THE ECONOMICS OF CONVERTING A SHEEP FARM INTO A SPRINGBUCK *(Antidorcas marsupialis)* RANCH IN GRAAFF-REINET: A SIMULATION ANALYSIS

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ABSTRACT

In Graaff-Reinet, domestic livestock farming and springbuck ranching are similar in that they both rely on the rangeland for their sustainability. However, as a consequence of repeated monotonous domestic livestock farming, resulting in compromised biological productivity and diversity, the rangelands have disintegrated. This, unfortunately, has placed the future sustainability of these rangelands and the livelihoods of the local people in an indeterminate state. In recent years, there has been an increasing interest in springbuck ranching for meat production as an alternative to domestic livestock farming in the area following (a) fears of worsening environmental challenges; (b) declining profitability in commercial domestic livestock farming and; (c) growing calls for the sustainable use of these rangelands for the benefit of future generations. The springbuck has emerged as a credible alternative to utilising the rangelands - as opposed to sheep - because of its promise to addressing the above challenges. This is in an attempt to tap into the multitude of benefits that the springbuck possesses (by virtue of being part of the natural capital of the area) that have a potential towards restoring ecological integrity by extenuating some of the detrimental effects of sheep farming on the rangelands and presenting opportunities for diversifying incomes. Yet, despite the general increase in interest, a resistance towards the uptake of springbuck ranching for meat production exists. The main contention is that springbuck meat production cannot out-perform the economic returns of wool sheep farming. This study attempts to address these concerns by investigating the profitability and economic sustainability of converting a sheep farm into a springbuck ranch in Graaff-Reinet.

The study uses stochastic simulation to estimate the probability distribution of some key output variables, namely: net cash income, ending cash balance, real net worth and the net present value (NPV) in evaluating the profitability of converting a 5 000ha sheep-dominated farm into a springbuck-dominated ranch under three alternative scenarios. The use of stochastic simulation allows for the incorporation of downside risk associated with the production and marketing of wool, mutton and springbuck meat. The study uses stochastic prices and yields to calculate net returns variability. Incorporating scenario analysis helped to evaluate how alternative wool sheep-dominated and springbuck-dominated combinations would perform based on the probable outcomes of different assumptions in the various scenarios. By applying stochastic efficiency with respect to a function (SERF) criterion to the simulated NPVs, this study compares the profitability of alternative scenarios based on various risk aversion coefficients.

The study finds that converting a 5 000ha wool sheep dominated farm into a springbuck dominated ranch could potentially be a more profitable investment than wool sheep farming over a 15 year planning horizon, in Graaff-Reinet. The SERF results indicate that for all scenarios tested, the best strategy of converting a wool sheep dominated farm into a springbuck ranch would be one which comprise a combination of 70% springbuck, 20% mutton and 10% wool production as the likely profitable enterprise mix. Using economic sustainability analysis, the study reveals that because of low costs in springbuck ranching, springbuck meat production enterprises are most likely to be more financially sustainable than wool sheep-dominated enterprises. This suggests that rangeland owners may be better off converting their wool sheep-dominated farms into springbuck-dominated ranches. Thus, as the call for more environmentally benign rangeland utilising economic-ecological systems intensifies, rangeland owners in the Eastern Cape Karoo have a practicable option. At the very least, there exists an option to broaden their incomes whilst promoting ecological restoration with springbuck meat production.

DECLARATION

Except for references specifically indicated in the text, and such help as has been acknowledged, this thesis is wholly my own work and has not been submitted to any other University for Degree purposes.

THULA SIZWE DLAMINI

DECEMBER 2011

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"Trust in the Lord with all your heart,
on your own intelligence rely NOT;
In all your ways be mindful of him,
and he will make straight your paths" –
Proverbs 3: 5-6

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INTRODUCTION

1.1 Introduction

The publication of Acocks' (1953) "Veld types of South Africa" marked a defining moment in thinking on the environment and domestic livestock farming in the Karoo. Subsequent to this, domestic livestock farming has received harsh criticism for its failure to address issues of environmental equity and quality (Milton *et al.*, 1994). Research in the Karoo documents widespread rangeland degradation (Roux, undated; Roux and Vorster, 1983), with clear signs of biological productivity loss (Visser *et al.*, 2004) and to some extent looming dryland degradation/desertification (Dean *et al.*, 1995) owing to an interplay of a variety of other factors as well as more than two centuries of monotonous domestic livestock farming (Roux, undated, Cowling *et al.*, 1986). Although the question of whether the Karoo is in fact expanding (Acocks, 1953) or not is still far from being settled. The recent release of the Millennium Development Goals (MDGs) country report titled "The South Africa I Know, The Home I Understand" cautions that the "degradation of the environment threatens the very basis of sustained economic growth" (SAGI, 2010:97), illustrating that degradation challenges could downplay any meaningful gains in economic and human development in South Africa.

The report underscores the importance of aligning agricultural production with environmental protection (SAGI, 2010), implying the need for prudent and farsighted rangeland utilisation ecological-economic systems that will promote ecological cohesion whilst maintaining the livelihoods of the people who live in these areas. However, despite considerable investment in environmental conservation (DEAT, 1997; SAGI, 2004) and rangelands restoration and reclamation programmes (NDA, 1998), rangelands in the Eastern Cape Karoo (EC Karoo) continue to linger under a cloud of controversy. This is with regard to the identification and perhaps adoption of an ecological-economic system that will promote their sustainable utilisation given the visible environmental effects of monotonous domestic livestock farming. The exploration for alternative and environmentally benign rangeland utilisation ecological-economic systems has not been without challenges.

First, the historical economic significance of the livestock industry, essentially wool sheep farming, has frustrated in a way any attempts aimed at conserving the rangeland by replacing domestic livestock in the area. Secondly, the economic returns in domestic livestock farming intertwined with historical state backing before 1994 have caused it to be an ‘untouchable’ sector, especially in the Karoo, despite its visible effects on the environment and ecology (Beinart, 2003). Because of these factors, traditional interventions aimed at improving environmental health have focused predominantly on how best to improve the productivity of the rangelands without compromising the existence of the very industry that has caused some of those problems. For example, earlier efforts aimed at curbing continued environmental degradation in the EC Karoo, included calls for a reduction in stocking rates to acceptable levels, which are at par with the carrying capacities of such rangelands (Nel and Hill, 2008). Whilst domestic livestock farmers took heed of the calls to reduce stocking rates, few benefits have accrued to the rangeland in terms of reversing actual degradation. This is understandable, as the focus on the stocking rates has missed an important aspect of one of the causes of environmental degradation: the failure of domestic livestock to promote biological diversity (see Donahue, 1999).

Against this backdrop, critics of domestic livestock farming in semi-arid areas have argued vigorously that natural ecosystems will only regain their native biodiversity and biological productivity once they are free of domestic livestock grazing (see Donahue, 1999; Fleischner, 1994; Vavra, 1992). Such authors (Donahue, 1999; Fleischner, 1994) have implicitly suggested that the total removal of livestock is necessary to stimulate their restoration (Curtin, 2002). These studies have recommended that this could be achieved through the production of those species of wild animals (indigenous species) that have coevolved with the ecology in such rangelands, otherwise known as natural capital (Donahue, 1999; Fleischner, 1994; Vavra, 1992). The argument is that wild animals are biologically better adapted to survive harsh arid climatic conditions and could, when used in their native ecosystems, minimise the environmental drawbacks of domestic livestock (Milton *et al.*, 2003). Numerous other studies in the biological sciences have also shown that game animals have a proficiency to reproduce at much higher rates than domestic livestock. For example in the EC Karoo, Skinner *et al.* (1986) identified the springbuck as naturally predisposed to convert plant biomass into saleable meat products much more efficiently than the sheep. Indeed, as Milton *et al.* (2003) opine, the restoration of natural capital in the context of South African rangelands is particularly important as a matter of urgency to tackle continued economic hardships of the rural masses in terms of job creation and maintaining livelihoods.

Consequently, as a result of increasing rangeland degradation owing to continued sheep farming, declining biological productivity and diminishing profits in traditional commercial livestock farming, many sheep farmers have embarked on an explorative search for viable rangeland utilisation economic systems, which could potentially ensure the continued economic sustenance of their enterprises and promote rangeland reclamation whilst producing food. Thus, it is not surprising that one common combination of game and livestock in Graaff-Reinet is sheep and springbuck ranching for meat production. In the meantime, meat production from the springbuck has bourgeoned in the area driven by an increase in demand in overseas markets (Neethling, personal communication; Hoffman, 2003) and to a small degree in the local market as well (Neethling, personal communication). This has further led to renewed interests in springbuck ranching for meat production following earlier warnings that because of poor venison prices, meat production from game animals was most likely to lose its economic impetus (Hoffman *et al.*, 1999). In the past 15 years, for example, meat production from the springbuck has grown from about 20 thousand animals harvested in 1996 to about 30 thousand bucks harvested in 2010 as shown in Table 1.1 (Camdeboo Meat Processors, 2010). The existence of an excellent abattoir in the area with a robust business structure for springbuck meat production has somewhat provided further proof of the potential of springbuck ranching for meat production as an alternative to wool sheep farming.

