Routledge
Taylor & Francis Group

Agrekon

Agricultural Economics Research, Policy and Practice in Southern Africa

ISSN: 0303-1853 (Print) 2078-0400 (Online) Journal homepage: www.tandfonline.com/journals/ragr20

Economic analysis of new generation vaccines for control of lumpy skin disease and Rift Valley Fever in South Africa

Zimbini Mdlulwa, Mampe Masemola, Petronella Chaminuka & Sipho Madyo

To cite this article: Zimbini Mdlulwa, Mampe Masemola, Petronella Chaminuka & Sipho Madyo (2019) Economic analysis of new generation vaccines for control of lumpy skin disease and Rift Valley Fever in South Africa, Agrekon, 58:1, 125-140, DOI: 10.1080/03031853.2018.1543052

To link to this article: https://doi.org/10.1080/03031853.2018.1543052

Published online: 30 Nov 2018.

AGREKON
2019, VOL. 58, NO. 1, 125–140
https://doi.org/10.1080/03031853.2018.1543052

Economic analysis of new generation vaccines for control of lumpy skin disease and Rift Valley Fever in South Africa

Zimbini Mdlulwa[a], Mampe Masemola[b], Petronella Chaminuka[c] and Sipho Madyo[d]

[a]Economic Analysis Unit, Agricultural Research Council, Pretoria, South Africa; [b]Agricultural Research Council, Pretoria, South Africa; [c]Agricultural Research Council, Pretoria, South Africa; [d]Agricultural Research Council, Pretoria, South Africa

ABSTRACT

Livestock disease outbreaks in Africa threaten improved animal and human health, increased productivity, and sustainable agricultural livelihoods. Investment into research and development of livestock vaccines has potential to generate new technologies that can benefit the livestock sector and result in control of diseases such as Rift Valley fever (RVF) and lumpy skin disease (LSD). Veterinary research and development efforts have focussed on the development of an improved, combined LSD RVF 2-in-1 vaccine, using new generation technologies. Through collaborative, multidisciplinary research, it is possible to create solid economic arguments that guide policy and investment on strategies for controlling livestock diseases. Using Monte Carlo simulation through various vaccination scenarios this paper evaluates *ex-ante* the costs and benefits of an LSD RVF 2-in-1 vaccine on dairy production in South Africa. Simulations over a 15 year period yielded positive net present values at R830 641 and R13 954 073 with internal rate of return at 32.4 per cent and 32.9 per cent for small scale and large scale operations, respectively. The results of the study provide decision makers with solid economic arguments regarding the potential benefits of investing in new generation vaccines for control of RVF and LSD. Continuous awareness on the importance of the vaccines, particularly for small-scale farmers is recommended for improved livestock productivity.

ARTICLE HISTORY
Received 18 April 2018
Revised 17 October 2018
Accepted 27 October 2018

KEYWORDS
benefits; costs; livelihoods; livestock vaccines; Monte Carlo simulation

JEL
D81; Q16; C15

1. Introduction

Livestock plays an important role in the economies of many developing countries including South Africa. It provides food, income, employment and foreign exchange (Bayiyana *et al*., 2012). Despite the economic importance of livestock production, livestock remains vulnerable to diseases. Livestock diseases sometimes result in outbreaks that vary in severity and magnitude of economic impact. While different measures are available to control the diseases, livestock vaccines have been globally identified as a cost-effective method to prevent livestock diseases thereby increasing productivity, reducing the costs of production, increasing incomes and food security for rural households (Roth, 2011). Notwithstanding the benefits of livestock vaccines when considered in totality, the costs to implement primary animal health care programmes for developing countries can be quite significant (Perry *et al*., 2002). Often, advanced biotechnological innovations that require collaborative multidisciplinary research, and substantial investment, are needed in order to accelerate research and

CONTACT Zimbini Mdlulwa MdlulwaZ@arc.agric.za

development (R&D), commercialisation and registration of livestock vaccines. Even where the veterinary vaccine is already available on the market, the costs of delivering the vaccine to farmers is often high.

According to Harrison (1996), government often needs to take action in animal health due to various cases of market failures. For example, the effort made by the private sector may not be sufficient to achieve disease prevention and control. In addition, some of the benefits of improved animal health are not captured by producers, as there may be externalities or spillover effects to the community through improved public health and nutrition. In some cases, only government livestock departments have the veterinary expertise and organisational ability to implement large-scale animal health programmes. Therefore, in order to achieve optimal effort level for diseases control and optimum mix of prevention and control, there is often justification for government to invest in animal health programmes. Similarly, livestock vaccine research is a public good often provided by government (Otte *et al.*, 2004). World over, governments spend significant amounts of public resources on control and prevention of animal diseases that are viewed to be of economic importance. Policy makers require information that will assist them in justifying use of public resources as well as to inform R&D investment decisions. Such information includes technical feasibility of the proposed interventions, costs of treatment and control options, wider economic impact of the disease, envisaged returns to investment before and after implementing the proposed interventions (FAO, 2016). For livestock vaccines, economic arguments will guide policy and investment on how best to allocate the limited resources available for strategies of controlling livestock diseases.

Review of existing literature reveals scarcity of information on economics of animal disease control measures. Internationally, the subject has progressively received interest from researchers, as in the analysis of (Bates *et al.*, 2003; Häsler *et al.*, 2012; Probst *et al.*, 2013; Leite *et al.*, 2018). These studies focus on economic evaluation of animal diseases control measures. However, in South Africa, little research exists on economics of animal disease control measures, particularly considering that vaccine development is an important R&D activity and the government supports public investment in development of livestock vaccines for growth of the livestock sector in southern and South Africa.

Despite the knowledge gap that exists on economics of vaccine research and development, there are significant advances in research on livestock vaccine development in South Africa in both the private and public sectors. The Agricultural Research Council (ARC) in partnership with the state owned entity Onderstepoort Biological Products (OBP) have been involved in development of new generation vaccines that are multivalent, with the ability to protect livestock from two or more diseases through a single vaccination. One such innovation is the LSD RVF 2-in-1 vaccine, which provides dual protection for two trans-boundary animal diseases: Rift Valley fever and lumpy skin disease (LSD) in cattle. Trans-boundary animal diseases are of significant economic, trade and /or food security importance for a considerable number of countries (Otte *et al.*, 2004). The diseases can easily spread to other countries and reach epidemic magnitudes and usually, their control and management, including exclusion, requires cooperation between several countries. The control of trans-boundary animal diseases necessitates for provision of public goods at the global or regional level (Otte *et al.*, 2004). Features of disease control that fall undoubtedly in the jurisdiction of public goods are surveillance, information provision and R&D on improved methods of prevention or diagnostics (FAO, 2016). Therefore, the zoonotic characteristic of RVF and the public good nature of vaccine development render the envisaged LSD RVF 2-in-1 vaccine a good case study for economic analysis in this special issue.

