006. Intermediate Theory: The Missing Link to Successful Student Scholarship. Faculty Publications-Political Science. Paper 39. http://ecommons.txstate.edu/polsfacp/39. Accessed 20/10/2010. Texas State University. San Marcos.

Sims, C.A., 1980. Macroeconomics and reality. Econometrica. 48(1), p 1-48.

Sloman, J., 1991. Economics. Harvester Wheatsheaf. London.

Small, K.A., Rosen, H.S., 1981. Applied welfare economics with discrete choice models. Econometrica. 49(1), p 105-130.

Smith, P.C., 2009. Measuring value for money in healthcare: concepts and tools. http://www.health.org.uk/public/cms/75/76/313/573/Measuring%20for%20value%20for%20money%20in%20healthcare%20Concepts%20and%20Tools.pdf?realName=mSOhjZ.pdf. Foundation, T.H. London.

Smyth, G.B., Dagley, K., Tainsh, J., 2011. Insights into the economic consequences of the 2007 equine influenza outbreak in Australia. Australian Veterinary Journal. 89, p 151-158.

Stalder, K.J., Lacy, R.C., Cross, T.L., Conatser, G.E., 2003. Financial impact of average parity of culled females in a breed-to-wean swine operation using replacement gilt net present value analysis. Journal of Swine Health and Production. 11(2), p 69-74.

Stevenson, G.W., Vanalstine, W.G., Kanitz, C.L., 1994. Characterisation of infection with endemic porcine reproductive and respiratory syndrome virus in a swine herd. Journal of the American Veterinary Medical Association. 204(12), p 1938-1942.

Stone, M., Kittelberger, R., 2004. Serological survey for PRRS during a response to PMWS. Surveillance (Wellington). 31(4), p 15-17.

Stone, R., Brown, A., 1962. A computable model for economic growth. Cambridge Growth Project. Cambridge, UK.

Sumner, D.A., Alston, J.M., Glauber, J.W., 2012. Evolution of the economics of agricultural policy. American Journal of Agricultural Economics. 92(2), p 403-423.

Sumner, J., Ross, T., Ababouch, L., 2004. Risk Ranger. Application of risk assessment in the fish industry; FAO Fisheries Technical Paper. No. 442. . FAO, Rome.

Suranovic, S.M., 2010. International trade: Theory and policy. Flatworld Knowledge. New York.

Sveiby, K.-E., 1997. The intangible assets monitor. Journal of Human Resource Costing & Accounting. 2(1), p 73-97.

Sveiby, K.-E., 2010. Methods for measuring intangible assets. http://www.sveiby.com/articles/IntangibleMethods.htm. Accessed May 31 2011.

Thieme Jr, A., 1987. Information requirements, funding priorities and resource allocation in the field of animal health. In: Howe, K.S., McInerney, J. (Eds.), Proceedings of a symposium in the community programme for coordination of agricultural research, Exeter.

Thrusfield, M., 2007. (3rd Edition), Veterinary Epidemiology. Blackwell Publishing. Oxford.

Tisdell, C., 2008. Chapter 4 - Economics of controlling livestock diseases: basic theory. In: Rushton, J. (Ed.), The economics of animal health and production. CABI, Wallingford UK. 46-49.

Tomassen, F.H.M., de Koeijer, A., Mourits, M.C.M., Dekker, A., Bouma, A., Huirne, R.B.M., 2002. A decision-tree to optimise control measures during the early stage of a foot-and-mouth disease epidemic. Preventive Veterinary Medicine. 54(4), p 301-324.

Upton, M., 2008. Tools for assessing the price and market impacts of livestock policies. The economics of animal health and production. CABI. 136-143.

UQ, 2013. Professional staff and professional research staff salaries - 1 January 2013. http://www.uq.edu.au/current-staff/index.html?page=180673&pid=11893. Accessed 4 June 2013. University of Queensland. Brisbane.

van der Linden, I.F., van der Linde-Bril, E.M., Voermans, J.J., van Rijn, P.A., Pol, J.M., Martin, R., Steverink, P.J., 2003. Oral transmission of porcine reproductive and respiratory syndrome virus by muscle of experimentally infected pigs. Veterinary Microbiology. 97(1-2), p 45-54.

Vargas, E.E., Schreiner, D.F., Tembo, G., Marcouiller, D.W., 1999. Computable general equilibrium modeling for regional analysis (www.rri.wvu.edu/regscweb.htm). Regional Research Institute, West Virginia University. Morgantown. WV.

Wagner, C.G., 2001. Making intangible assets more tangible. The Futurist. 35(3), p 14.

Walker, J., 2013a. High stakes of the Hendra virus. The Weekend Australian Magazine. News Limited, Sydney.

Walker, J., 2013b. 'Lax' vets mean few Hendra vaccines. The Australian. News Limited, Sydney.

Wander, A.E., Magalhaes, M.C., Vedovoto, G.L., Martins, E.C., 2004. Using the economic surplus method to assess economics impacts of new technologies: Case studies of EBMRAPA. Conference on international agricultural research for development. Berlin, Germany.

Weinstein, M.C., 1980. Clinical decision analysis. W.B. Saunders Co. Philadelphia.

Weinstein, M.C., Torrance, G., McGuire, A., 2009. QALYs: the basics. Value Health. 12, p 5-9.

Western Research Institute Ltd, 2012. Economic Impact Repot: Pig production and pig meat processing in Australia 2010-2011. Accessed Western Research Institute LTD. Bathurst NSW.

Whitehead, S.J., Ali, S., 2010. Health outcomes in economic evaluation: the QALY and utilities. British Medical Bulletin. 96(1), p 5-21.

Wilson, S.-J., Ward, M.P., Garner, M.G., 2013. A framework for assessing the intangible impacts of emergency animal disease. . Preventive Veterinary Medicine. http://dx.doi.org/10.1016/j.prevetmed.2013.05.003.

Wing, I.S., 2004. Computable general equilibrium models and their use in economy-wide policy analysis. Joint Program on the Science and Policy of Global Change. Massachusetts

Institute of Technology. http://web.mit.edu/globalchange/www/MITJPSPGC_TechNote6.pdf. 22/6/2010. Cambridge, MA.

Winpenny, J.T., 1991. Values for the environment. A guide to economic appraisal. Overseas Development Institute. London.

Wittum, T.W., Dewey, C.E., 1996. Partial budget analysis of sow *Escherichia coli* vaccination. Journal of Swine Health and Production. 4(1), p 9-13.