However, despite its obvious economic potential and benefits on the environment, springbuck ranching for meat production has failed to make it as a practicable alternative ecological-economic system to wool and mutton sheep farming in the area. Even where farmers have tried to take advantage of the economic benefits of the springbuck, it has only been through a combination that favours sheep farming more than it does springbuck meat production. The leading reasons for this include allegations that springbuck ranching cannot outperform the profitability and risk efficiency of sheep farming in the area, the results of which have been a general bias against springbuck ranching as the main ecological-economic system in these rangelands. Moreover, equally true is that for farmers to fully accept springbuck ranching as an alternative ecological-economic system in the area, springbuck ranching for meat production must be a comparatively more profitable and have lesser risks than sheep farming. A risk and profitability analysis of springbuck ranching for meat production is therefore required to determine whether it would be profitable to convert a sheep farm into a springbuck meat production ranch to harness its ecological benefits on the environment.

Table 1.1: Numbers of Springbuck Cropped for Meat Production in Graaff-Reinet

Year	Quantity (animal units)	Average Dressed weight (Kg)	Price/kg (Yearly average) (R)
1996	20 975	19.20	8.00
2001	31 563	15.50	11.00
2009	24 814	14.60	20.00
2010	29 678	14.00	25.50

Source: Camdeboo Meat Processors, Graaff-Reinet.

1.2 Statement of the Problem

According to Krug (2001:4), the perception that public institutions are incapable of safeguarding the adequate provision and conservation of biological biodiversity in natural ecosystems in developing countries is a testimony to the need to develop "new and innovative approaches" to stimulate their conservation and preservation. The idea of restoring biodiversity through the production of natural capital is fast gaining precedence in South Africa's arid to semi-arid rangelands (see Milton *et al.*, 2003). The growth in demand for wildlife meat products in overseas markets (Hoffman, 2003; Hoffman and Wikund, 2005) presents a scope for further innovative approaches to arrest widespread degradation challenges and improve the biological diversity of the rangelands in Graaff-Reinet. Economically speaking, the role of biological diversity in an ecosystem is important for several reasons. Firstly, it increases the mean level of ecosystem services thus improving its productivity (Baumgatner, 2007; Baumgatner and Quaas, 2005); and, secondly, it provides ecological insurance for the continued provision of those ecosystem functions that are the building blocks for some crucial ecological processes thus ensuring ecological stability (Constanza *et al.*, 1997; Baumgatner, 2007). The realisation of these fundamental properties of biodiversity from an economic view makes biodiversity the single most important injection in the production function of natural ecosystems.

However, for biodiversity conservation initiatives to be successful, biodiversity boosting ecological-economic systems must compete with commercial domestic livestock farming economic systems in these areas. Similarly, for domestic livestock farmers to convert their wool sheep farms to springbuck ranches in Graaff-Reinet, meat production from the springbuck must be paying comparatively higher returns than wool sheep farming. In the light of this, it is the expectation of this study that if meat production from the springbuck is a profitable ecological-economic system in Graaff-Reinet, rangeland owners might be more than willing to convert their sheep farms into springbuck ranches to take advantage of both the ecological and economic benefits of springbuck ranching. The effect of this conversion is anticipated to aid in biodiversity restoration and to jump-start the much-needed reclamation of the rangelands. It is, therefore, necessary to determine (a) under what conditions springbuck ranching will compete successfully with sheep farming, and (b) the extent to which production, yield and price risk would affect the profitability of springbuck ranching for meat production. No studies have utilised simulation analysis to investigate the economics of converting from sheep farming to springbuck ranching in South Africa. Given the ecological benefits of springbuck ranching on the rangelands, this study is important in that it will provide valuable insights into the profitability and risk efficiency of converting a wool sheep dominated farm into a springbuck dominated enterprise, in Graaff-Reinet.

1.3 Objectives of the Study

The purpose of this study is to analyse the economic profitability of converting a 5 000ha sheep farm into a springbuck ranch in Graaff-Reinet whilst overtly considering risk. Springbuck ranching differs from sheep farming in that it has the potential to promote the sustainable use of rangelands by stimulating biological diversity and rangelands reclamation and restoration (Skinner *et al.*, 1986). In addition, a springbuck enterprise incurs minimal operational costs and presents an opportunity to landowners to conserve their rangelands whilst earning some income (Skinner *et al.*, 1986). However, since the current dominant rangeland utilisation system in the area is wool and mutton sheep farming, there arises options through which farmers can introduce springbuck ranching, as a medium towards rangelands reclamation and conservation. Moreover, not all of these options can present the decision maker with the best outcome in terms of maximising expected net returns. Thus, in this study, three different rangeland utilisation scenarios grouped into four cohorts are used to analyse the economic profitability of converting from sheep farming into springbuck ranching in Graaff-Reinet.

The central assumption of this study is that landowners in Graaff-Reinet are profit maximisers. Thus, it is subsequently assumed that rangelands utilisation choices are dependent upon economic superiority of the different enterprise mixes on the farm. This means that the rangeland owner might be enticed to continue with the current ecological-economic system despite its effect on the rangeland, if it maximises his net returns and *vice versa*. Thus in order to reconcile the profit maximisation goal of rangeland owners with the constitutional obligation of wanting to conserve natural ecosystems through biodiversity restoration and environmental conservation, the study explores the effect of some policy incentives on the profitability of converting from sheep farming to springbuck ranching. This is done through the introduction of a set of incentives for springbuck ranching. The study also aims to investigate the economic sustainability of the different alternative scenarios in a bid to understand the performance of springbuck meat production on farm profitability over a 15-year planning horizon. A profitability analysis of the various rangelands utilisation ecological-economic systems is also required to evaluate which ecological-economic system decision makers would prefer under different absolute risk aversion coefficients.

The specific objectives of this study are as follows:

1. To evaluate the profitability of converting a 5 000ha wool sheep dominated farm into a springbuck dominated ranch, whilst overtly taking risk.
2. To investigate the requisite factors influential in the prospect of returning a positive net present value (NPV) for a 5 000ha springbuck dominated ranch, in Graaff-Reinet.
3. To explore the effect of some policy incentives on the profitability of converting a 5 000ha sheep dominated farm into a springbuck dominated ranch in Graaff-Reinet.
4. To analyse the economic sustainability of converting a 5 000ha wool sheep dominated farm into a springbuck dominated ranch in Graaff-Reinet.

1.4 Research Methods

In order to address the objectives of this study, the following methods were employed. Firstly, an initial step which involved the use of a system of simultaneous equations to construct a model to estimate farm profitability so that the stochastic analysis could be carried out by specifying a multivariate empirical (MVE) probability distributions of outcomes of the various strategies was carried out. The MVE probability distribution was used to correlate stochastic variables based on their deterministic means. Prices of both inputs and output yields are affected by risk, which also affects the efficiency with which the enterprise realises positive net returns. Stochastic simulation allows for the incorporation of risk from wool sheep output, mutton output and springbuck output and their prices. Secondly, upon specification, the stochastic variables were used to create Monte Carlo financial statements necessary to explore the profitability of the different utilisation scenarios. Because the use of Monte Carlo financial statements enable the creation of various key output variables (KOVs), which included net cash income (NCI), ending cash balances (ECB), real net worth (RNW) and net present value (NPV), the first two objectives were accomplished using stochastic simulation. Since simulation allows for the incorporation of risk from stochastic variables, which in turn presents the decision makers with a rounded feel of their management actions on the profitability of their enterprises, the effect of risk on the profitability of the various enterprise mixes has also been analysed. Stochastic efficiency with respect to a function (SERF) is used to rank the NPVs of the alternative scenarios across a range of absolute risk aversion coefficients (ARACs).

The introduction of incentives could have an effect on the sustained profitability of the enterprises and thus may be very instrumental in the decision making process of whether to convert a sheep farm into a springbuck ranch. This study uses scenario analysis to necessitate the incorporation of various alternative control variables to assess three alternative rangeland utilisation options, grouped into four cohorts. Therefore, the combined usage of stochastic simulation and scenario analysis will return a distribution with alternative NPVs for the alternative rangelands utilisation scenarios in the four cohorts and the results therein shall be used to explore the question of which of the alternative scenarios is mostly preferred by decision makers. To achieve the last objective, the probability of returning total variable costs greater than a maximum threshold of total variable costs relative to total income in both wool sheep farming and springbuck ranching is explored using stochastic simulation. It is anticipated that the results of this study will provide rangeland owners with an impartial examination of converting from sheep farming into springbuck ranching in Graaff-Reinet.