RVF is a viral zoonotic disease of livestock, mostly affecting cattle and small ruminants (sheep and goats), and is considered a disease of economic importance although RVF outbreaks are sporadic in nature with inter-epidemic periods of 5 to 10 years. This serious disease also can affect humans[1], even causing death in isolated cases. Since its first occurrence in 1950, South Africa has experienced three major epidemics that affected an extensive area of the country in the years 1950–1951, 1974–1976 and 2010–2011 (Pienaar & Thompson, 2013). Several cases of RVF in humans, as well as mortalities, were also reported during the 2009/10 outbreaks. In livestock, outbreaks are characterised by the so-called "abortion storms", where nearly all gestating animals in affected herds abort. Mortality in young lambs is high (90–100%), and animals usually die within 2–3 days of exposure. Adult sheep are less susceptible, with 10–30 per cent mortality. In pregnant ewes, abortion rates vary from 5 per cent to almost 100 per cent in different outbreaks and different contexts. Meanwhile, abortion rates in cattle are usually less than 10 per cent and mortality ranges between 5 and 10 per cent. In calves, mortality rate may be as high as 70 per cent (Centre for Food Security and Public Health, 2015).

On the other hand, LSD is an acute infectious disease of cattle, which is characterised by high fever and multiple circumscribed skin nodules (DAFF, 2015). The disease occurs widely throughout South Africa and especially in autumn (Agribenchmark, 2012). Up to 45 per cent of the herd could be infected and the mortality rate may reach 10 per cent (DAFF, 2015). The dairy industry views LSD as a disease of economic importance as it can result into milk losses of up to 50 per cent (Hunter & Wallace, 2001).

In South Africa, RVF and LSD are classified as notifiable diseases under the Animal Diseases Act (1984) (Act No. 35). Currently, vaccination is the only recommended viable means of control as there is no specific treatment for both diseases. Given that both LSD and RVF are notifiable diseases, state veterinary services should be notified of outbreaks, however it remains the responsibility of the farmers to vaccinate their livestock at their own expense (DAFF, n.d.).

Given the importance of vaccines as a viable strategy to control both diseases, the study seeks to evaluate the costs and benefits of the envisaged LSD RVF 2-in-1 vaccine under various scenarios on dairy production in South Africa. Although RVF affects humans, the analysis of the paper has excluded the human dimension of the disease and focused only on the animal facets of both diseases. Therefore, the estimated costs and benefits are conservative.

2. Overview of publicly funded veterinary vaccine development in South Africa and development of the LSD-RVF 2-in-1 vaccine

The Agricultural Research Council (ARC)'s Ondersterpoort Veterinary Institute (now known as Ondersterpoort Veterinary Research (OVR)) conducts most publicly funded research on veterinary vaccines in South Africa. Established in 1899 the OVR has been credited over the years with successful development of a number of livestock vaccines, which include those for prevention of Bluetongue, Foot and Mouth Disease and Heartwater. Vaccines developed by the OVR are predominantly manufactured by Onderstepoort Biological Products (OBP), which is also state-owned. OBP is responsible for process development, stability studies, master seed stock development, working stock, commercialisation and dossier registration according to manufacturing standards. The Department of Agriculture, Forestry and Fisheries (DAFF) plays a regulatory role in vaccine development, priming for acceptance and where possible provide funding for R&D and guidance to prioritise the interests of the livestock industry in South Africa. In multidisciplinary vaccine development research projects, socio-economic studies provide information on the potential market for the vaccine, the potential return to investments in livestock vaccine R&D and preferences for vaccine attributes by farmers. The ARC developed the LSD-RVF 2-in-1 vaccine through a collaborative project with some Canadian R&D organisations and partly funded by the Canadian International Development Research Centre (IDRC) and Global Affairs Canada.

Currently, there are monovalent vaccines for prevention of both diseases on the market, with three different types for RVF. This implies that to prevent a livestock herd from both diseases, a farmer will have to buy a vaccine for each disease. While there is a general acceptance of the LSD vaccine by farmers, there is an observed low uptake of RVF vaccines in the market, which could be attributed to the sporadic nature of the disease outbreaks (Mdlulwa, 2015). In addition, during the 2010/11 RVF outbreaks, farmers raised concerns about the safety of the RVF vaccines which they claimed were ineffective and resulted in a storm of abortions (Mdlulwa, 2015). It is envisaged that the LSD RVF 2-in-1 vaccine would have a high adoption rate due to its competitive advantage over the current vaccines. The competitive advantage stems from several factors. Firstly, the relative low production cost of the multivalent vaccine, would make the envisaged vaccine cheaper and affordable to farmers. Secondly, the 2-in-1 vaccine would be more efficient. Currently, a farmer needs to wait for six weeks after vaccination against LSD before vaccinating for RVF, therefore vaccinating for both at the same time would be time efficient. Thirdly, there would be better protection and less risk for RVF outbreaks. Due to the sporadic nature with 5 to 10 years epidemic intervals of RVF, farmers usually do not practise sustained vaccination. This vaccine combines a disease that usually occurs annually (LSD) with RVF and thus should provide better overall levels of protection against RVF outbreaks. Fourth, it is envisaged that the vaccine will not cause abortions and therefore can be used in pregnant animals (Wallace *et al.*, 2006).

3. Economic impact of livestock disease control measures: literature review and framework for analysis

Three major components: people, products and resources underlie the basic conceptual model for economic analyses of livestock diseases (McInerney, 1987 in Dijkhuizen et al., 1995). The decisions people make in pursuit of satisfying their needs drive economic activity (Dijkhuizen *et al.*, 1995). Products are goods and services that satisfy the needs and may be regarded as the outcome of economic activity. Physical factors and services are resources used for generating the products and are thus the starting point of economic activity.

3.1 Framework for analysis

The presence of animal diseases in a given production system reduces productivity (Rushton *et al.*, 1999). Animal diseases can therefore be considered an influence, which affects the process of transforming resources into products, the resources required and products produced (Dijkhuizen *et al.*, 1995). In the presence of disease, livestock producers operate on a lower production function than if there were no disease. The economic benefit from controlling a livestock disease can be measured by taking into account the reduction in economic loss from the disease, considering expenditure levels incurred in disease control (McInerney, 1991). The framework for impact of animal disease on a farming system developed by Rushton et al., (1999) has provided the basis for a number of studies assessing impact of animal disease control measures. Since then, various modifications and adjustments have been made on the framework.

For instance, Bennett (2003) illustrated the physical effect of disease on livestock production in terms of both output losses and input use (Figure 1). Instead of operating at point *D* on the 'attainable health' production function with output level '*Amn*' and input level '*Bmn*', production shifts to a new equilibrium point such as *E* on the 'disease' production function with output level '*A0*' and input level '*B0*' (i.e., where $dA/dB = pA/pB$, where *pB* is the input price and *pA* the output price). Disease may have an effect not only on production but also on input and output prices. Veterinary inputs used to control disease may result in increased livestock production, which can lower output prices under certain market conditions. The shift in equilibrium to point *E* from *D* shows that the price of output has increased in relation to the price of inputs.

Rushton (2009) further elaborated the framework for impact of animal disease on a farming system and posited that overall the economic cost of disease is comprised of disease losses and expenditure (Figure 2). Losses *(L)* are restricted to the reductions in the value of output due to disease. In financial terms, these effects appear as lowered revenues in production. Disease expenditures (*E*) are mostly other financial effects on the input side. Instead of simply enduring disease losses one can choose to incur treatment expenditure to moderate the impact after a disease has struck, or prevention expenditure to forestall its occurrence. Drugs and medication, veterinary services, vaccination, dry cow therapy, etc. are examples, but many other disease control activities are submerged into the complex of good management practice.