World Health Organisation, 2013. Using economic valuation methods for environment and health assessment. Economic Assessment. http://www.who.int/heli/economics/valmethods/en/index.html. Accessed 13th March 2013. World Health Organisation.

World Trade Oganisation, 2011. What is the World Trade Organisation? Accessed 23rd March 2011. Geneva, Switzerland.

XE, 2013. USD/AUD currency conversion chart Dec 2010. Currency Conversion Charts. http://www.xe.com/currencycharts/?from=USD&to=AUD&view=5Y. Accessed 6 May 2013. XE.com.

Xevi, E., Khan, S., 2005. A multi-objective optimisation approach to water management. Journal of Environmental Management. 77(4), p 269-277.

Young, A., 1998. Towards an interim statistical framework: selecting the core components of intangible investment. Measuring Intangible Investment. OECD Secretariat. OECD.

Young, J.R., Selvey, C.E., Symons, R., 2011. Hendra virus. Medical Journal of Australia. 195(5), p 250-251.

Young, P.L., Halpin, K., Selleck, P.W., Field, H., Gravel, J.L., Kelly, M.A., Mackenzie, J.S., 1996. Serologic evidence for the presence in pteropus bats of a paramyxovirus related to equine morbillivirus. Emerging Infectious Diseases. 2(3), p 239-240.

Zambon, S., 2003. Study on the measurement of intangible assets and associated reporting practices. Commission of the European Communities Enterprise Directorate General.

Zepeda, L., Buelow, K.L., Nordlund, K.V., Thomas, C.B., Collins, M.T., Goodger, W.J., 2000. Corrigendum to "a linear programming assessment of the profit from strategies to reduce the prevalence of Staphylococcus aureus mastitis" [Prev. Vet. Med. 33 (1998) 183-193]. Preventive Veterinary Medicine. 44(1/2), p 61-71.

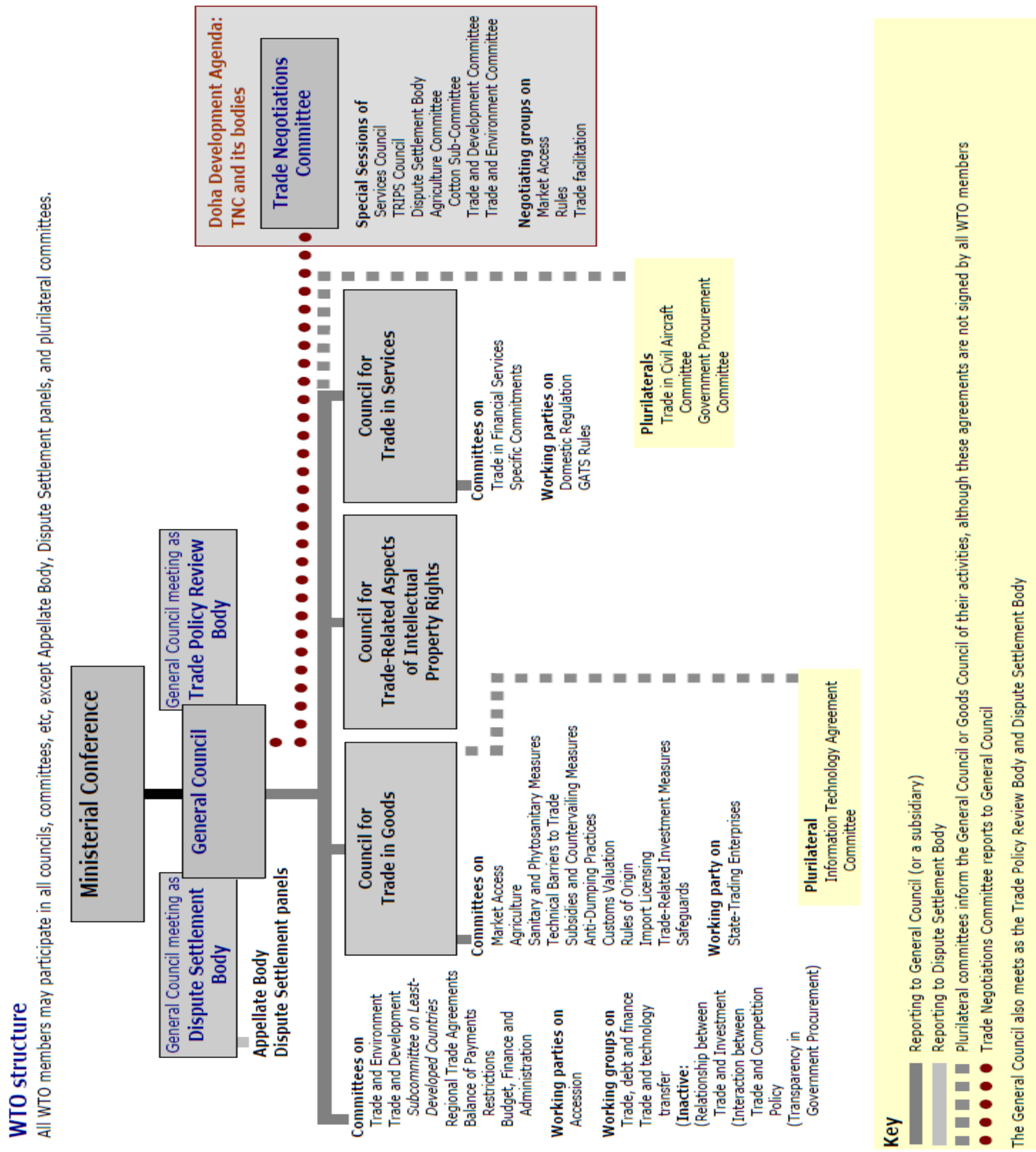
Zhang, J., Kim, N.-H., Lasdon, L., 1985. An improved successive linear programming algorithm. Management Science. 31(10), p 1312-1331.

Zimmerman, J., Yoon, K.J., Pirtle, E.C., Wills, R.W., Sanderson, T.J., McGinley, M.J., 1997. Studies of porcine reproductive and respiratory syndrome (PRRS) virus infection in avian species. Veterinary Microbiology. 55, p 329-336.

Zoetis, 2012. Myth busting Hendra vaccine. http://www.royalqueenslandshow.com.au/media/41577/zoetis_myth_busting_fact_sheet.pdf. Accessed 4 June 2013. Zoetis. West Ryde NSW.