1.5 Study Area

Graaff-Reinet lies in the Eastern Cape Province part of the Nama Karoo (called Eastern Cape Karoo in this study) – which is a semi-arid to arid constituent of the Republic of South Africa (see Figures 1.1). The area receives an average annual rainfall of between 200mm and 400mm per annum, with peak rainfall occurring mostly in February and March, accompanied by a great number of thunderstorms (Esler *et al.*, 2006). The soils are generally wide ranging and have been summarised by Esler *et al.* (2006:10) to vary based on the "nature of the underlying bedrock, position of the soil in the landscape, and with annual rainfall." Although Graaff-Reinet has been argued to yield better vegetation cover than most parts of the Karoo, the question of how grassy the Karoo veldt should be has engaged researchers for many years (Esler *et al.*, 2006). However, there is a consensus that the grazing capacity of the rangelands fluctuates as per the annual variation in rainfall. Because of high rainfall variability and extremely high daytime temperatures, the rangelands have been used for over two centuries generally for commercial domestic livestock farming, and are arguably South Africa's oldest.

These rangelands owe their popularity to the arrival of early European farmers who found them to exhibit a potential towards pastoral production (Beinart, 2003). Indeed, soon after the arrival of early farmers, the area became synonymous with livestock farming, essentially sheep, goat and to a small degree cattle farming (Beinart, 2003). For hundreds of years before the arrival of early farmers, however, it is believed that the rangelands were well endowed with a variety of wildlife, including a wide selection of wild animals and plant kingdom species (Acocks, 1953). Moreover, with the arrival of early farmers and particularly, the introduction of the sheep in the late 1700s to early 1800s, a great number of wild animals were displaced in the Karoo to make way for domestic livestock farming (Roche, 2008; 2000Roche, 2004; Beinart, 2003; Archer,).

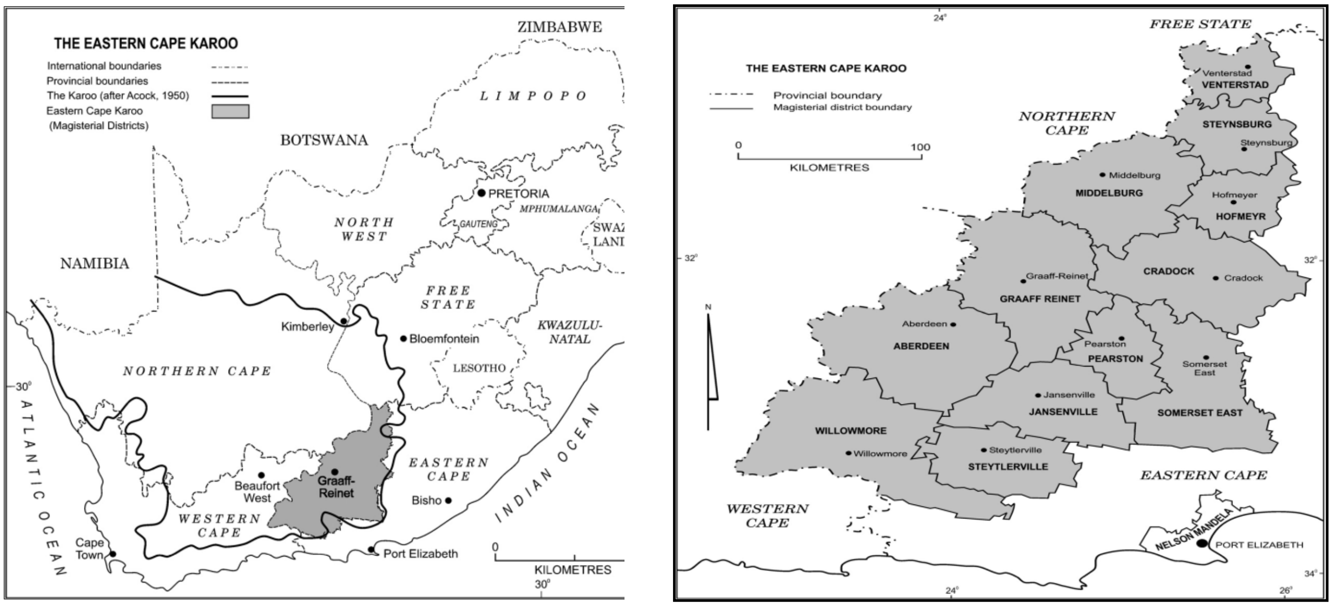

Figure 1.1: Map showing location of study area (Graaff-Reinet) in the Eastern Cape Karoo (to the left) and (to the right) location of study area in relation to other areas in the Eastern Cape Karoo. Source: Nel and Hill (2008).

Although there are traces of legislation in the late 1800s geared towards environmental protection and the conservation of the wild [flora and fauna] (Carruthers, 2008; Grove, 1987), the significance of the livestock farming sector – essentially wool sheep farming – played a huge role in driving the economy of South Africa at the time (Beinart, 2003; Nel and Hill, 2008) so that even with such attempts, it continued to dominate the rangelands (Nel and Hill, 2008). Not surprisingly, with the ostrich products boom in the US before the First World War, farmers were able to switch to ostrich production, some only temporarily to take advantage of the lucrative ostrich products market, only to revert to livestock farming when the ostrich industry plummeted (Beinart, 2003). This signalled the importance of economic gains as a key determinant of the choice of rangeland utilisation economic systems. Of course, this also explains the prevalence of livestock of all kinds in the area in spite of their effects on the environment.

Historically, livestock farming in Graaff-Reinet was largely dependent on the natural productivity of the veldt. Nonetheless, with the introduction of modern farming techniques, farmers were soon able to intervene in winter by providing supplementary feeding, or through periodic resting of paddocks. Because of an influx of large numbers of sheep in the early 1800s to mid-1950s, many problems associated with the destruction of valuable, productive and soil protective plants occurred in the Karoo (Roux, undated). Expectedly, as in most arid to semi-arid areas of South Africa (Wessels *et al.*, 2007), land degradation soon became a serious risk to the sustainability of these rangelands. In Graaff-Reinet, historians have contended that some of the early cases or fears of land degradation were reported shortly after the beginning of commercial pastoral expansion in the Karoo (Beinart, 2003). Acocks (1953) observed that the vegetation of much of the area was changing, raising critical questions regarding what the rangelands might have looked like before the onset of domestic livestock farming. Although many have disputed the idea of an expanding Karoo, the effect of domestic livestock farming on the vegetation especially on land degradation, has received much attention from researchers. Roux (undated) argues that the degradation of the rangelands has been caused largely by domestic livestock, primarily sheep that have decimated indigenous fauna. This led to the development of less palatable grasses, which saw the advancement of bare patches that reached their climax in the mid-1940s. Roux (undated) states that even though the vegetation has somewhat stabilised, under what he has termed a "most critical stage … which, if mismanaged, will inevitably develop into a… [less desirable] situation" opportunities exist through which grazing can operate for better. Similarly, the status of the EC Karoo's degradation varies from one study to the next and there is no conclusive answer as to what is the exact state of degradation. Notwithstanding, evidence suggests that there is a great deal of land degradation characterised by vast patches of dry land without cover that has come about as a result of sheep farming (Roux and Vorster, 1983).

The yearnings to conserve the rangelands began in the early years of the 20th century, with many interventions from the state aimed at curbing soil erosion, overstocking, veldt degradation and destruction of riparian areas by domestic livestock (Beinart, 2003). However, almost a century later issues of environmental quality and the need to halt unrelenting land degradation have continued to surface, more so in recent years given fears of climate change and its projected likely impact on the environment (Archer, 2004). This has led some researchers in rangeland ecology to suggest that the reintroduction of those wild animal species (see Milton *et al.* 2003) which are naturally endemic in the area could perhaps stimulate biological diversity, which could lead to the resumption of some of the basic ecological processes thus aiding their restoration, recovery and reclamation.

The springbuck have come out as a natural choice because of their endemic nature in the area, and they have been argued by Roche (2008) to be the cornerstone of the Karoo ecosystem. Roche (2004) and Roche (2008) further give an elaborate recollection of springbuck movement and what could have led to their subsequent displacement, whilst Liversidge (1970) has shown that springbuck do indeed feed differently to the sheep on the rangeland. The dominance and economic potential of springbuck meat production presents the rare opportunity to rangeland owners in Graaff-Reinet to incorporate conservation practices whilst earning income through meat production and other ecotourism related economic systems.

1.6 Study scenarios

Figure 1.2 presents an illustration of the study scenarios. In its entirety, the study investigates the profitability of converting a 5 000ha wool sheep farm into a springbuck ranch based on four cohorts with three scenarios per cohort. The scenarios are based on two alternative ecological-economic systems taking place on a real 5 000ha sheep farm in Graaff-Reinet. The farmer currently uses his farm predominantly for wool sheep farming (70%), but culls his wool sheep herd for mutton production from time to time (20%). A very small portion of his sheep herd is also kept exclusively for mutton production. Springbuck are naturally occurring on the farm, and they form a small portion (10%) of the population of animals on the farm. The farmer harvests the springbuck on an annual basis, using the skill of professional harvesters, to sell at the local springbuck meat processing facility known as Camdeboo Meat Processors. The farmer is paid a per kilogram dressed weight price for the springbuck carcases. The animals feed entirely on the rangeland except in wool sheep farming where supplementary feeding in winter is provided.