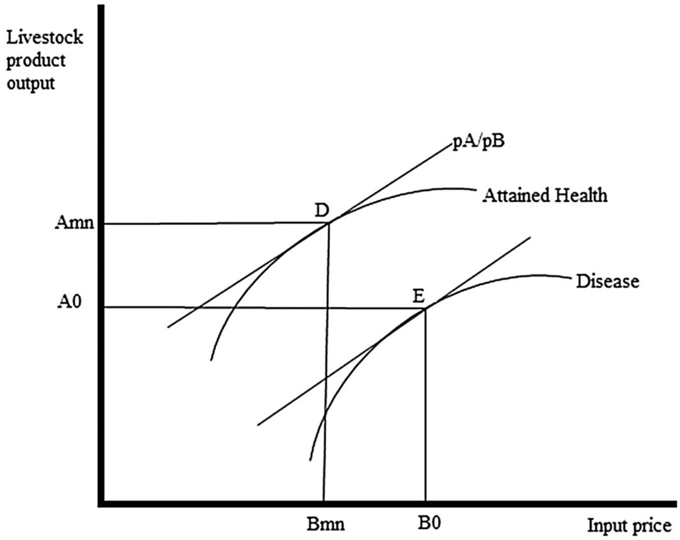

Figure 1. The effect of disease on livestock production. **Source:** Bennett (2003).

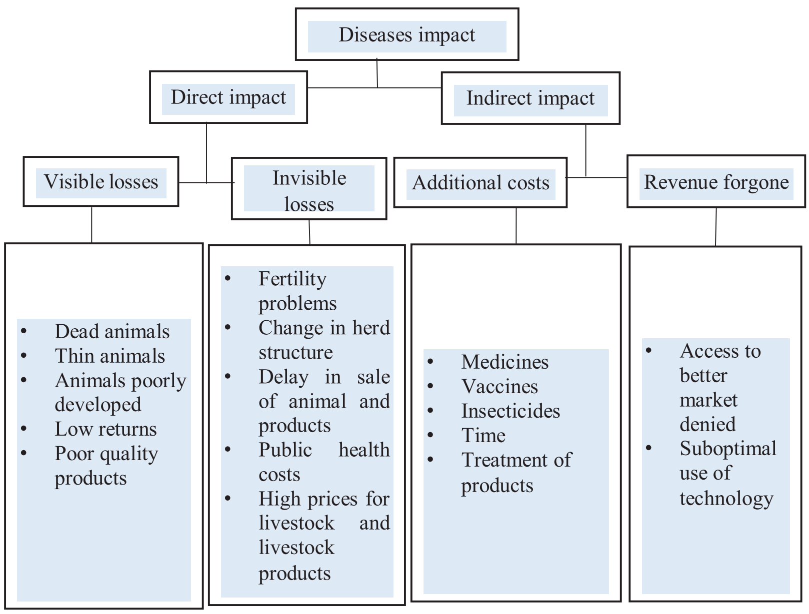

Figure 2. Direct and indirect losses due to animal losses. **Source**: Rushton (2009).

Bennett (2003) summarises seven main economic impacts of disease in livestock. These are:

- A reduction in the level of marketable outputs.
- A reduction in (perceived or actual) output quality.
- A waste (or higher level of use) of inputs.
- Resource costs associated with disease prevention and control.
- Human health costs associated with diseases (zoonosis) or disease control.
- Negative animal welfare impacts (i.e., animal suffering) associated with disease.
- International trade restrictions due to disease and its control.

3.2 Methods used for ex-ante analysis of animal disease control measures

Over the years, various methods have been developed and applied to evaluate benefits and costs for ex-ante research programmes. These methods include cost–benefit analysis (CBA), simulation models and mathematical programming. The two most commonly used methods of CBA and simulation models will be discussed briefly highlighting their advantages and disadvantages as well as their application.

3.2.1 Cost–benefit analysis

CBA is conceivably the best-known method for economic analysis of animal health programmes and projects (FAO, 2016). It can be applied to a proposed project before it is accepted for implementation. The analysis is designed to determine whether the project is worthwhile in economic terms, and hence a justifiable use of investment funds (Harrison, 1996). CBA can provide an effective method to estimate the impact of a disease control measure on a given herd or farm. A major strength of CBA lies in its analysis of costs and benefits associated with an activity and the reduction of those costs and benefits into monetary values to permit comparisons to be made (Ramsay *et al.*, 1999). Nonetheless, a few shortcomings of CBA have been noted. One of the limitations is that it only examines influences for a particular activity in isolation. In addition, price effects are often omitted from the analysis. Consequently extrapolating CBA results from a representative herd to a region or nation is likely to distort costs if widespread diseases would affect supply enough to influence prices (Harrison, 1996).

Regardless of its disadvantages CBA remains the most popular method used for ex- ante analysis of animal disease control measures. Due to the dynamic and risk facets of animal diseases, recent publications such as (Gethmann *et al.*, 2015; Leite *et al.*, 2018) have revealed refined and sophisticated assessments of animal diseases which have thus far combined a form of CBA with epidemiological models of disease spread to assess the costs and benefits of alternative control strategies. The detailed budgets used in CBA are combined with an epidemiological model to conduct simulations of alternative disease mitigation strategies and determine changes in profits or programme cost under different scenarios (Rich *et al.*, 2005). Generally, when there is uncertainty about parameters in the model, CBA can incorporate the implied risk through use of probability distributions rather than point to estimates in the stream of benefits and costs (Ramsay *et al.*, 1999).

A number of international studies (such as in the analyses of Bates et al., 2003; Rich and Winter-Nelson 2007; Gethmann et al., 2015 and Leite et al., 2018), have applied CBA using simulation for estimating costs and benefits of animal control measures. In Bates et al., (2003), the authors applied CBA using a spatial stochastic simulation model to assess relative costs and benefits of vaccination and pre-emptive herd slaughter to control transmission of the foot-and-mouth disease (FMD) virus in California. The baseline strategy was compared with alternative control strategies, followed by sensitivity analysis for greater precision of estimates and assumptions that were inherent in the model. The study revealed that all alternative strategies involving use of vaccination were economically efficient (B/C range of 5.0 to 10.1) and feasible, whereas alternative strategies involving use of slaughter programmes were not economically efficient (B/C range of 0.05 to 0.8) or feasible.

3.2.2 Simulation models

Simulation models are normally applied through scenarios to simulate the likely outcomes associated with different situations. They permit experimentation with a model of a system rather than the system itself (Bennett, 1992). Monte Carlo simulation is the most popular applied method, which includes the use of random numbers applied to probability distributions to simulate the real world. It is the mostly useful approach in animal health as it takes into consideration the dynamic and risk aspect of livestock disease. A stochastic spreadsheet simulation model is one of the highly accessible and commonly used methods to simulate an outbreak of a disease, which integrates specific disease parameters and disease control strategies and herd demographic data (Smith *et al.*, 2007; Häsler *et al.*, 2012; Probst *et al.*, 2013). This model is a flexible tool allowing for simulation of varying temporal and spatial spread scenarios for a disease at the herd levels. The limitation of this model is that it relies a lot on assumptions, which in some cases result in over- or under-estimation of losses. Häsler et al., (2012) used a stochastic spreadsheet model using @Risk software for Excel version 5.0 to conduct economic evaluation of the surveillance and intervention programme for bluetongue virus serotype 8 in Switzerland, both retrospectively (2008–2009) and prospectively (2010–2012).