APPENDICES

Appendix 1a- Structure of World Trade Organisation



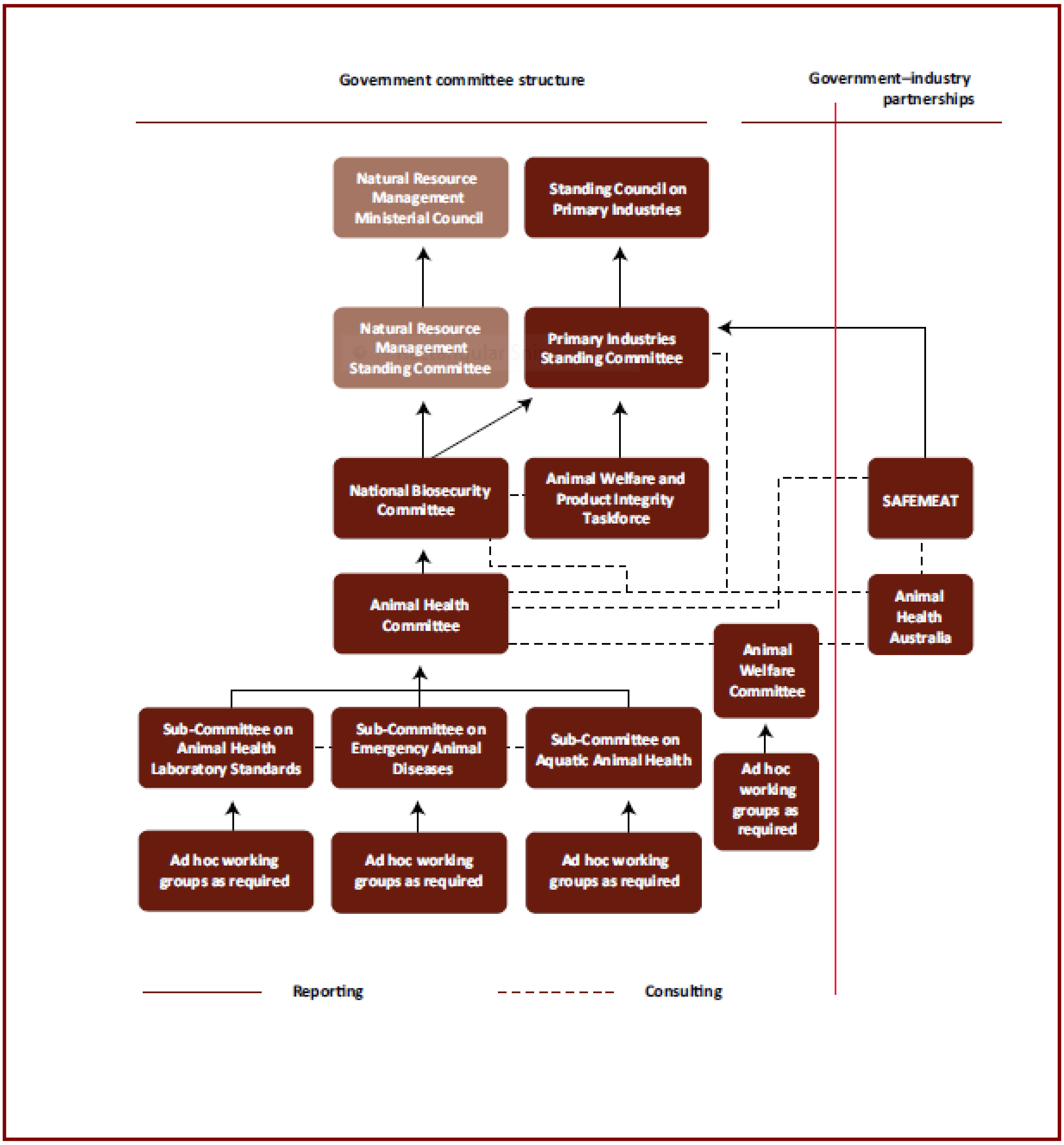
Source: (World Trade Oganisation, 2011)

Appendix 1b - Worldwide organisational structure of the OIE

Source: (OIE, 2011b)

Appendix 2 – Organisation of Animal Health in Australia

Organisation of animal health management committees and organisations in Australia



Source: (Animal Health Australia, 2009)

Appendix 3 – Example economic studies relevant to animal Health using different methodologies

Studies using partial budgets

- The economics of caesarean sections in dairy cows (Rougoor et al., 1994)
- Financial analysis of east coast fever control strategies on beef-production under farm conditions (Mukhebi et al., 1989)
- Partial budget analysis of sow Escherichia coli vaccination (Wittum and Dewey, 1996)

Studies using cost-benefit analysis

- Economic evaluation of bovine brucellosis and tuberculosis eradication programmes in a mountain area of Spain (Bernués et al., 1997)
- Foot-and-mouth disease vaccination in South Sudan: benefit-cost analysis and livelihoods impact (Barasa et al., 2008)
- Cost-benefit evaluation of alterative control policies for foot-and-mouth disease in Great Britain (Power and Harris, 1973)
- Benefit-cost analysis of animal identification for disease prevention and control (Disney et al., 2001)
- A model to estimate the financial consequences of classical swine fever outbreaks: principles and outcomes (Meuwissen et al., 1999)
- Benefit-cost analysis of the national pseudorabies virus eradication program (Miller et al., 1996)
- Measuring welfare impacts of an FMD outbreak in the United States (Paarlberg et al., 2003)

- The application of Benefit-Cost Analysis to compare alternative approaches to the Brucellosis problem in California (Carpenter, 1976)
- Simulation Analysis to estimate the economic impact of Foot-and-Mouth Disease in the United States (Aulaqi and Sundquist, 1978)
- A dynamic model for cost-benefit analyses of foot-and-mouth disease control strategy (Berentsen et al., 1992b)

Studies using decision analysis

- A decision-tree to optimise control measures during the early stage of a foot-and-mouth disease epidemic (Tomassen et al., 2002)
- The use of decision analysis to determine the value of laboratory services to farmers
- (Christiansen, 1985)
- An application of computerized decision analysis in animal health economics (Carpenter and Dilgard, 1982)
- Decision analysis tree for deciding whether to remove an undescended testis from a young dog (Peters and van Sluijs, 2002)
- Multi Criteria Decision Making to evaluate control strategies of contagious animal diseases (Mourits et al., 2010)
- A tool for the job: a simplified multi-criteria decision analysis of emerging threats to UK's animal health (Del Rio Vilas et al., 2009)

Studies using input-output models

- An evaluation of alternative control strategies for foot-and-mouth disease in Australia: a regional approach (Garner and Lack, 1995)

- Simulated economic consequences of foot-and-mouth disease epidemics and their public control in France (Mahul and Durand, 2000)
- The economic impact of BSE: a regional perspective (Caskie et al., 1999)