In the springbuck ranching enterprise, the farmer does not conduct any management practices, except basic visual examination of the herd for diseases and through clinical examination of faecal samples. The other two scenarios are hypothetical. In the second and third scenarios, respectively, the farmer is assumed to increase his output on springbuck to explore the effects of an increase in springbuck ranching on the profitability of the base scenario. Since output on the farm is constrained by land, scenario two assumes that the farmer increases his springbuck output and by default the amount of land utilised by the springbuck to 20% and reduces his wool sheep herd by 20% to 50%, by culling more wool sheep for mutton production (30%). In the third scenario of cohort one, it is assumed that the farmer uses 70% of his rangeland for wool sheep production whilst 30% is used for springbuck ranching.

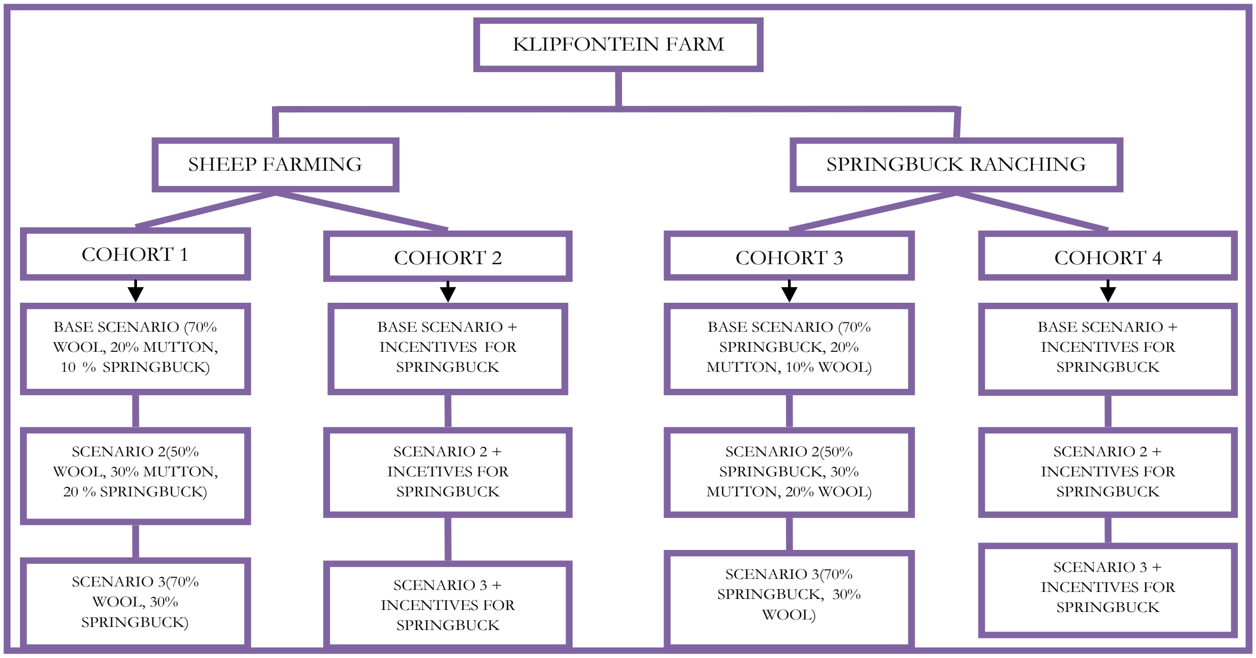

Figure 1.2: Schematic representation of study scenarios

Cohort two scenarios are similar to the cohort one scenarios, only that the farmer is assumed to receive subsidies for springbuck ranching. Cohort three and four are hypothetical and represent a scaled up commercial springbuck ranching enterprise, producing springbuck meat (venison) as a premier product, with a minimal number of wool sheep on the farm. In the first scenario of cohort three, the farmer is assumed to allocate 70% of his rangeland to springbuck ranching, 20% to mutton production and 10% to wool sheep. In the second scenario, the study explores a combination of 50% springbuck, 30% mutton production and 20% wool sheep production on the profitability of the farm. The third scenario assesses the profitability of converting to a combination of 70% springbuck and 30% wool sheep. Cohort four scenarios are similar to cohort three scenarios, with the exception that the farmer is assumed to receive incentives for springbuck ranching.

1.7 Research Outline

This thesis contains six chapters: chapter 1, which is an introductory chapter, and five subsequent chapters. In chapter 2 a review of literature on game ranching and its ecological benefits is undertaken. The chapter also includes a review of the literature on the benefits of biodiversity before presenting the economic theory related to rangelands utilisation. In chapter 3 the thesis reviews the theory on decision making under uncertainty. Theories, assumptions, and the procedures used to quantify risk in profitability studies are also reviewed in this chapter. Chapter 4 presents the method used to quantify the profitability of converting a sheep farm into a springbuck ranch in Graaff-Reinet. In chapter 5 the results and findings are presented whilst chapter 6 presents the summary, conclusions and recommendations.

Chapter 2.

GAME RANCHING AND RANGELANDS UTILISATION THEORY

"[An] old South African farmer ... when asked whether he had seen any changes on his farm over his lifetime, replied, upon serious reflection, *'I think the rocks are growing*'" – Vanclay (1992, as cited in Archer, 2000: 675).

2.1 Introduction

The subject of sustainable rangeland utilisation in the semi-arid to arid areas of South Africa has been revived by the increase in game ranching. Especially in the Karoo, this is in response to a drastic change of rangelands in the last 200 years, from highly productive, open savannas to land with vast amounts of woody plant cover (Acocks, 1953) characterised by a significant degree of degradation (Milton *et al.*, 2003). An increasing amount of literature pinpoints the evident ecosystem degeneration of the Karoo to overstocking and overgrazing by domestic livestock, essentially sheep and goats. However, in Graaff-Reinet, the endemic nature of the springbuck presents opportunities to rangeland owners to initiate the restoration of these rangelands whilst gleaning some income through meat production from the springbuck, through springbuck ranching. The first part of this chapter motivates the benefits of wild animals on the environment: their agricultural potential, reclamation, and biodiversity restoration capabilities. This is in an attempt to make a case for springbuck ranching as a medium towards rectifying over two centuries of commercial domestic livestock farming in the Karoo, which has left visible scars on the environment in terms of land degradation and compromised forage productivity (Archer, 2004; Milton *et al.*, 2003).

Secondly, as a means to circumvent the challenges brought about by rangeland degradation, a significant number of farmers have been converting their farms to game ranching (Nel and Hill, 2008). A growing number of farms have also incorporated springbuck ranching for meat production. Conveniently, the re-introduction of the springbuck in most farms in Graaff-Reinet comes as an attempt from farmers to improve the profitability of their enterprises, whilst playing their part in the conservation and reclamation of degraded rangelands (Smith and Wilson, 2002). Accordingly, and with respect to the main goals of this study, the second part of this chapter presents a discussion of the economic theory on rangelands utilisation. The chapter is concluded with a review of economic studies on rangelands utilisation.

2.2 Game Ranching

Bothma (2002: viii), defines game ranching as: "the managed, extensive production of free living animals on large fenced or unfenced private or communal land, usually for the purposes of hunting, live sales, trophy hunting, venison, tourism or other uses." It is a capital-intensive business (ABSA, 2003) requiring the use of large tracts of land (Tomlinson *et al.*, 2002). Enough evidence is available that proves the feasibility of wildlife production as a worthwhile land use option (Ntiamoa-Baidu, 1997: 50), more especially in South Africa where game ranching has been argued to be highly developed (Carruthers, 2008). Recent studies, for example, have dared that it has been the production of wildlife that South Africa vaunts "one of the greatest reversals of fortune ever seen in wildlife conservation" (Bothma, Suich and Spenceley, 2009: 147).

A number of factors have spurred the growth of the game ranching industry in South Africa. These range from socio-economic to political and environmental factors. It was, however, not until the demise of apartheid, that wildlife utilisation gained tremendous favour amongst landholders (Child, 2009a; Carruthers, 2008). For example, prior to 1994, the heavy hand of the South African government with its conservative agricultural policies (e.g. subsidies) aimed at the conservative farm vote frustrated the development of wildlife enterprises by making uneconomical agricultural production in marginalised, unproductive lands economical (Child, 2009b; Carruthers, 2008). Nonetheless, it has been through the adoption of a new constitution that emphasises the need to protect the environment for the benefit of future generations, coupled with a realisation and comprehension of the contribution of livestock farming towards environmental degradation, that land use practices geared towards reclaiming and preventing unnecessary degradation have gained precedence in privately owned lands (Child, 2009a; Carruthers, 2008).