Bennet (2003) together with the framework by Rushton (2009) and the reviewed studies provided a basis for the approach taken in this study. As indicated earlier CBA is the most appropriate method for ex ante studies and simulations are best suited when there is limited data. In addition, CBA is a useful technique if the analysis is carefully documented and is interpreted in accordance with the assumptions made and data limitations (Ramsay *et al.*, 1999). Recent studies on ex-ante analysis of animal control measures have combined CBA with epidemiological models to estimate the short-term farm level impacts. Given data needs and limitations as well as considering the dynamic and risk facets of livestock disease,this study therefore used simulation analysis as an appropriate technique to evaluate the costs and benefits of adopting the envisaged vaccine on small and large scale dairy operations.

4. Research methodology

4.1 Selection of study areas

Data was collected and captured in the form of farm enterprise budgets. Western Cape and Free State provinces were selected for farm level analysis of the impact of the envisaged LSD RVF 2-in-1 vaccine on large scale and small scale dairy operations, respectively. Selection of the study areas was done purposively based on the availability of enterprise budgets, the prevalence of the two diseases (LSD and RVF) and the number of milk producers in the province. To control bias that could result from purposive sampling, data was verified through literature review, industry consultation and expert opinion. The current enterprise budget for large scale production was obtained from the provincial department of agriculture while for small scale production, where data were not readily available, it was collected through face-to-face interviews and inspection of on-farm records to develop the enterprise budgets. In addition, relevant epidemiological and economic data for LSD and RVF were collected from different sources as detailed in Tables 1 and 2. All collected data was captured in a standard spreadsheet (Microsoft Excel 2016).

4.2 Identification of model herds

The average herd size for dairy farms in South Africa is 300 cattle with herds varying from less than 50 to 1000 (Agribenchmark, 2012). The lactation period varies from 2 to 3 years depending on the type of

Table 1. Parameters used for analysis.

	Farming enterprise	
	Small scale	Large scale
Cattle population	34	550
Number of milked cows	30	460
Mortality rate on calves	40%	12%
Number of bull calves sold	60%	60%
Number of pregnant heifers sold	53%	53%
Average milk production per cow on a yearly basis	12 litres/day	16 litres/day
Lactation period	300 days	300 days
Number of lactations before culling	2.3	3

Source: Milk, 2017; WC DoA, 2016; Nowers *et al.*, 2013; Scholtz and Grobler, 2009; KZN DoA, n.d.; Scholtz and Bester, n.d.

Table 2. Input data used to estimate the impact of vaccination.

Direct and indirect impacts of:	Scenario	Distribution	Source
LSD morbidity	Without vaccine With vaccine	Pert (0.15, 0.3, 0.45) Pert (0.05, 0.1, 0.15)	World Organisation for Animal Health (2017) and Coetzer and Tuppurainen (2004).
Abortion due to LSD outbreak	Without vaccine With vaccine	Pert (0.03, 0.05, 0.07) Pert (0.01, 0.02, 0.03)	Abdulqa et al., (2016); World Organisation for Animal Health (2017) and Coetzer and Tuppurainen (2004).
Mortality on neonatal animals due to LSD outbreak	Without vaccine With vaccine	Pert (0.03, 0.06, 0.1) Pert (0.01, 0.02, 0.03)	Abdulqa et al., (2016); Iowa State University (2008); Abera et al., (2015) and DAFF (2015).
Decrease in milk production due to LSD outbreak	Without vaccine With vaccine	Pert (0.17, 0.34, 0.50) Pert (0.05, 0.12, 0.17)	Hunter and Wallace (2001).
No. of days for temporal milk reduction		Pert (80, 90, 100)	Assumed
Mortality (neonatal animals) due to RVF outbreak	Without vaccine With vaccine	Pert (0.05, 0.08, 0.1) Pert (0.01, 0.03, 0.05)	Centre for Food Security and Public Health (2015).
Mortality (calves) due to RVF outbreak	Without vaccine With vaccine	Pert (0.23, 0.46, 0.70) Pert (0.08, 0.15, 0.23)	
Abortions due to RVF outbreak	Without vaccine With vaccine	Pert (0.05, 0.08, 0.1) Pert (0.01, 0.03, 0.05)	
Milk yield (L)SH		Pert (9, 12, 15)	Milk SA (2017).
Milk yield (L)LS		Pert (12, 16, 20)	
Price of vaccine/50ml doses (R)		Pert (500, 550, 600)	Vaccine developers
Data			**Source**
Dairy enterprise budgets	Small scale farmers: Primary data		Field survey conducted in Thabo Mofutsanyane District, Free State, (2017).
	Large scale farmers: Secondary data		WC DoA (2016).

Notes: 'Pert' denotes a pert distribution with minimum, most likely and maximum values in brackets. The values in brackets were used to estimate the gross income under various scenarios.

breed. Cows normally give birth when they are 2 or 3 years old (Scholtz & Grobler, 2009). The inter-calving period is 380 days with 300 days of lactation. Average annual milk production per cow was estimated at 15 litres per day. Gross margin analysis was conducted on a herd size of 460 Jersey milking cows and 30 mixed dairy breeds for large scale and small scale operations, respectively (Table 1).

4.3 Simulation

Simulation through creation of two scenarios was performed to quantify the impact of both diseases and the related vaccine cost (Table 2). Two scenarios were set:

Scenario 1: Outbreak where farmers vaccinated with the envisaged vaccine.

Scenario 2: Outbreak where farmers did not vaccinate their herds.

During an outbreak, outputs and variable costs might change due to morbidity, mortality, reduced milk yield and veterinary expenses (Bates *et al.*, 2003; Gerthman *et al.*, 2015). Interactions with vaccine developers suggested that the envisaged vaccine does not guarantee full protection; hence simulations were done at a protection level of 50–90 per cent. Subsequently, the minimum impact of the disease under the "no vaccination scenario" was assumed to be the maximum impact under the "with vaccine scenario". Although there is no specific treatment for both diseases, farmers indicated that during an outbreak they usually apply antibiotics to manage and control the outbreak. Hence, in a scenario when there is an outbreak and the farmers did not vaccinate, up to two veterinary visits were integrated in the enterprise budgets and use of antibiotics was doubled. The study focused mainly on animal health, hence only veterinary visits and treatment costs were varied (Bates *et al.*, 2003; Gerthman *et al.*, 2015) while other variable costs were not changed.

Taking into consideration the development and manufacturing costs, the vaccine developers estimated the cost of vaccine to be between R400 and R600 at R10 per animal. To evaluate the economic impact of the envisaged vaccine, empirical distributions were used on a stochastic spreadsheet model that was developed for the economic analyses using @Risk software for Excel version 7.5 (Palisade Corporation, Newfield, NY, USA). Pert, triang and normal distributions were used to model the costs, revenue and expert opinion. After all uncertain data were integrated as distributions the model was run with 30 000 iterations.