Studies using SAM models

- Using economic analysis to assess the equity impacts of foot and mouth disease and its control on the poor in Zimbabwe (Poulton et al., 2003)
- The economic impact of BSE: a regional perspective (Caskie et al., 1999)
- A comparison of input-output and social accounting methods for analysis in agricultural economics (Roberts, 1990)
- A 2006 Social Accounting Matrix (SAM) for Nigeria: Methodology and Results (Nwafor et al., 2006)
- An Aggregated Social Accounting Matrix (SAM) for the Australian economy: Data sources and methods (Pang et al., 2006)

Studies using CGE models

- Quantifying the impact of foot and mouth disease on tourism and the UK economy (Blake et al., 2003)
- Integrated Poverty Assessment of Livestock Promotion: An example from Viet Nam (Roland-Holst et al., 2010)
- Economic implications of the EU accession of Bulgaria and Romania: a CGE approach (Baourakis et al., 2008)

- Epidemic and economic impacts of delayed detection of foot-and-mouth disease: a case study of a simulated outbreak in California (Carpenter et al., 2011)

Appendix 4 - Equations presented in the thesis

<u>Equations for Cost-Benefit Analysis</u>

Equation 1 - Formula used to calculate Present Value (PV)

$$PV = \frac{FV}{(1+\frac{r}{100})^n}$$

Where:
FV = Future Value
r = annual interest rate
n = number of years in the future

Equation 2- Mathematical representation of NPV

$$\text{NPV} = \sum_{t=0}^{n} \frac{B_t - C_t}{(1+r)^t}$$

Equation 3 - Mathematical formula for the Calculation of BCR

$$\text{BCR} = \sum_{t=0}^{n} \frac{B_t}{C_t}$$

Equation 4 - Mathematical formula for solving IRR

$$\text{NPV} = \sum_{t=0}^{n} \frac{B_t - C_t}{(1+r)^t} = 0$$

(Where IRR will be given by solving r through an iterative process)
And where:
n = number of years in the future, *B* = Benefits, *C* = costs, *r* = discount rate
Equations from (Thrusfield, 2007)

Equations for Decision Analysis

Equation 1 - Algebraic expression of a decision analysis problem

Algebraically decision analysis appears as follows -

$$A_i = f(A_i, S_1, S_2, ..., S_j, P_1, P_2, ...P_j, V_{i1}, V_{i2}, ...V_{ij})$$

Where

Ai = decision option (action)

Sj = state of nature

Pj = probability of state of nature (Sj); and

Vij = value of each action and state of nature.

Therefore if the main decision criteria are monetary values expected as a result of the decision the EMV (expected monetary value) for each action (Ai) will be

$$EMV(A_i) = \sum_j (P_j V_{ij})$$

Equations from (Ngategize et al., 1986; Huirne and Dijkhuizen, 1997)

Equations for Input-Output models

Equation 2 - Mathematical equation for I-O Models

$$X_i = \sum_{j=1}^{n} a_{ij} X_j + F_i$$

Where X_i is the output for sector i, (assumed to be proportional to sector j),

X_j is the outcome for sector j,

a_{ij} is the input-output coefficient and

F_i is the final demand if sector i.

Equation from (Mahul and Durand, 2000)

Equations for Linear Programming and optimisation

Equation 3 - Mathematic formula for Linear Programming

$$Optimise : \sum_{j=1}^{n} c_j x_j$$

Subject to: $\sum_{j=1}^{n} a_{ij} x_j \geq b_i$ for i = 1,2,.....m

$x_j \geq 0$ for j = 1,2,.....n

Where:

c_j = vector net benefit coefficient of program activity x_j
x_j = vector of program activities
a_{ij} = matrix of technical coefficients – showing how much of resource b_i, that activity x_j will use
b_i = vector of constraints on available resources

Formula from Habtemariam (1984)

Equation 4 - Mathematical function of Dynamic Programming

If a function is required to maximise a serial process with i stages, as occurs in DP then the following algorithm can be used from Pike (2001)-

$$f_i(s_i) = \max_{d_i}\left[R_i(s_i, d_i) + f_{i-1}(s_{i-1})\right]$$

Where Ri(si,di) is the return from stage *i* with inputs s_i and d_i and output s_{i-1}; $f_{i-1}(s_{i-1})$ is the maximum return for stages 1 through *i*-1 as a function of input s_{i-1} and $f_i(s_i)$ is the maximum return for stages 1 through *i* as a function of s_i.

Equation 5 - Algebraic equation for Multi-criteria programming

The economic model y(x) and the constraints fi(x) can be linearised around a feasible point xk to give:

Maximise $$\sum_{j=1}^{n} c_j x_j - \frac{1}{2}\sum_{j=1}^{n}\sum_{k=1}^{n} q_{jk} x_j x_k$$

Subject to: $\sum_{j=1}^{n} a_{ij} x_j \leq b_i$ for i = 1,2,….m

$x_j \leq 0$ for j = 1,2,….n

Where $q_{jk} = q_{kj}$ would be the second partial derivatives with respect to x_j and x_k of the nonlinear economic model.

Equation 6 - Mathematical function of successive quadratic programming

Optimise: $$\sum_{j=1}^{n} c_j \Delta x_j = y - y(x_k)$$

Subject to: $$\sum_{j=1}^{n} a_{ij} \Delta x_j \leq b_i - f_i(x_k)$$ for i = 1,2,….m

$$u_j - x_{jk} \leq \Delta x_j \geq l_j - x_{jk}$$ for j = 1,2,….n

and

$$\Delta x_j = x_j - x_{jk} \quad c_j = \frac{\partial y}{\partial x_j}(x_k) \quad a_{ij} = \frac{\partial f_i}{\partial x_j}(x_k)$$

<u>*Equations for Equilibrium Models*</u>

Equation 7 - The supply curve equation

$P_{(s)} = f_s(Q_s)$

Equation 8 - The demand curve equation

$P_{(d)} = f_d(Q_d)$

Equation for Case prediction Load

Equation 9 - Case prediction load equation

$CPL_y = P_{en} \times P_{exp} \times P_{det} \times N_y$

P_{en} = Probability of agent entry into system of concern,

P_{exp}= probability of exposure to agent,

P_{det}= probability that the agent will remain undetected,

N = number of animals in population *y*

Appendix 5 - Conceptual framework of measurement methods categories for intangibles