Amongst the leading land use practices that gained favour among private rangelands owners is wildlife production and conservation for ecotourism and meat production, through game ranching (Lindsey, Romanach and Davies-Mostert, 2009). Indeed, while game ranching was not an entirely new ecological-economic system in South Africa, a distinction between early (traditional) game ranchers and the new (modest) game ranchers existed. For example, it is argued that, early game ranchers were mainly driven by non-economic pointers to game ranching, such as different individual approach and a way of life (Carruthers, 2008, 1995; Brown, 2002), whereas in recent times the determinants have fundamentally changed, with economic and environmental factors gaining more precedence (Carruthers, 2008; Palmer, Peel and Kerley, 2006; Nell, 2003). For instance, Smith and Wilson (2002: 11) reiterate the observation that a combination of both economic and ecological motivations has induced landholders to convert to game ranching in South Africa. Others (e.g. Child, 2009b; Lindsey *et al.*, 2009; Carruthers, 2008) have identified conservation policy experimentation in privately owned lands; political regime change; and shared expertise between private game ranchers and state conservancies, as some of the leading pull factors to convert into game ranching in South Africa. The development of relevant skills, research and development geared towards the game ranching industry, adherence to existing values and practices and the lustre of profits, as Nell (2003) adds, have also played a significant role in fuelling the interests of private landholders in game ranching, in South Africa.

Moreover, it appears that the development of favourable policy towards wildlife ownership, which has also enabled private landholders to invest in game ranching with the aim of making a profit, has been of paramount importance (Palmer *et al.*, 2006). Palmer *et al.* (2006) posit that this has also benefitted from political stability and sustained economic growth, after the fall of the apartheid regime. These developments have further encouraged the uptake of wildlife utilisation, especially in semi-arid areas of South Africa, where commercial livestock farming thrived as a result of apartheid government regime policies that promoted the farming of marginalized agricultural lands, through state subsidies (Nel and Hill, 2008). In conjunction with this, there has been a tremendous increase in demand for wildlife products and a rise in ecotourism in South Africa and abroad (Hoffman and Wiklund, 2006; Hoffman, 2003; Hearne *et al.*, 2000). The continued lack of competitiveness[1] in agriculture as a result of "closed

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[1] See, for example, the Strategic Plan of South African Agriculture (NDA, 2006).

international markets and an altered agricultural regime devoid of state subsidies, control boards and other organs of state that protected South Africa's white commercial farmers" (Carruthers, 2008: 161), along with rising cost of land and diminishing profitability in the livestock production sector, has made game ranching even more appealing to the land holder from an income diversification point of view (Palmer *et al.*, 2006). Fuelling the transition have been changes in labour legislation, increased stock theft and stock losses due to predation, rangeland degradation, and the desire to reclaim, conserve and stop further degradation in rangelands (Smith and Wilson, 2002). Other studies have identified high maintenance costs in livestock farming (e.g. disease control) and bush or woody shrub encroachment as some of the other reasons why game ranching has gained much favour amongst land owners (Palmer *et al.*, 2006).

In particular, new labour laws in South Africa at the turn of the millennium necessitated the introduction of minimum wages for farm workers which further worsened the already ailing commercial domestic livestock farming situation (Carruthers, 2008), leaving rangeland owners looking for alternatives which are "potentially less labour intensive than traditional stock farming"(Smith and Wilson, 2002: 11). Unlike in game ranching, commercial livestock farmers are persistently losing money as a result of stock theft, which has reached epidemic levels, with the National Stock Theft Forum estimating the loss to have amounted to R327.6 million in 2007 alone (NDA, 2009a). Increasing predation (especially for small stock) as a result of a growing number of vermin (e.g. jackals), which overflow from neighbouring game ranches, and stock theft add to the reasons that have motivated land owners and farmers to convert their farms into game ranches in an attempt to avoid economic losses (Smith and Wilson, 2002).

However, such reasons are not universal, as differences in rangelands utilisation exist from one region to the next in South Africa. In the semi-arid and arid rangelands, for example, game ranching has grown because of an increased awareness of the negative effects of domestic livestock farming on the environment and the perceived ability of wild animals to aid in ecosystem health (Carruthers, 2008; Du Toit, 2007; Beinart, 2003; Milton *et al.*, 2003). In these rangelands, land degradation caused by continued small stock farming and the influence of climate variability has led to a change in vegetation composition, which has largely affected the sustainability of commercial livestock enterprises, and often put it in an indeterminate state (Archer, 2004; Milton *et al.*, 2003; Dean, Hoffman, Meadows and Milton, 1995). Unsurprisingly, game ranching has been heralded as the antidote necessary to achieve ecosystem health and at most revive the livelihoods of the communities, in such areas (Milton *et al.*, 2003). For example, literature is increasingly associating game ranching with improving biodiversity conservation and halting desertification in some semi-arid to arid areas in South Africa, e.g. the Karoo (Palmer *et al.*, 2006; Milton *et al.*, 2003). Others have connected it with having revived the economic status of landholders and the creation of much needed jobs in such areas (Esler *et al.*, 2006; Nel and Hill, 2008), whereas some glorify game ranching for aesthetic reasons (DEAT, 2006). For farmers, however, game animals present the possibility of turning land degradation challenges into opportunities for restoration: creating a new source of livelihood and contributing to the restoration of natural capital[2] and biodiversity in rangelands (Milton *et al.*, 2003).

This thinking and trend has spread across South Africa, causing a transformation in land use patterns (Palmer *et al.*, 2006; NDA, 2009b). The transformation is inspired by, among other things, the desire to generate more income following a realisation that game has equal opportunities to make money through both consumptive (e.g. meat production) and non-consumptive (e.g. ecotourism) uses (Tomlinson *et al.*, 2002) and the need to halt further degradation in rangelands (Milton *et al.*, 2003).

2.2.1 Agricultural Potential

It is not surprising; therefore, that others have also looked at various ways in which wild animals could be used to produce food for humans (Barnett, 2000; Prins *et al.*, 2000). In the late 1960s and early 1970s, much of the work concentrated on the merits of wild animals over domestic animals. It was after the work of Dasmann and Mossman (1960) and Dasmann (1964), that game ranching was seen as a practicable land use option to domestic livestock farming. Soon after that, a variety of studies that tried to assess game ranching versus commercial domestic livestock farming followed. However, many of the initial studies focused on the comparisons between domestic animals and wild ungulates with the intention of mapping out

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[2] Milton *et al.* (2003: 247) draw on Daly and Cobb (1989); Costanza and Daly (1992); and Hawken (1993) to define natural capital as those "renewable and non-renewable resources that occur independently of human action or fabrication."

the set of competencies that wild animals appeared to possess over domestic livestock. For example, it was discovered that wild ungulates are proficient users of local vegetation as opposed to domestic livestock (Taylor and Walker, 1978; Bigalke, 1982; Skinner, 1971). Others associated them with superior and efficient rangeland utilisation abilities over domestic livestock; and went on to show that they tend to achieve higher rangelands carrying capacities (Mentis and Duke, 1976). According to Skinner (1970), wild animals are better developed to reproduce and multiply under harsh arid environments because of their distinct features, which make them survive even the longest of dry spells in arid ecosystems. A significant amount of literature further correlates wild animals with an intrinsic potential to reproduce at quantitatively higher rates coupled with higher growth rates than domestic livestock (Dasmann and Mossman, 1960; Dasmann, 1964; Macnab, 1991; Cooper, 1995).

Recent studies have gone a step further by developing an understanding of the nutritional composition of meat from wild animals. It has been shown, for instance, that the meat of wild animals is nutritionally superior (Hoffman, 2008; Hoffman and Wiklund, 2006; Ntiamoa-Baidu, 1997: 50) and contains a higher protein and lesser fat content per animal unit than domestic livestock (Beinart, 2003). Moreover, from an agricultural production point of view, game ranching presents other benefits, which far outweigh livestock farming. According to Pollock (1969), game ranching is comparatively easier to operate and has lower development costs than livestock farming. For example, in game ranching, the costs of dams, boreholes and inoculation and dipping against pests and diseases are minimal and sometimes not part of the equation at all. Moreover, since wild animals, in most cases, are naturally resistant to certain diseases, which are often menaces in livestock farming; the management of game ranching enterprises, from a production costs based perspective, is much more appealing than livestock farming based enterprises. The advent of better cropping techniques for game has also improved their carcass quality and has opened other potential uses of venison (in the kitchen) making it an integral part of the modern consumer's diet (Hoffman and Wiklund, 2006).

Incidentally, the characteristics of game meat such as low fat content, leanness, wholesomeness, freshness, high nutritional value and succulence, are all coinciding with a growing international (and to a lesser extent in local) trend of consumers demanding a healthy lifestyle which is characterised by minimal consumption of red meat. These issues pertain to the safety and quality of red meat products (Hoffman and Wiklund, 2006). In particular, growing health concerns of consumers are being cited as the major reasons behind the high demand of low kilojoule and low cholesterol foods. A rise in environmental consciousness has also led to consumers demanding products produced by natural means (Hoffman and Wiklund, 2006). From the private landholders' point of view, game ranching does not only provide the means through which such vibrant consumer markets can be tapped into - it presents opportunities to improved incomes and restores hope, especially, in semi-arid and arid rangelands. Climate variability and land degradation may have obliterated the economic supremacy of domestic livestock farming making it a highly challenging and risky rangeland utilisation economic system. On the other hand, this has further opened an unending criticism of domestic livestock farming, especially its environmental effects on rangelands in semi-arid and arid places.