Partial budgeting using gross margin analysis was used to estimate the net benefits of vaccination. The first step involved estimation of the costs of diseases. These included reduced milk yields, high mortality rate, abortions as well as delay/reduction in selling live animals. The analysis did not include fixed costs (e.g., property rates and electricity) since they are long-term costs and are not influenced by a diseases outbreak or the control strategy chosen. Hence, the focus was on the total variable costs (TVC) such as purchased feed, veterinary costs, treatment costs dips and doses, etc. as they have a direct input on production (Gethmann *et al*., 2015).

The second step involved the determination of the gross income for each enterprise. The total gross income (TGI) for dairy:

$$TGI = TVM + S \tag{1}$$

where *TVM* is the product of price of milk per litre multiply by the quantity of milk produced and *S* is the sum of revenue from selling live animals (heifers, steers, bull calves, cull cows).

The third step involved the estimation of the gross margin (GM):

$$GM = TGI - TVC \tag{2}$$

4.4 Evaluating the costs and benefits of vaccination

A CBA was performed to evaluate whether adopting the envisaged vaccine would be economically worthwhile for farmers. This was achieved through evaluation of three economic performance indicators: Net present value (NPV), internal rate of return (IRR) and benefit–cost ratio (BCR). Assuming no major disruptions on operational and farming activities, and given the inter-epidemic intervals of 5 to 10 years for RVF outbreaks (Pienaar & Thompson, 2013), a 15-year discounted cash flow was simulated to illustrate the impact of RVF outbreaks and the profitability of vaccination in a herd. Simulation of the cash flows was done on the developed enterprise budgets using the @Risk built-in discounted cash flow model with changing growth rates.

The simulation process involved selection of appropriate discount and annual growth rates as well as a standard deviation. One of the best proxies for the discount rate is the average yield on bonds issued by the government employer (Bui & Randazzo, 2015). The average South African treasury bond yield over the 1993–2018 period is 10.76 per cent (FRED, 2018), hence for analysis, this study adopted a 10 per cent discount rate. Since farm-specific growth rates are not constant over time, growth domestic product (GDP) rate was used. The GDP rate in South Africa averaged 2.82 per cent from 1993 until 2018 (Tradingeconomics, 2018), hence use of the 3 per cent annual growth rate. There is a risk that due to other factors farmers may not yield the expected returns from adopting the envisaged vaccine, so a market risk premium was used as a proxy for standard deviation. A market risk premium is the premium that investors demand for investing in an average risk investment, relative to the risk free rate. Thus, based on South Africa's 2016 market risk premium, a 6 per cent standard deviation was adopted (Fernandez *et al*., 2016).

Interaction with farmers revealed that during a disease outbreak, they normally do not bring in new animals until they are confident that the disease is cleared. Subsequently, this paper did not make provision of replacement costs for adult cows (culled and dead), instead, for replacement, a reduction was made on the number of pregnant and in-calf heifers sold. After applying the normal production parameters, using RVF epidemiological data, mortality was imposed on pregnant heifers and this had an impact on the number of pregnant and in- calf heifers sold. The number of bull calves sold was impacted by the number of cows aborted after considering the normal production parameters. Similar assumptions were used for LSD impacts. Milk production losses were determined by considering the number of cows aborted and the temporal milk reduction suggested by the LSD epidemiological data.

The difference between gross margins of the enterprise budget in an event of an outbreak without the envisaged vaccine, and when there is an outbreak with vaccination was used to determine the net benefits and costs of vaccination.

The net benefit was estimated using the following formula:

$$NB = \sum_{t=0}^{t} B_t - C_t \tag{3}$$

where *NB* stands for net benefit, *B* for the difference in the benefit, *C* for difference in the costs and *t* for time (years).

Net present value was then determined to estimate the potential change in farmer's capital because of adopting the envisaged vaccine. This was done to also account for time value of money. NPV was estimated using the following formula:

$$NPV = \sum_{t=1}^{n} DB - \sum_{t=1}^{n} DC \tag{4}$$

where *DB* is the discounted benefit and *DC* represents the discounted cost.

The profitability of adopting the envisaged vaccine was assessed in terms of the rate of return, using the formula:

$$\sum_{t=1}^{n} DB = \sum_{t=1}^{n} DC \tag{5}$$

A benefit–cost ratio (BCR) was used to determine whether the amount of money made through adopting the envisaged vaccine would be greater than the costs incurred in adopting it. A BCR >1 was interpreted to indicate the vaccine strategy was economically efficient.

The formula used for BCR:

$$\frac{\sum_{t=1}^{n} DB}{\sum_{t=1}^{n} DC} \tag{6}$$

Sensitivity analysis has been advocated as one of the powerful decision-analytic techniques in determining the significance of targeted inputs on the depended variable (Dijkhuizen and Morris, 1997). Following Bates et al., (2003), Häsler et al., (2012) and Probst et al., (2013) this study conducted a sensitivity analysis to determine the impact of increased vaccine price on benefits of vaccination. Assuming all other factors to be constant, the cost of vaccination per animal was increased by 30 per cent to determine its impact on the results.

5. Results and discussion

5.1 Gross margin analysis

Results of the gross margins under vaccine strategy confirmed that vaccination yields higher benefits when compared to non-vaccination. The reliability of the analysis was confirmed by the positive results of the sensitivity analysis. The cost of the vaccine would have to increase substantially above the original estimated cost of R10/cow for the vaccination strategy to be unfavourable. Similar findings were reported by Bates et al., (2003). Although the increase in cost of the vaccine decreased the gross income this did not change the benefits of vaccination. Farmers still obtained high returns when vaccinating their herds using the envisaged vaccine. Simulation results revealed that adoption of the LSD RVF 2-in-1 vaccine would be comparatively cheaper for farmers that are

Table 3. Changes in gross margin under with and without vaccine scenarios.

	Small scale		Large scale	
Changes in gross margin (R) due to:	Without vaccine	With vaccine	Without vaccine	With vaccine
LSD outbreak	149 582	163 144	2 924 823	5 256 577
RVF outbreak	116 631	140 228	4 001 232	5 215 107

currently buying two different vaccines for prevention of both diseases. The proposed price of the envisaged vaccine seems to be 50 per cent cheaper than the combined vaccine price of the two diseases, currently available in the market. In addition to the reduced price, extra benefits will be realised in terms of reduced labour costs and time for vaccination, once off withdrawal period from milk production, as well as reduced expenditure in terms of treatment costs such as immune boosters and antibiotics. The results also showed that in the absence of the vaccine during an outbreak of any of the two diseases, the dairy industry would experience immediate production losses and related impacts. For both large scale and small scale dairy farmers, direct impacts of the disease in the no vaccine scenario were on reduced milk yield fuelled by abortions, followed by mortality, especially of calves and neo-natal animals. A look at the impact of a RVF outbreak alone revealed a mean total gross margin of R140 228 and R116 631 for small scale farmers and R5 215 107 and R4 001 233 for large scale operations with vaccine and without a vaccine, respectively (Table 3).

Overall, the benefits from the vaccines scenario would be higher than without vaccination if farmers adopted the envisaged LSD RVF 2-in-1 vaccine. Bates et al., (2003) reported similar findings where they concluded that supplemental strategies that involved the use of vaccination were considered economically efficient. Hence, disease outbreaks and the necessary measures to manage and control them could change the profitability of the whole production chain.