		Non-monetary Valuation		**Monetary valuation**	
Holistic level (Organisational)	**Methods**			Return on Assets Methods (ROA) Market Capitalisation Methods (MCM)	
	Uses	Pros	Cons	Pros	Cons
				❖Allows $ measures ❖Provides representat-ion of IC ❖Useful in mergers and acquisitions ❖Can be used for comparisons within an industry ❖Methods are auditable	❖Very general ❖Don't allow individual assets to be managed ❖Not useful for public sector or not for profit organisations ❖Sensitive to interest rate assumptions
Atomistic level (Components identified)	**Methods**	Score Card Methods (SC)		Direct Intellectual Capital Methods (DIC)	
	Uses	Pros	Cons	Pros	Cons
		❖Can be applied at all levels of the company ❖Can be used for public sector, social and environmenta l purposes	❖Don't allow for additive properties or comparisons ❖Often rely on proxies to represent the assets ❖Contextual representations need to be customised for each organisation ❖Generate large quantities of data	❖Can be applied at all levels of the company ❖Can be used for public sector, social and environmental purposes ❖Are usually faster and more accurate than ROA or MCM regarding resources	❖Doesn't provide a company level view ❖Generate large quantities of data ❖Cannot easily be connected to financial results

Appendix 6 – Exposure and release assessment identifying relevant pathways for a PRRS outbreak in Australia

Release Assessment for PRRS in imported Pigs and Pig Products — Exposure Assessment

Mode of Entry	Item	Uses	Pre-importation Processing	Planned Post-Importation use	Post-importation processing	Post processing risk pathways	End Disposal	Post disposal exposure risks
Illegal Import	*Live Animal	*Pet/Show/ Trade	Unlikely	Pet/Show/Trade	Husbandry Medical Tx Grooming Feeding Waste Disposal	Travelled and displayed Travel and swapped Kept at home (risk of direct contact in all pathways)	Death of animal – Bury, let lie, incinerate	Scavenging or contact by susceptible species
		Food	Unlikely	Consume Trade	Slaughter Meat Processing Storage Cooking Freezing Preserving	Consumption Disposal Storage	Food waste/ Refuse treated or untreated Food waste for fodder	Scavenging At dump by susceptible species Swill feeding
		*Breeding/ Genetic Material collection	Unlikely	Embryo transfer Insemination	Chilling Freezing Thawing	Conception Abortion	Incinerate, let lie, bury	Scavenging of aborted material Dumping of waste material
	*Animal Product	*Genetic Material	Chilled Frozen					
		*Food	Variable Fresh/Raw Preserved (↓A_w) Chilled Frozen	Consume Trade	Cooking Freezing Preserving	Consumption Disposal Storage	Food waste Refuse (Treated or untreated)	Scavenging At dump By susceptible species Swill feeding

		Textile Hide, Wool or fibre prod	Scouring Tanning	Manufacturing On-selling (e.g. instruments) Personal use	Manufacturing Tertiary processing (e.g. wool) NIL	Storage Sale Personal use	Garbage, waste or unknown	General exposure, fomites, garbage, spread by pest vector
	Fomite/ Human carrier	Unintentional import	Nil	NIL	NIL	Detected and mitigated Undetected and release into susceptible population		Disposal, garbage, fomite, scavenged raw material
		Agri-terrorism	Unknown			Release into susceptible population Storage for later release	Undefined	Undefined
Legal Import	Live Animal	Breeding or collection of genetic material	As per AQIS protocol for importation	Stud Semen collection Ova Collection	Nil Chilling Freezing	Insemination Laboratory Use Bio-Waste	Biohazard Waste disposal Abortive material	Successful disposal via incineration or Treatment Unsuccessful disposal (breakdown in system) Scavenged Fomite
		Pet/Show		Pet Showing Trade/Sale	Husbandry Grooming Feeding Waste Disposal	Travelled and displayed Travel and swapped Kept at home (risk of direct contact if sub-clinical or PI case)	Death of animal – Bury, let lie, incinerate	Direct contact with susceptible animal, spread by pest vector or fomite.
	Animal Product	Genetic Material	PRRS-free country IETS protocol followed IETS protocol not	Embryo Transfer	Chilling Freezing	Conception – pregnancy – live at parturition	Live young	A/A

			followed PRRS- active country IETS protocol followed IETS protocol not followed	Insemination Research	Thawing	Abortion	Death post parturition	Scavenging
		Food	Variable Fresh/Raw Preserved (↓A_w) Chilled Frozen	Consumption Trade/Sale Manufacturing	Cooking Freezing Cold storage Storage	Consumption Disposal Storage	Food waste refuse	Scavenging At dump By susceptible species Swill feeding
		Textiles Or products that contain such (e.g. Pig bristle brushes)	As per importation protocol Spray treatment/disinfection Quarantine Other treatment (heat)	Trade/Sale	AS per protocol	Breakdown in protocol of treatment	General exposure, fomites, garbage	Scavenging Fomites

Appendix 7 – Background information on risk analysis performed for Case Study 5A

Case Study 5A background information		Source:
1. Hazard Severity	Notifiable disease	(Animal Health Australia, 2009; Department of Agriculture Fisheries and Forestry, 2011)
2. Susceptibility of population	Naive	
3. Length of Exposure	48 Hours max (2 x AI treatments over 2 days)	(McIntosh, 2005)
4. Proportion of population exposed	Very few (5% or less)	
5. Size of population in risk area	Average sized sow farm selected as infected premise 1 (IP1).	(Australian Bureau of Statistics, 2010; Department of Environment and Primary Industries, 2011; Australian Bureau of Statistics, 2012; Australian Pork Limited, 2012)
6. Probability of virus arriving in Australia	Rare event (1 in 1,000 specimens)	
7. Effect of Quarantine	Reliably eliminates hazards (99.9%)	
8. Can a persistent state of infection occur	Yes but minor occurrence (1%)	
9. How well-controlled is on-farm biosecurity	Well-controlled – reliable and effective systems in place	
10. What increase risk in disease spread occurs with a delay in diagnosis of up to 48 hours	Extreme risk	
11. Impact of medical treatment of symptomatic animal on farm	No effect	(Animal Health Australia, 2004b)
Predicted number of Cases	50	MORR
Farms infected	1	OIS
Dangerous contact Premises per farm (Average)	3	(Garner et al., 2001)
Size of Dangerous contact farm	1 x mixed enterprise 1 x contract grower (no sows) finisher only - 1 x lifestyle/hobby farm – 3 pigs total	(Australian Pork Limited, 2012)

Assumptions Case Study 5A –
No movements off-farm since semen was used for artificial insemination
All sows in batch will be exposed over the 20 weeks to PRRS
Average Age of Sows 15 months