2.2.2 Sheep and the Environment

According to Hickman, Roberts, Keen, Larson and Eisenhour (2009: 42), "[p]opulations of animals are part of a larger system, called the community, within which populations of different species interact." In a habitat, species interact at a certain levels that inform its diversity (fauna and flora). Species in a community exist in what Hickman *et al.* (2009: 42) has termed "detrimental (-), beneficial (+) or neutral (0) … [interactions]." As Hickman *et al.* (2009) continue to argue, there are different levels of interaction within a community, which further shape the way a community is organised in terms of species and ecological diversity. These interactions are more intricate and less oblivious to the scientist and his microscope. However, more and more evidence is coming to the fore with respect to the level of interaction amongst species. One such condition relates to the competition between species, which is now understood on a different level by ecologists around the world. First, it is now widely accepted that some species may have a neutral effect on others whilst others might exert a negative and or positive effect on others, a phenomena that has been named amensalism, or asymmetric competition (Hickman *et al.*, 2009). According to Jepson and Ladle (2010), agriculture is one such example. It leaves a legacy of compacted soils and altered hydrology, that when it stops "the land is vulnerable to rapid invasion by undesirable species" (Jepson and Ladle, 2010: 102).

Similarly, the introduction of exotic (domestic livestock) species in an ecosystem can alter its ecological makeup, particularly if such species have to compete with keystone species for their existence. According to Vander Zanden, Olden and Gration (2006: 165), "no species exists in a vacuum. Rather, each species is embedded within a network of predator-prey interactions in …Charles Darwin's … 'entangled bank' …known in the most general sense as a *food web*." A food web can be seen as relating to either: 1) the number of trophic levels in a food chain; and or 2) the degree or extent of involvedness in a food web network, in ecological communities (Vander Zanden *et al.*, 2006). A food web can also be viewed from the perspective of biomass distribution across trophic levels. According to Bukovisnszky, van Veen, Jongema and Dicke (2008: 804), diversity of communities is a product of "past evolutionary processes and immigration and extinction", which may be driven by food web dynamics. These food web dynamics are often looked at from two perspectives: direct and indirect food web effects (Vander Zanden *et al.*, 2006). Direct food web effects are those processes that lead to visible changes on the structure or population of another species or organism due to such things as predation or competition for resources. Indirect food web effects relate to processes where the changes in either species are because of an interaction with a third species (Vander Zanden *et al.*, 2006). This suggests that there exists a link between food web structure and ecosystem function and stability, since the diversity (degree of species richness) and involvedness of food webs are fundamental determinants of ecosystem function and stability. The link therein, is argued by Bukovisnszky *et al.* (2008: 804) to be measureable through the extent of "connectance", which is the "fraction of all possible trophic links that can be realised."

Although there are no studies as yet, in as far as the literature reviewed is concerned, that have sought to understand how the introduction of the sheep impacted food web dynamics in the Karoo; evidence does suggest that it may have, especially if one draws from Bukovisnszky *et al.*'s (2008) 'optimal foraging theory' which asserts that the connectance of the ecosystem relies on both the body size of predators and prey. Others have tried to explain this through the concept of "regime shifts" (Crépin, 2007; Folke *et al.*, 2004; Carpenter and Turner, 2000). For example, "the combined and often synergistic effects of … [domestic livestock] pressures can make ecosystems more vulnerable to changes that previously could be absorbed" (Folke *et al.*, 2004: 557) by the ecosystem. Fundamentally, what this means is that the sheep may have disrupted or even compromised ecological cohesion, thus leading to poor biological productivity. For instance, it is now increasingly understood that the morphological, behaviour and life history of many living organisms - especially animal kingdom species - was influenced, largely, by their interaction with their desired nutritional requirements (Vavra, 1992). The sheep and most of the livestock in the Karoo did not originate there, meaning that they are not indigenous to, or do not form the natural capital of the area. Others have shown that, for instance, exogenous species do affect the development of certain grass species (Fleischner, 1994; Vavra, 1992; Solbrig, Medina and Silva, 1996; De Leo and Levin, 1997; Cooper and Huffaker, 1997; Khanina, 1998). It has long been established that historic grazing by domestic livestock on preferred perennial grasses is to blame for the compromised dynamism in rangelands, which make them more susceptible to degradation and invasions by alien plant species (Cooper and Huffaker, 1997: 59). For instance, Cooper and Huffaker (1999: 59 – 60) draw on Steward and Hull (1949) to illustrate the environmental drawbacks associated with alien grasses in a rangeland. They argue that alien grasses usually are artificially rooted compared to indigenous perennial grasses and thus are not compatible for binding or holding the soil together, thus promoting soil erosion that harms riparian habitat for wildlife.

2.2.3 Game Ranching and Rangeland Conservation

Not surprisingly, on privately owned lands, game ranching has gained the support of landholders as an ecological management option, wherein wild animals are kept at optimum numbers to ensure ecosystem health and ecological resilience through the outlawing of over-stocking and overgrazing (Beinart, 2000: 5; Lindsay *et al.*, 2009). According to Fairall (1989: 244), game ranching "capitalises on the ecological adaptations of indigenous species while satisfying the requirement of establishing ownership and managing a closed system." The adaptation proficiency of wild animals in marginalised and water stressed agricultural lands (Skinner, 1971: 151 -152), which is borne in their ability to balance range utilisation through "specialised and complementary feeding habits" (Fairall, 1989: 244), has set them apart from domestic livestock. In contrast, game is naturally better adapted to the prevailing environmental conditions in most African ecosystems: be it insufficient rainfall or the presence of certain disease organisms, which make domestic livestock farming difficult (Ntiamoa-Baidu, 1997). It further forms the natural capital in most rangelands across South Africa and complements their biological diversity (Milton *et al.*, 2003; Bothma *et al.*, 2009; Bothma, 2002).

Pollock (1969) advances several benefits of game on the environment. Firstly, he contends that, since wild animals are both grazers and browsers, they are subsequently better equipped to use local vegetation efficiently and sustainably. Secondly, he identifies their long-term adaptation to African habitats as their competitive advantage over domestic livestock in conserving the environment. Finally, he cites their ability to spread out more widely and go on for longer periods without water as opposed to domestic livestock as a fundamental property that makes wild animals more suitable for environmental management. According to Gibson (2009: 13), wild herbivores are "beneficial, adaptive, or even critical" and a range of them act as keystone species for many rangelands ecosystems and hence are "pertinent repositories of biodiversity" (Gibson, 2009: 15). Indeed, a growing amount of literature associates the production of wild animals, which are keystone species or natural capital in an area, as beneficial towards environmental management in semi-arid rangelands (Joubert *et al.*, 2007; Milton *et al.*, 2003; Rosenzweig, 2003).

Batabyal (1999) explains that natural capital is essential in the continuance of certain critical and basic ecological functions; in their absence an ecosystem might lose its ecological resilience thus risking the possibility of flipping into Westoby *et al.*'s (1989) undesired states, in the presence of continued external perturbations. Khanina (1998) has qualified the concept of keystone species as relating to only those species "whose populations (or … [herds] of animals, as a rule) either support or essentially alter the main vegetation pattern of the ecosystem". This understanding implies that keystone species vary from one ecosystem to another. For example, certain indigenous trees would form the keystone species in a forest ecosystem whilst in African grasslands only the relevant wild animals and plants can be considered as keystone species. Similarly, the ecological structure and composition of a particular rangeland "will alter when keystone species disappear for some reason, or when new 'stronger' keystone species [are introduced]" (Khanina, 1998). According to Hodgson *et al.* (2005), natural rangelands are beset with severe conservation problems and, consequently, degradation problems because of continued domestic livestock farming that have displaced natural capital thus compromising species richness and biodiversity.

2.2.4 Biodiversity and Conservation

Biodiversity is defined by Purvis and Hector (2000:212) as "the sum total of all biotic variation from the level of genes to ecosystems." Biodiversity is accredited with increased ecosystem functioning and is especially common in those ecosystems which generally have a diverse number of organism than in a monoculture. For example, such ecosystems are also linked with a high composition of and they represent the "'natural capital' that, together with man-made capital and human capital, produce goods and services which are consumed by households in the economy" (Turpie, 2004: 88). For instance, the production of goods and services from natural rangelands can be thought of as follows: goods are the tangible products provided by the natural rangelands, such as meat, and services including benefits such as "those associated with ecosystem functioning" (Turpie, 2004: 88), like carbon sequestration. Likewise, rangeland ecosystems also derive economic attributes from biodiversity, which are a prerequisite for ecotourism value or continued existence for that particular rangeland (Batabyal, 2004).