5.2 Cost–benefit analysis

The net present value (NPV) and internal rate of return (IRR) were positive and the benefit-cost ratio (BCR) were greater than 1, indicating the positive impact of vaccination. In a scenario where farmers would adopt the LSD RVF 2-in-1 vaccine with 90 per cent protection level, there is probability (0.10) that the revenues would range between −R22–R153 million and R600 000–R1million for large scale and small scale operations, respectively (Figure 3). It is noteworthy to acknowledge that losses could be incurred despite the vaccination as the envisaged vaccine does not guarantee full protection. The severity of the outbreak and the implemented vaccine coverage by the farmer will be among the key factors that will influence the scale of losses. Results showed that it would take 2 years and 1 year for a small scale farmer and large scale farmer, respectively, to recover costs in a scenario where they used the LSD RVF 2-in-1 vaccine and were struck by an RVF outbreak 5 years after an LSD outbreak. The NPV was R830 641 and R13 954 073 while IRR was 34.7 per cent and 33.2 per cent for small scale and large scale operation, respectively. In a scenario where a farmer only vaccinated for LSD, which is a common practice, and was struck by RVF 5 years after an LSD outbreak, it would take more than four years for both small scale and large scale operations to recover costs and operate at full production level. The NPV was R724 598 and R13 540 620 while IRR was 32 per cent and 32.9 per cent for small scale and large scale operation, respectively. The results of the IRR compare well with those of other studies that evaluated the impact of R&D on livestock research, Townsend and Thirtle (2001) reported rate of returns on investment of 18 to 35 per cent.

The innovation of developing a multivalent vaccine for prevention of a common disease such as LSD and RVF, which is a sporadic disease, proved to be beneficial for farmers when compared with a situation where farmers only vaccinated for LSD (Table 4). Simulation results showed that, *ceteris paribus*, it would take a longer period for farmers to recover after an RVF outbreak compared with a LSD epidemic. In a state where farmers vaccinated for LSD only and were later struck by an RVF

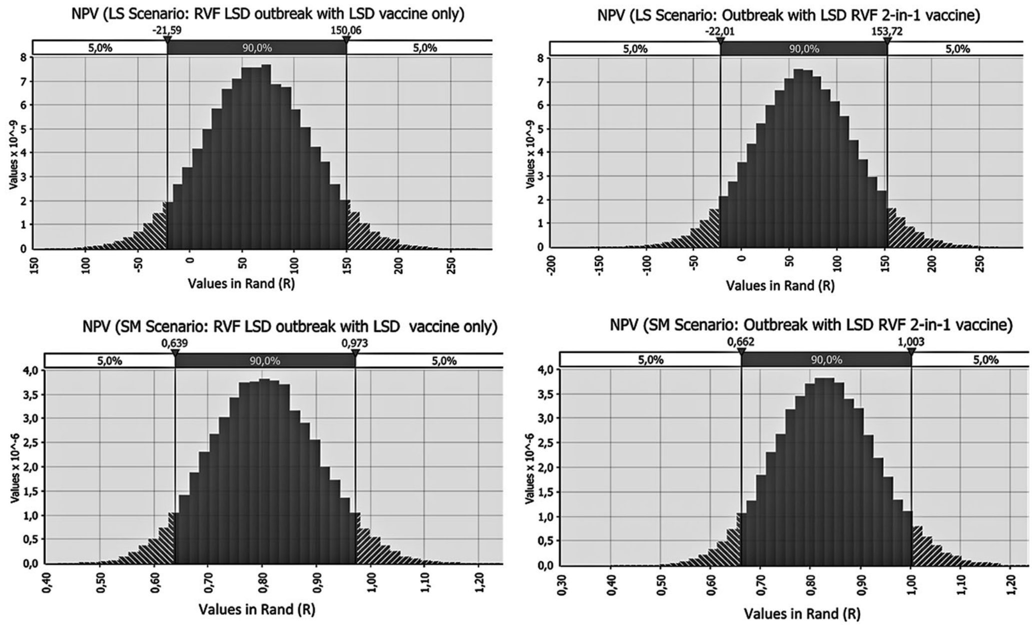

Figure 3. Profitability of using the LSD RVF 2-in-1 vaccine.

outbreak, results revealed that it would take small scale operations between 5 to 8 years to recover while large scale operations could recover within 5 years.

Further analysis of the impact of vaccine at different levels of protection from 80 per cent to 50 per cent, revealed significant variations in the profitability of the enterprise and such variants were also observed in returns on investment (Table 5). Results revealed that in a scenario where a farmer would have used the LSD RVF 2-in-1 vaccine and were struck by an RVF outbreak 5 years after an LSD epidemic, NPVs would be reduced from R10 272 658 to R4 807 930 and from R571 751 to R268 713 for large and small scale production, respectively. The simulated IRR decreased from 28.8 per cent to 20.7 per cent and from 21.9 per cent to 20.9 per cent from large and small scale production, respectively.

The present analysis only considered directly and indirectly measurable costs and benefits of vaccination. The direct benefits of vaccination included reduced number of mortalities, abortions and milk losses and these resulted into improved revenues. However, in adopting the vaccine strategy an indirect cost was incurred in the form of additional costs of vaccination. The additional cost associated with adoption of the envisaged vaccine included only the purchase price as farmers administered the vaccine on their own. The packaging (50 ml bottle) of the vaccine could make it less expensive for small scale farmers as the majority of them keep less than 20 cattle. Subsequently, due to the wide variation in operation between the two types of farmers, there is also a variation in net benefits and benefit–cost ratios. While this difference in the vaccine cost may discourage adoption by small scale farmers, if animals are not vaccinated, the farmer may save money on veterinary costs but in the long run the gross income could be substantially lowered (Gethmann *et al.*, 2015).

6. Conclusion and recommendation

This study demonstrates the importance of economic impact assessment for R&D interventions in control and prevention of livestock disease. Using the framework for economic analysis of impacts of livestock disease adapted from notable work by McInerney (1987), Dijkhuizen et al., (1995), Bennett (2003) and Rushton (2009), the study builds up a case for *ex ante* impact analysis of an envisaged livestock vaccine development which can be applied to other contexts in South Africa and

Table 4. Summary of simulation results under different vaccine scenarios.

Changes in profitability per herd as a result of RVF outbreak		Small scale: LSD vaccine only	Small scale: LSD RVF 2 in 1 vaccine	Large scale: LSD vaccine only	Large scale: LSD RVF 2 in 1 vaccine
1 year after LSD outbreak	Mean NPV (R)	738 850	821 162	62 185 785	66 404 860
	IRR (%)	28.8	30.7	31.8	33.1
	Period to recover (years)	8	5	5	3
2 years after LSD outbreak	Mean NPV (R)	746 454	812 560	62 152 424	65 538 433
	IRR (%)	33.1	34.1	32	32.9
	Period to recover (years)	8	5	5	2
3 years after LSD outbreak	Mean NPV (R)	760 346	812 064	62 507 979	65 154 690
	IRR (%)	33.6	34.2	32.3	32.9
	Period to recover (years)	7	5	5	2
4 years after LSD outbreak	Mean NPV (R)	779 601	818 408	63 244 674	65 216 043
	IRR (%)	30.3	34.9	32.6	33
	Period to recover (years)	6	3	5	1
5 years after LSD outbreak	Mean NPV (R)	803 344	830 658	64 252 698	65 648 757
	IRR (%)	34.4	34.5	32.9	33.2
	Period to recover (years)	5	3	5	2

Table 5. Summary of simulation results under different vaccine scenarios and protection levels.