Appendix 8 – Background information on risk analysis performed for Case Study 5B

Case Study 5B background information		Source:
1. Hazard Severity	Notifiable disease	(Animal Health Australia, 2009; Department of Agriculture Fisheries and Forestry, 2011)
2. Susceptibility of population	Naïve	Australian Pork Limited, 2012)
3. Length of Exposure	Month (4 weeks)	
4. Proportion of population initially exposed	Some (25%)	
5. Size of population in risk area	Sows – 2,878 on IPs, 8,615 on IP plus DCP Grower/Finisher – 30,713 on IP plus DCP	(Australian Bureau of Statistics, 2010; Department of Environment and Primary Industries, 2011; Australian Bureau of Statistics, 2012; Australian Pork Limited, 2012)
6. Probability of virus arriving in Australia	Rare event (1 in 1,000 specimens)	
7. Effect of Quarantine	Reliably eliminates hazards (99.9%)	
8. Can a persistent state of infection occur	Yes but minor occurrence (1%)	
9. How well-controlled is on-farm biosecurity	Well-controlled – reliable and effective systems in place	
10. What increase risk in disease spread occurs with a delay in diagnosis of up to 48 hours	Extreme risk	
11. Impact of medical treatment of symptomatic animal on farm	No effect	(Animal Health Australia, 2004b)
Predicted number of Cases	1,331 Sows on IPs (up to 3,101 inlcuding DCPs) Up to 11,978 grower finisher on IP plus DCPs	MORR
Dangerous contact Premises per IP	3	(Garner et al., 2001)

Assumptions Case Study 5B

100% exposure to virus in all establishments on DCP and IP

Finisher only COP (feed, labour and other) without birth-weaning costs equal to 15.5% (extrapolated by dividing average Victorian sow farm stock numbers/average Victorian contract Grower stock numbers)

(see also Appendix 10)

Appendix 9 – Background data for PRRS economic analysis

Background Data

Item	Value	Reference and extrapolations/assumptions
Average number of Piglets weaned pre-PRRS	9.55	a,
Average number of piglet weaned with PRRS	7.95	a, h, i
Post weaning mortality pre-PRRS	0.07%	A
Post weaning mortality with PRRS	4.3%	h, i
Sow Mortality pre-PRRS	13.2%	a,
Sow Mortality with PRRS	18.2% (increase 5%)	m
Farrowing Rate	82%	a,
% Gilts	23.9%	
Herd FCR kg/kg Cwgt	3.95	
Feed Costs	$225/Tonne	
Production Costs $/kg Cwgt (other than feed/labour)	0.887	l,
Labour costs per hour $	17.14	f
Labour per pig (hour)1.34bExtended Value Processing $/pig slaughtered$73.21e, a (Divide total value chain flow on by number of pigs slaughtered)Cost destocking per sow $	798.2	b, c
Compensation per sow $	474	d, c
Surv test $/animal	$5	g,j (assuming large scale testing would reduce cost to commercial price as seen in USA)
Replacement cost (gilt/sow)$	319	k, j (5 year average market rate for cwt and add genetic premium as per Stalder et al 2003, adjusted to AUD for time period)
Feed Conversion Ratio (kg for kg liveweight)	2.63	a
Market Liveweight	97.11	N
Weaning liveweight	17.5	O (average of 15-20kg)

[a] Australian Pig Annual–Statistical Data (Australian Pork Limited, 2012), [b] Economic Data (Garner et al., 2001), [c]Inflation Calculator (Reserve Bank of Australia, 2013), [d]AUSVETPLAN-Valuation and Compensation Manual (Animal Health Australia, 2005), [e]Pork Value Chain (Western Research Institute Ltd, 2012), [f]Wage Data (Fair Work Australia, 2011), [g]Diagnostic Test Prices for commercial serology (Indiana Animal Disease Diagnostic Laboratory, 2010) [e]Epidemiological Parameters (Done et al., 1996) and [i](Neumann et al., 2005), [j] Currency Conversion (XE, 2013), [k] Gilt Prices (Stalder et al., 2003), [l] Cost of Production data (Campbell, 2013), [m]Ausvetplan PRRS manual (Animal Health Australia, 2004b), [n]Pig Operation Data (Cutler and Holyoake, 2007), [o]Piggery information (Department of Agriculture Fisheries and Forestry, 2012)

Appendix 10 – Cost-benefit analysis outcomes for case study 5A

Cost Benefit Analysis Case Study 5A

Scenario - PRRS outbreak

	OIS 1 - slaughter all sows		OIS 2 - farrow and slaughter
Number of Sows affected		430	430
Expected dwght slauger		76	76
Value of Product per kg		2.8	2.8
Value of dead animal		0	0
Value of slaughtered animal		212.8	212.8
Total animals on premises			
Total animals to be compensated		550	550
Number of animals serology		1300	1300
Expected Mortality in sows %		18.2	18.2
Total sow deaths (not culled)		0	78.26
# piglets per litter weaned infected pigs		0	7.93
Additional Piglets to Slwgt		650	540
Post weaning mortality %		0.07	4.3
Total number piglets slaughtered per litter		0	7.59
Total product in kg at slaughter for batch		49,365	243,938
Total Product Value at Slaughter on farm	$	138,223.18	$ 683,025.56

COSTS/LOSSES				
Production				
Feed Costs total Piglets	$	43,873.52	$	216,799.63
Labour Piglets	$	14,824.44	$	73,719.26
Additional feeding costs Piglets			$	26,015.96
Other Costs of Production	$	43,787.13	$	216,372.74
Disease Response				
Destocking	$	439,010.00	$	439,010.00
Surveillance	$	6,500.00	$	6,500.00
Compensation	$	260,700.00	$	260,700.00
Restocking	$	175,450.00	$	175,450.00
Industry				
Processing	$	238,935.48		
Product Trade Lost (number not at slaughte	$	725,626.72	$	182,451.10
TOTAL COSTS	$	1,948,707.28	$	1,597,018.69

Benefits				
Production Salvaged			$	683,025.56
Feed saved	$	180,325.33		
Labour Costs Saved	$	56,219.52		
Production Costs Saved	$	179,970.26		
Processing	$	47,553.19	$	234,982.62
Other saleable stock on farm	$	137,351.76	$	114,912.00
Reduced compensation and response				
TOTAL	$	601,420.06	$	1,032,920.18