Often, conservation is assumed to mean preservation of the ecosystem and thus is thought of as completely independent of such systems in any use. Perrings and Walker (2004) argue that conservation is not only an alternative to exploitation, but also a feasible land use alternative that can be simultaneously used in the protection of stocks and the regulation of flows. Lindsay *et al.* (2009) exposit that conservation can lead to increased biodiversity. Indeed, the structural components and organisation of biodiversity are a fundamental property in the functioning of the ecosystem (Turpie, 2004). For instance, biodiversity is thought to play a significant role in the determination of the resilience of an ecosystem, or their capacity to withstand external perturbations without losing their resilience (Baumgartner, 2007; Baumgartner and Quaas, 2005). Certainly, as De Leo and Levin write:

"In most cases, it is indeed groups of species, rather than individual species that assume importance, forming "keystone groups" or "functional groups", a generalization of the notion of keystone species. Functional groups (guilds) are a collection of species that perform the same functions and that, to some extent, may be substitutable and viewed as a unit. For example, the removal of a numerically dominant species may result in its replacement by functionally similar competitors that had been suppressed, leaving untouched macro-level indicators of ecosystem functioning (like productivity, or the amount of matter processed). Yet, loss of species within a guild may reduce the long-term resilience properties of the system, and may lead to noticeable change in short-term system dynamics" (De Leo and Levin, 1997).

The importance of biodiversity in the earth's buffering and resilience capabilities cannot be over-emphasised. According to Baumgartner and Quaas (2005: 1), "biodiversity reduces the variance of ecosystem services" as it provides the necessary ecological insurance to risk averse economic actors who are deriving some utility from these ecosystems. This point is echoed by Heal (2000), who observes that the contribution of biodiversity to the economic value of natural ecosystems is enormous because it improves the services and goods we obtain from the ecosystem through its inherent contribution to ecosystem productivity and insurance. However, the production of such ecosystem goods and services is highly uncertain given the various ecosystem perturbations that exist in the environment. Because of this, ecosystem services can appear random because of the exogenous effect of risk, its distribution and the influence of biodiversity on their quality (Baumgartner and Quaas, 2005).

Moreover, the rates of species extinctions and biodiversity loss because of the activities of mankind on the ecosystem, compound the problem (Polasky *et al.*, 2004). According to Polasky *et al.* (2004), human activity and action threaten or lead to biodiversity loss in several ways. They contend that human activity threaten biodiversity through the displacement of native species and subsequent habitat loss, introduction of exotic species, climate change, pollution and over-exploitation of renewable natural resources. These factors resonate well with the livestock sector, especially in semi-arid regions, where centuries of domestic livestock farming have led to increased rangeland degradation due to the anthropogenic activities of domestic livestock. The displacement of natural capital in rangeland ecosystems has had profound implications for ecological resilience and biodiversity. According to Perrings (1997), ecosystems retain a certain level of stability over defined ranges of biophysical stocks that are essential for driving the various ecological functions necessary for an ecologically stable ecosystem. Similarly, if the biophysical stocks exceed or fall below a certain critical level or threshold such systems tend to lose their stability (become unstable). This means that whenever the resources of such an ecosystem are driven past certain threshold values, the system will move from one 'thermodynamic path' to another or from one self-organisation to another (Perrings, 1997).

It has been argued that because disastrous changes in one ecosystem impose changes in the degree or level of stress on other systems with which it interacts, it follows, therefore, that economic activity that leads to unsustainable levels of strain on the natural environment may generate feedback effects which are themselves disastrous (Perrings, 1997). The recognition of the incompatibility of the properties of biophysical systems has led other commentators in natural resource economics to suggest that capital stock conservation be strengthened to include at least components of natural capital stock in physical terms (Pearce, 1988; Pearce and Turner, 1990). For example, Perrings (1997: 26) cites Pearce (1987), as having argued that the first step should be in the form of restriction on the rate of "extraction of renewable resources to a rate no greater than the regeneration rate." This is mainly justified by the uncertainty that continues to surround the role of natural capital or natural resources in the ecosystem (Batabyal, 1999). For instance, evidence emanating from the Nama Karoo of South Africa suggests that it was the extirpation of the eland and the springbuck, *inter alia*, which robbed the Karoo of a cornerstone of its ecosystem by severely disrupting the natural processes of the ecosystem (Roche, 2008).

2.2.5 Substitutability and Natural Capital

Another issue that exists is the debate on the extent to which natural capital can be substituted by produced capital (Batabyal, 1999; Turner, 1992; Deb, 2009). In most semi-arid to arid ecosystems, rangelands form the settings for economic activities such as grazing for domestic livestock, hunting for venison and ecotourism. However, because of inappropriate land uses, such as the displacement of natural capital, overstocking and overgrazing by domestic livestock, the rangelands have suffered a severe loss in biological or economic productivity (Hahn *et al.*, 2005). For example, in the Karoo of South Africa, near consensus exists to the observation that domestic livestock farming is the leading cause of rangeland degradation (Hahn *et al.*, 2005; Archer, 2004; Vetter, 2005; Milton *et al.*, 2003). Recent evidence also points to the annihilation, extirpation and displacement of natural capital as having contributed immensely to ecosystems degeneration in the area (Roche, 2008; Beinart, 2003).

Fundamentally, this highlights the pre-eminence of species diversity in an ecosystem: for instance, they are individually responsible for certain roles in the performance of ecological functions (Perrings, 1997). According to Turpie (2004), the importance of species diversity in an ecosystem varies in space and time, however, what is salient is that some species become important when the environmental circumstances change. Batabyal explores the notion of substitutability by using two variables x (natural capital e.g. springbuck) and y (produced capital e.g. sheep) in an ecosystem and juxtaposes that if the two species (x and y) play the same role then they are substitutes (Batabyal, 1999). However, if the two species do not play the same role in an ecosystem, they are not substitutes, which mean that the loss of x, for example, due to displacement by y (because of overgrazing or over-exploitation as has been in the Karoo (with livestock and the springbuck respectively)) would undermine the buffering role played by ecological redundancy (Turpie, 2004). According to De Leo and Levin (1997), ecological redundancy is pertinent because it plays a "fundamental role in maintaining an ecosystem's ability to respond to changes and disturbances and, provides a hedge against stresses and catastrophes". For example, De Leo and Levin (1997) cited Tilman and Downing (1994) as having proven that ecosystems with a diverse number of species (keystone included) are more naturally resistant to external perturbations like drought than species-poor ecosystems.

According to Turner (1992), one of the fundamental properties of sustainability between natural and produced capital that needs clear understanding is the degree or level of substitutability in them. Deb (2009) noted that produced capital could not match the sustainability of natural capital, arguing that it would be puerile to misconstrue the two. This is particularly because of the intricacy involved in the execution of various ecological functions by organisms that have co-evolved over millions of years; with each trying to derive the greatest benefit from the other and in concert producing the unique ecosystem processes that informs ecosystem health. This is particularly true if one looks at it from the viewpoint of domestic livestock farming in rangelands ecosystems around the world. Domestic stock, which have been selected for their various behavioural, and production traits make indigenous ungulates incapable of competing in as far as meat production or forage utilisation is concerned (Hoffman *et al.*, 1999). Indigenous animals, regardless, have important fundamental roles to play in ensuring ecosystem processes and consequently health, through the maintenance of certain basic ecological functions which humankind may not be aware off. Further, as Skinner *et al.* (1986) contend, they (indigenous ungulates) also possess other benefits which, when markets are conducive (prices good, high demand), can make a significant contribution into the ranch's total cash inflow or revenue. Other benefits that come with indigenous ungulates or wild animals include "genetic diversity" and biodiversity, which can further add to the recreational value of a rangeland (Turpie, 2004: 88).

The contribution of wild animals to some critical ecological processes is particularly important from a biodiversity point of view or from a genetic diversity perspective. Evidence emanating from Mauritius elucidates this point further. According to Deb (2009), the extinction of the dodo (*Raphus cacullatus*) is a case in point. Following endless and insensitive extraction of the dodo by both sailors and Portuguese settlers in the Island, news of the bird's extinction finally hit home in the late 1700s. However, it was not up until the late 1970s that the true conspicuous yet irretrievable value of the dodo dawned, when it was discovered that a certain Mauritian tree, calvaria (*Sideroxylon majus*), was endangered because of the dodo's extinction (Deb, 2009). Essentially, as Deb writes: "its seeds failed to germinate because they were not passing through the dodo's gut" (Deb, 2009: 70) thus robbing the island not only of an important component of the ecosystem but also of various other ecological processes and functions that also came with both the tree calvaria and the dodo. On the same plane, any human device or even any other species (Deb, 2009) can hardly substitute the ecological functions of earthworms driven into extinction by the use of chemical fertilisers in agricultural lands, or that of crabs from a mangrove ecosystem.

2.2.6 Discussion

Without sufficient information on the degree of substitutability (if there is any) between produced capital and natural capital, it remains logical to deduce that, by and large, the introduction of produced capital (exotic species like cattle, sheep and goats) has contributed to the disintegration of ecological cohesion and health of rangeland ecosystems. Making the argument more solid in South Africa are the recent assertions by, amongst others, Child (2009b), Bothma *et al.* (2009) and Lindsay *et al.* (2008) that as a result of game ranching and the implicit environmental conservation that comes with it, South Africa now boasts one of the greatest reversals of wildlife fortune in the entire world. However, such wildlife reversal success stories are still marred by colossal land degradation and biodiversity problems in semi-arid and arid rangelands, like the Karoo (Lindsay *et al.*, 2008) – where repeated monotonous commercial domestic livestock farming continues, unabated. This has made land degradation a matter of topical nature in southern Africa. It, further, has divided scholarly work, with some identifying land degradation with climate change whilst others have associated it with the anthropogenic activities of domestic livestock (e.g. Roux, undated; Roux and Vorster, 1983). Other sets of studies have pointed to racially motivated agricultural policies that emphasised the dominance of unsustainable rangeland utilisation economic systems (for example, Milton *et al.*, 2003), whilst others have maintained a steady balance between the competing ideologies (Archer, 2004).