Changes in profitability per herd as a result of RVF outbreak		Protection level of the envisaged vaccine (%)			
		0.8	0.7	0.6	0.5
Small scale production					
2 years after LSD outbreak	NPV (R)	558 492	459 136	359 781	260 426
	IRR (%)	28.6	26.2	23.5	20.5
5 years after LSD outbreak	NPV (R)	571 751	470 738	369 725	268 713
	IRR (%)	29.1	26.6	23.9	20.9
Large scale production					
2 years after LSD outbreak	NPV (R)	10 272 658	8 451 082	6 629 505	4 807 930
	IRR (%)	28.6	26.2	23.5	20.5
5 years after LSD outbreak	NPV (R)	10 303 268	8 477 866	6 652 463	4 827 061
	IRR (%)	28.8	26.4	23.7	20.7

other developing countries. The specific case study considered involves analysing the costs and benefits of alternative scenarios for control of LSD and RVF with new generation vaccines. The simulation results of the gross margins under vaccine strategy confirm that vaccination yields higher benefits when compared with non-vaccination. The reliability of the analysis was confirmed by the positive results of the sensitivity analysis. The cost of the vaccine would have to increase substantially above the original estimated cost for the vaccination strategy to be unfavourable. Furthermore, adoption of the LSD RVF 2-in-1 vaccine could be beneficial and profitable as well as comparatively cheaper for farmers that are currently buying two different vaccines for prevention of both diseases. Results have also shown that low protection levels of the vaccine will yield lesser benefits and that it would take longer for farmers with a small-scale operation to recover from disease outbreaks when compared with large-scale operations. Continuous awareness about the importance of vaccines particularly for small scale farmers is recommended as vaccination can ensure protection of animals from diseases, thereby increasing productivity, reducing the costs of production and increasing incomes and food security for rural households.

Analysing the economics of livestock vaccines can provide decision makers with solid economic arguments regarding the potential benefits of investing in the up-scaling and roll out of the vaccine. The results suggest that given the potential of vaccines to mitigate production losses, efforts to facilitate commercialisation of livestock production in the small scale agricultural sector, and maintenance of current large scale production should include programmes to make vaccines more accessible to farmers.

This study has only focussed on two diseases and one type of vaccine. From a methodological point of view, the study has made use of approaches developed elsewhere and applied them in the South African context to provide evidence of benefits attributed to research and development of livestock vaccines. Although this analytical model does not signify all possible situations during the disease outbreak and implementation of the necessary control measures, the model herds and the epidemiological sceneries used in the analysis are reasonable and supported by existing literature. The stochastic simulations, expressing results as probability distributions, makes it possible to include risk concerns in the process of making policy decisions. This approach can be extended to evaluate the costs of other research and development interventions in the livestock industry. Such work, however, requires multidisciplinary collaboration with animal health specialists that have an understanding of different diseases and their dynamics. Scope exists for more *ex ante* studies to inform policy makers, farmers, and commercial manufacturers of livestock vaccines on the benefits and costs of technologies being developed through research in the livestock sector.

Acknowledgements

The majority of the work reported in this paper is funded by the Canadian IDRC-CIDA from their CIFSRF grant and is supported by the respective research institutions to which the authors belong.

Note

1. Humans can contract RVF from infected animals through handling of tissues during slaughtering or butchering, assisting with births, conducting veterinary procedures, or from the disposal of carcasses or foetuses (Pienaar & Thompson, 2013).

References

Abdulqa, H.Y., Rahman, H.S., Dyary, H.O. and Othman H.H. 2016. Lumpy skin disease. *Reproductive Immunology* 1(4): 25 (1–6).

Abera, Z., Degefu, H., Gari, G. and Ayana, Z. 2015. Review on epidemiology and economic importance of lumpy skin disease. *International Journal of Basic and Applied Virology* 4: 8–21.

Animal Diseases Act 1984 (Act No. 35). Department of Agriculture, Forestry and Fisheries, Pretoria, South Africa.

Agribenchmark. 2012. *Dairy production in South Africa – impressions*. Country Report 2012/1. http://www.agribenchmark.org/fileadmin/Dateiablage/BDairy/Country_Report/12_country_information_SA.pdf (accessed 3 November 2017).

Bates, T.W., Carpenter, T.E. and Thurmond, M.C. 2003. Benefit–cost analysis of vaccination and pre-emptive slaughter as a means of eradicating foot-and-mouth disease. *American Journal of Veterinary Research* 64: 805–812.

Bayiyana, I., Ekere, W. and Mugisha, J. 2012. *Economic analysis of transboundary animal disease control in Ntungamo and Rakai districts in Uganda*. Third RUFORUM Biennial Meeting 24–28 September 2012, Entebbe, Uganda.

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: 63–76.

Bennett, R.M. 2003. The "direct costs" of livestock diseases: the development of a system of models for the analysis of 30 endemic livestock diseases in Great Britain. *Journal of Agricultural Economics* 54(1): 55–71.

Bui, T. and Randazzo, A. 2015. *Why discount rates should reflect liabilities: Best practices for setting public sector pension fund discount rates*. Reason Foundation Policy Brief No. 130. Los Angeles, United States of America. https://reason.org/wp-content/uploads/files/pension_discount_rates_best_practices.pdf (accessed 25 July 2018).

Centre for Food Security and Public Health (2015). *Rift Valley Fever: Infectious enzootic hepatitis of sheep and cattle*. Iowa State University, College of Veterinary Medicine, Iowa. https://www.semanticscholar.org/paper/Rift-Valley-Fever-Infectious-Enzootic-Hepatitis-of/51b5903612d598626f551bd19f4813cc92e452c8 (accessed 4 March 2016).

Coetzer, J.A.W. and Tuppurainen, E. 2004. *The detection of lumpy skin disease virus in samples of experimentally infected cattle using different diagnostic techniques*. http://repository.up.ac.za/bitstream/handle/2263/23004/00dissertation.pdf?sequence = 1 (accessed 4 March 2016).

DAFF (Department of Agriculture, Forestry and Fisheries). 2015. *Lumpy skin disease, a disease of socio-economic impact*. http://www.nda.agric.za/doaDev/sideMenu/Food%20Import%20&%20Export%20Standard/docs/Lumpy-skin%20disease.pdf (accessed 15 May 2017).

DAFF (Department of Agriculture, Forestry and Fisheries). (n.d.) Controlled and notifiable animal diseases. http://www.nda.agric.za (accessed 16 February 2018).

Dijkhuizen A.A., Huirne R.B.M. and Jalvingh A.W. 1995. Economic analysis of animal diseases and their control. *Preventive Veterinary Medicine* 25 (2): 135–149.

Dijkhuizen, A.A. and Morris, R.S., 1997. *Animal health economics: principles and applications*. University of Sydney: The Postgraduate Foundation Publisher, 60–67.

FAO (Food and Agricultural Organisation of United Nations). 2016. *Economic analysis of animal diseases.* FAO Animal Production and Health Guidelines. No. 18. Rome, Italy.