OUTPUTS				
NPV	-$	1,347,287.22	-$	564,098.50
BCR		0.31		0.65

Appendix 11 – Cost-benefit analysis outcomes for case study 5B

Cost Benefit Analysis Case Study 5B

Scenario - PRRS outbreak

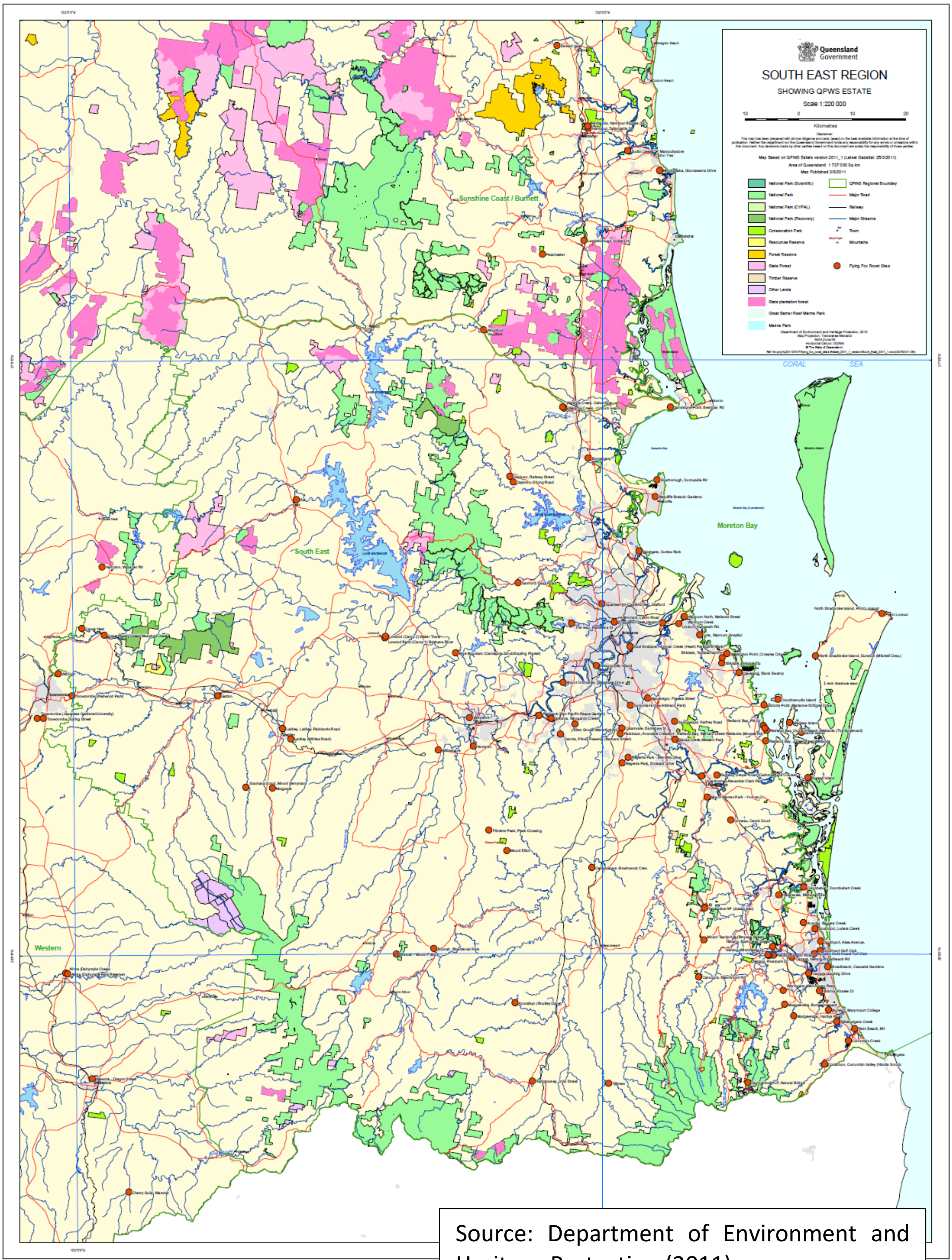
	OIS 1 Endemic Disease	OIS 2 - farrow and slaughter
Number of Sows total impacts	6216	6216
Expected Slaughter weight of	76	76
Value of Product per kg	2.8	2.8
Value of dead animal	0	0
Value of slaughtered animal	212.8	212.8
Total animals on premises	8615	8615
Total animals to be compensated	0	7047.07
Number of animals serology TOTAL	10265	10265
Piglets estiamted in Nursery currently	6781	6781
Incidence of Disease	95%	95%
Expected Mortality in sows %	18.2	18.2
Total sow deaths	1131.312	1131.312
# piglets per litter weaned	7.93	7.93
Post weaning mortality %	4.3	4.3
Total number piglets slaughtered per sow per y	7.59	7.59
Total product in kg at slaughter for batch	5,660,065	5,660,065
Finisher Farms		
Total Animals	30,713	30,713
Average Weight to gain for slaughter kg Lwgt	79.6	79.6
Total Product Value at Slaughter	$ 15,848,182.09	$ 15,848,182.09

COSTS				
Production				
Feed Costs total Piglets	$	476,920.45	$	476,920.45
Labour Piglets	$	1,035,429.91	$	1,035,429.91
Additional feeding costs Piglets	$	57,230.45	$	57,230.45
Other Cost of Production (37.3%)	$	5,020,477.69	$	5,020,477.69
Grower/Finisher feed costs	$	692,238.13	$	692,238.13
Grower finisher additional feed costs	$	83,068.58	$	83,068.58
Grower finisher Labour	$	280,899.50	$	280,899.50
Grower/Finisher Extra cost of production	$	10,848.23	$	10,848.23
Disease Response				
Destocking			$	5,624,971.27
Surveillance	$	51,325.00	$	51,325.00
Compensation			$	3,340,311.18
Restocking	$	500,169.67	$	2,748,185.00
TOTAL COSTS	$	8,208,607.61	$	19,421,905.39

Benefits				
Production Salvaged	$	15,848,182.09	$	15,848,182.09
Feed saved				
Labour Costs Saved				
Processing	$	3,321,814.57	$	3,321,814.57
Reduced compensation and response	$	11,213,297.78		
TOTAL	$	30,383,294.45	$	19,169,996.67

OUTPUTS				
NPV	$	22,174,686.85	-$	251,908.72
BCR		3.70		0.99

Appendix 12 – Flying-fox roost locations in Southeast Queensland



Source: Department of Environment and Heritage Protection (2011)
Red dots are known flying-fox roosts

Appendix 13 – Background information for risk analysis performed for Case study 6