Fernandez, P., Ortiz, A. and FernandezAcin, I. 2016. *Market risk premium used in 71 countries in 2016: a survey with 6,932 answers*. IESE Business School. University of Navarra, Madrid, Spain.

FRED (Federal Reserve Bank of St Louis). 2018. *Long-term government bond yields 10-year: main (including benchmark for South Africa) 1993-01-01 to 2017-01-01*. https://fred.stlouisfed.org/series/IRLTLT01ZAM156N#0. Economic Research, One Federal Reserve Bank Plaza, St Louis, MO 63102.

Gethmann, J., Probst, C., Sauter-Louis, C. and Conraths, F.J. 2015. Economic analysis of animal disease outbreaks- BSE and Bluetongue diseases as examples. *Berliner und Munchener Tierarztliche Wochenschrift* 128(11–12): 478–482.

Harrison, S.R. 1996. *Cost benefit analysis with applications to animal health programmes: Basics of CBA*. Working Paper No. 18. School of Economics, The University of Queensland, Australia. http://ageconsearch.umn.edu/record/164568/files/WP18.pdf (accessed on 15 March 2018).

Häsler, B., Howe, K.S., Di Labio, E., Schwermer, H. and Stärk, K.D.C. 2012. Economic evaluation of the surveillance and intervention programme for bluetongue virus serotype 8 in Switzerland. *Preventive Veterinary Medicine* 103: 93–111.

Hunter, P. and Wallace, D. 2001. Lumpy skin disease in Southern Africa: a review of the disease and aspects of control. *Journal of the South African Veterinary Association* 72(2): 68–71.

Iowa State University. 2008. *Lumpy skin disease*. Centre for Food Security and Public Health Technical Factsheets. 84. http://lib.dr.iastate.edu/cfsph_factsheets/84 (accessed 4 March 2016).

KZN DoA (Kwa Zulu Natal Department of Agriculture). (n.d.) *Dairying in Kwazulu-Natal. Dairy herd structure/dairy herd dynamics*. https://www.kzndard.gov.za/images/Documents/Resource_Centre/Guideline_Documents/Production_Guidelines/Dairying_in_KwaZulu-Natal/Dairy%20Herd%20Structure%20-%20Dairy%20Herd%20Dynamics.pdf (accessed 12 May 2018).

Leite, B.M., Lobo, J.R., Ruas, J.R.M, Ferreira, F., Geeverghese, Freitas, M.L. and Goncalves, V.S. P. 2018. Economic analysis of the policy for accreditation of dairy farms free of bovine brucellosis and tuberculosis: Challenges for small and large producers in Brazil. *Journal of Agricultural Economics* 69(1): 262–276.

Mclnerney, J. P. 1987. An economist's approach to estimating disease losses. In: K.S. Howe and J.P. Mclnerney (Eds), Disease in farm livestock: Economics and policy. Commission of EEC, Luxembourg: 25-60.

Mclnerney, J.P. 1991. *Cost–benefit analysis of livestock disease: A simplified look at its economic foundations.* Proceedings of the Sixth International Symposium on Veterinary Epidemiology and Economics.

Mdlulwa, Z. 2015. The socio-economic impact of the 2008–2010 Rift Valley fever outbreaks on livestock farmers in South Africa. MSc. Agric. Dissertation. University of Pretoria, Pretoria.

Milk SA, 2017. *Lacto data.* 20(1): 1–32. May. http://www.mpo.co.za/ Information/lactodata (accessed 20 May 2016).

Nowers, C.B., Nobumba, L.M. and Welgemoed, J. 2013. Reproduction and production envisaged of communal cattle on sourveld in the Eastern Cape Province, South Africa. *Application of Animal Husbandry and Rural Development* 6: 48–54.

Otte, M.J., Nugent, R. and McLeod, A. 2004. *Transboundary animal diseases: assessment of socio-economic impacts and institutional response*. Livestock Policy Discussion Paper No. 9. Livestock Information and Policy Branch, AGAL. Food and Agricultural Organisation of United Nations, Rome, Italy.

Perry, B.D., Randolph, T.F., Mcdermott, J.J., Sones, K.R. and Thornton, P.K. 2002. *Investing in animal health research to alleviate poverty*. Nairobi, Kenya: International Livestock Research Institute.

Pienaar, N.J. and Thompson, P.N. 2013. Temporal and spatial history of Rift Valley fever in South Africa: 1950 to 2011. *Ondersterpoort Journal of Veterinary Research* 80(1.384): 1–13.

Probst, C., Gethmann, J.M., Heuser, R., Niemann, H. and Conraths, F.J.2013. Direct costs of Bovine Spongiform Encephalophy control measures in Germany. *Zoonoses and Public Health* 60: 577–595.

Ramsay, G.C., Philip, P. and Riethmuller, P.1999.The economic implications of animal diseases and disease control at the national level. *Scientific and Technical Review of the Office International des Epizooties* 18(2): 343–356.

Rich, K.M., Miller, G.Y. and Winter-Nelson, A. 2005. A Review of Economic tools for the assessment of animal disease outbreaks. *Scientific and Technical Review of the Office International des Epizooties* 24(3): 833–845.

Rich, K.M and Winter-Nelson, A. 2007. An integrated epidemiological-economic analysis of foot and mouth disease: Applications to the southern cone of South America. *American Journal of Agricultural Economics* 89: 682–697.

Roth, J.A. 2011. Veterinary vaccines and their importance to animal health and public health. *Procedia in Vaccinology*. 5: 127–136.

Rushton, J., Thornton, P.K. and Otte, M.J. 1999. Methods of economic impact assessment. *Scientific and Technical Review of the Office International des Epizooties* 18 (2): 315–342.

Rushton, J. 2009. *An overview of analysis of costs and benefits of government control policy options*. Royal Veterinary College and Leverhulme Centre for Integrative Research on Agriculture and Health, United Kingdom.

Scholtz, M.M. and Bester, J. (n.d.) *Off-take and production statistics in the different South African cattle sectors: Results of a structured survey*. Paper presented at 43rd Congress of the South African Society of Animal Science.

Scholtz, M.M. and Grobler, S.M. 2009. A systems approach to the South African dairy industry. *South African Journal of Animal Science* 39 (Supplement1): 116–120.

Smith, G.C., Bennett, R., Wilkinson, D. and Cooke, R. 2007. A cost–benefit analysis of culling badgers to control Bovine Tuberculosis. *The Veterinary Journal* 173(2): 302–310.

Townsend, R. and Thirtle, C. 2001. Is livestock research unproductive? Separating health maintenance from improvement research. *Agricultural Economics* 25: 177–189.

Tradingeconomics. 2018. *South Africa GDP growth rate*. https://tradingeconomics.com/south-africa/gdp-growth (accessed on 15 June 2017).

Wallace, D.B., Ellis, C.E., Espach, A., Smith S.J., Greyling, R.R. and Viljoen, G.J. 2006. Protective immune responses induced by different recombinant vaccine regimes to Rift Valley fever. *Vaccine* 24: 7181–7189.

WC DoA (Western Cape Department of Agriculture). 2016. *Large scale Jersey enterprise budget*. George, Western Cape Province, South Africa.

World Organisation for Animal Health. 2017. Lumpy Skin Disease: Aetiology epidemiology diagnosis prevention and control references. OIE, Paris, 21.