Case Study background information		Source:
1. Hazard Severity	Notifiable disease	(Animal Health Australia, 2012c)
2. Susceptibility of population	Naive if unvaccinated	
3. Length of Exposure	Few times a year	
4. Proportion of population exposed	75%	
5. Size of population in risk area	50,0000 unvaccinated horses in OPS 1 80,000 horses unvaccinated in OPS 2	(Anonymous, 2008; Walker, 2013b)
6. Probability of virus in Bats	10%	(Halpin et al., 1999; Breed et al., 2011; Field et al., 2011)
7. Effect of Quarantine of sick animal	Slightly reduced cases (50%)	
8. Can a persistent state of infection occur	Not in horses that we know	
9. How well-controlled is on-farm biosecurity	Controlled – mostly reliable procedures in place	
10. What increase risk in disease spread occurs with a delay in diagnosis of up to 48 hours	Moderate	
11. Impact of medical treatment of symptomatic animal on farm	No effect	
Predicted number of Cases	OPS 1 - 7 OPS 2 - 22	MORR
Assumptions	Scenarios are based on either/or Horse and bat population remains relatively static over the time period Level of viral shedding remains constant in bat population	

Appendix 14 – Cost-benefit analysis outcomes for case study 6

Cost Benefit Analysis Case Study 6 - Hendra	OPS 1 Vaccination	OPS 2 Roost removal
Number of horses infections predicted	7	22
Value of Horses average	12625	12625
Value of response/horse	18032	18032
Value of Veterinary service/hr	54.49	54.49
Number of Vet hours involved	4200	0
Number of horses vaccinated	30000	0
Cost of vaccine wholesale	53.8	53.8
Cost of Microchip wholesale	10.41	10.41
Veterinary Equipment & consumables	22,000	
Value per horse extended	3471	3471
Roosts removed	0	25
Costs per roost	$ 57,000.00	$ 57,000.00
Remaining unvaccinated live horses	50000	80000
Veterinary Milage	60,000	
Cost per KM	0.95	
COSTS/LOSSES		
Production		
Value of Horses destroyed	$ 88,375.00	$ 277,750.00
Extended industry value lost	$ 24,297.00	$ 76,362.00
Disease Response/Prevention		
Reponse to infection	$ 126,224.00	$ 396,704.00
Vaccination Costs	$ 3,228,000.00	$ -
Microchip costs	$ 312,300.00	$ -
Veterinary Wages	$ 228,858.00	$ -
Vet Kit	$ 22,077.00	
Milage	$ 57,000.00	
Advertising Horse Clinics	$5,000	
Environmental Costs		
Cost of roost removal	$ -	$ 1,425,000.00
TOTAL COSTS	$ 4,092,131.00	$ 2,175,816.00

Item	Price per unit
Sharps Containers x 300	$24.43
Nitrile disposable gloves x 600 boxes	$6.91
Alcohol medi-swabs x 300	$8.72
Virkon disinfectant 20kg x 6	$687.50
Stethoscope x 4	$54.30
Thermometers x 300	$8.20
Vaccinations HeV x 60,000	$53.80
Microchips x 30,000	$10.41
Car Fridge (evacool 95L) x 4	$1,399

Source: Provet Customer Hotline Personal Comms 4/6/2012 (Sharps Containers to Microchips)

Source: BCF Nerang (Car Fridge)

Benefits			
Horse lives saved		$ 189,375.00	
Extended Industry		$ 52,065.00	
Response costs saved		$ 270,480.00	
Revenue from Vaccinations		$ 6,600,000.00	
Vax and MC saved			$ 3,540,300.00
Vet Wges and consumables Saved			$ 312,935.00
TOTAL		$ 7,111,920.00	$ 3,853,235.00
OUTPUTS			
NPV		$ 3,019,789.00	$ 1,677,419.00
BCR		1.74	1.77

Appendix 15 – Weighting values for use in the MORR analysis

Criteria	Weighting Value
Question 1 - Hazard Severity	
Notifiable Disease - Exotic or EADRA cat A or B	1
Notifiable Disease - Non exotic	0.1
Other Notifiable disease	0.001
Other EADRA disease	0.0001
Question 2 - How susceptible is the population of interest	
GENERAL - whole population susceptible	100%
SLIGHT - some members of population at risk	20%
VERY - Specific groups at risk	3%
EXTREME -only a few members of population at risk	0.10%
Questions 3 - What is the frequency of Exposure	
daily	365
weekly	52
monthly	12
a few times per year	3
Other (Days)	
Question 4 - What proportion of the animals are exposure to the pathogen	
all (100%)	1
most (75%)	0.75
some (25%)	0.25
very few (5%)	0.05
Question 5 - What is the size of the population of interest	
To be determined by user	
Question 6 - What is the liklihood of the pathogen arriving (either in Australia - PRRS or in the area of interest- HeV)	
Rare (1 in a 1000)	0.001
Infrequent (1 per cent)	0.01
Sometimes (10 per cent)	0.1
Common (50 per cent)	0.5
All (100 per cent)	1
Question 7 - What are the effects of Quarantine (PRRS), Isolation housing (HeV)	
The process RELIABLY ELIMINATES hazards	0

The process USUALLY (99% of cases) ELIMINATES hazards	0.01
The process SLIGHTLY (50% of cases) REDUCES hazards	0.5
The process has NO EFFECT on the hazards	1
The process INCREASES (10 x) the hazards	10
The process GREATLY INCREASES (1000 x) the hazards	1000
Question 8 - Can a state of persistent infection occur increasing risk	
NO	0.00
YES - minor (1% frequency)	0.01
YES - major (50% frequency)	0.50
Question 9 - How conscientious is the on-farm biosecurity	
WELL CONTROLLED - reliable, effective, systems in place (no increase in pathogens)	1
CONTROLLED - mostly reliable systems in place (3-fold increase)	3
NOT CONTROLLED - no systems, untrained staff (10 -fold increase)	10
GROSS ABUSE OCCURS - (e.g.1000-fold increase)	1000
NOT RELEVANT - level of risk agent does not change	1
Question 10 - what increase in disease spread risk occur with a 48 delay in detection	
Extreme (10,000x increase)	1
significant (1000-fold increase)	0.1
moderate (100-fold increase)	0.01
minimal	0.0001
none	1.E-05
Question 11 - What is the impact of slaughter or destruction of the animal upon the pathogen	
Slaughter RELIABLY ELIMINATES hazards	0
Slaughter USUALLY ELIMINATES (99%) hazards	0.01
Slaughter SLIGHTLY REDUCES (50%) hazards	0.5
Slaughter has NO EFFECT on the hazards	1