As already been argued, and in Deb's (2009) sense, it can be reasoned that whilst domestic livestock has played its fair share in the environmental degradation continuum, compounding the problem has been the failure of livestock to promote the various ecological processes and functions of the rangeland ecosystems to maintain their stability or ecological resilience. Continued over-use of rangelands by domestic livestock has promoted the development of certain grass species that are favoured by livestock and in the process has compromised the composition and structure of natural rangelands ecosystems (Roux, undated; Fleischner, 1994). Drawing from Szaro (1989), Fleischner (1994) adds that, specifically, livestock grazing has affected the biodiversity of ecological niche areas through selective herbivory and through the effects that grazing may have on different plant species. This, in turn, has not only interfered with the biological processes of the ecosystem in its natural state, but has further compromised biodiversity in the ecosystem thus creating a litany of problems that are now manifesting in the form of rangeland degradation.

According to Fritz and Loison (2006), biodiversity tends to be highest in ecosystems, which show the smallest degree of disturbances and where there is a presence of the variables related to primary production and habitat diversity suggesting that there is interplay between productivity, habitat diversity and herbivore diversity. Studies undertaken elsewhere have further revealed that not only do livestock grazing interfere with plant biodiversity, but they also impact wildlife biodiversity as well (Fleischner, 1994). Numerous studies have reported that indigenous herbivores prefer plants that are more abundant even though they can tolerate plants of low quality for their survival whereas domestic livestock tend to require less-abundant but highly nutritious plants or forage (Soest, 1982; Belovsky, 1986; Jarman, 1974). For example, the effects of domestic livestock grazing on indigenous species vary from one habitat to the next

(Fleischner, 1994). In a study by Bock *et al.* (1984), livestock grazing was found to influence negatively bird species' populations. Roche (2008) has recently shown that domestic livestock farming is, on the whole, not only to blame for the extirpation of the eland in the Karoo, but also for the cessation of one of the greatest migration of wild animals[3] ever seen in southern Africa: the springbuck trek (colloquially known as the *trekbokke*).

This, in the words of Fleischner (1994), is the unfortunate price that rangeland ecosystems have to pay for keeping domestic livestock. In semi-arid to arid ecosystems, livestock grazing has further been associated with altering the physical structure of the ecosystem including vegetation stratification (Fleischner, 1994), removing soil litter (Schultz and Leininger, 1990) and increasing soil compaction (Orodho *et al.*, 1990). These have led to reduced water infiltration, which given the importance of water in semi-arid and arid rangelands, has led to reduced vegetation cover (Dean *et al.*, 1994). In the Karoo, the problem is exacerbated by the fact that domestic livestock is exotic, having only been introduced in the late 1700 to early 1800 (Beinart, 2003). The problem with this is that such domestic herbivores have not co-evolved nor evolved with the vegetation (Vavra, 1992). Wild animals like the springbuck, on the other hand, boast a long period of co-existence with the vegetation of the Karoo (Roche, 2008). Wild ungulates do not only complement the ecological processes of semi-arid rangelands, they also form an integral component of the biological diversity of these areas, which means that in Turpie's (2004) logic, they also compliment the diverse ecological processes that informs ecosystem functioning.

Indeed, as argued by Tilman and Downing (1994: 363), biodiversity preservation is imperative for the "maintenance of stable productivity in ecosystems." The displacement of indigenous ungulates to free land for agriculture or through over exploitation can have serious negative implications for biodiversity (Vavra, 1992; Fleischner, 1994; Deb, 2009; Gibson, 2009). Firstly, herbivores whether wild or tamed, are selective grazers and browsers (Vavra, 1992) who live by the "law of least effort" (Geist, 1982; as cited by Vavra, 1992: 58). In other words, this means that herbivores in general maximise net gain by either increasing forage consumption or

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[3] This can be seen through the dominant notion in the early 1900s up to the 1950s that wildlife was vermin, and needed to be removed to make way for agriculture and through the erection of fences throughout rangelands (Carruthers, 2008).

nutrient intake through selective grazing. This gives credence to the assertion that wild animals can promote biodiversity in their ecological niche areas because of their co-evolution with their surroundings, and hence their removal or extirpation can be detrimental to ecosystem health (Roche, 2008). Secondly, any given herbivores (like humans) will inhabit an area based on "forage availability, food preference of the herbivore species and nutrient demand" (Vavra, 1992: 58). This means that indigenous animals have an advantage over domestic animals in semi-arid to arid systems, because they are naturally selected to survive whilst promoting ecological resilience.

An ecosystem is made up of many varieties of animal and plant species, which have co-existed and co-evolved for many years. Here genetic diversity functions as the foundation for adaptive evolution and to ignore it is to disregard the fundamental characteristic that shapes the ecology of all living organisms (Falk *et al.*, 2006: 14). Without losing generality, the point here is that indigenous ungulates can be assumed to have taken up an ecological niche area based on the suitability and capacity of the environment to support its population needs. If animal populations grow beyond certain levels that cannot be supported by the ecosystem or because of external influences like unfavourable climate (e.g. drought) that make the environment not ideal for habitation, animals will (in most cases) die naturally only to recuperate when the conditions are better. In springbuck (wild animal) populations, this is called irruption and has been argued by Roche (2008: 159) to be witnessed throughout the duration of the *trekbokke* migration in the Karoo; in all cases it was "in sync with the cyclical fluctuations and functioning of the Karoo ecosystem."

However, as has been seen with commercial livestock farming, and more especially as has been noted in the Karoo, commercial farmers maintain more or less the same number of animals on the rangeland throughout the year regardless of the prevailing climatic conditions, by providing their animals with supplemental feeding (Mucina *et al.*, 2006). This creates a problem in that continued heavy grazing reduces species richness (Hoare, 2002) and affects species composition over and above the already mentioned problem of compromised ecological diversity (i.e. development of less palatable species or bush encroachment) (Mucina *et al.*, 2006). Fleischner (1994) adds that the deleterious effects of domestic livestock grazing on ecosystems go beyond the visible species richness and composition. In semi-arid to arid ecosystems, there are other living organisms, which are vital for the performance of various ecological processes. These include microbiotic soil crusts, cyanobacteria, lichens, and mosses of various genera. Microbiotic soil crusts play a pertinent role in cycling of nutrients and nitrogen fixation, hence are correlated with high organic matter and phosphorus contents; stable soil structure and improved soil water infiltration in ecosystems. However, given their relatively fragile nature, microbiotic soil crusts (like the cyanobacteria, lichens and mosses) are highly affected by livestock grazing through loss of microbiotic cover and richness (Fleischner, 1994). Other studies have shown that livestock grazing can in fact disrupt ecological succession. For example, continued livestock grazing has been shown to lead to the introduction of early withering or drying of vegetation in some natural ecosystems (Longhurts *et al.*, 1982).

This, however, is not to insinuate that wild herbivores do not have a negative effect on the environment. On the contrary, high population concentrations of indigenous animals can also have an effect on the structure and composition of plant species (Mucina *et al.*, 2006). As shown in a study[4] by Skinner *et al.* (1987: 197), springbuck did have an effect on the vegetation by promoting the development of non-palatable grass species and the disappearance of less palatable Karoo shrubs (particularly those favoured by the springbuck) and a “preponderance of lignified grass.” As Mucina *et al.* (2006: 357) write: “[t]he primary difference between domestic livestock and wild herbivores is scale related: the provision of supplementary fodder in commercial farming areas during drought periods prevents animal mortality so that grazing pressure is maintained during all seasons whereas wild herbivores’ impacts are more spatially and temporally heterogeneous.” Thus, it has been observed that domestic livestock chose riparian habitats in a rangeland, whereas wild animals tend to spread their grazing, going on for days without water (Skinner, 1970). The over-dependence of domestic livestock on riparian habitats in semi-arid to arid ecosystems has significant ecological impacts since the risks are higher on these areas.

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[4] Notwithstanding the interesting results that this study produced, such results should further be interpreted with caution, as the animals were kept in an enclosure, which frustrated their natural movements, thus leading to the identified ecosystem problems.

This has rejuvenated the argument that "total removal of livestock [is] necessary to restore ecosystem health" (Fleischner, 1994: 638). This view is supported by the diversity – stability hypothesis, which is based on the premise that "species differ in their traits and that more diverse ecosystems are more likely to contain some species that can thrive during a given environmental perturbation and thus compensate for competitors that are reduced by that disturbance" (Tilman and Down, 1994: 363). A growing body of literature has shown that domestic livestock has actually taken the place of indigenous herbivores like the springbuck (see Gibson, 2009; Deb, 2009; Roche, 2008; Rosenzweig, 2003; Donahue, 1999; Fleischner, 1994). The introduction of domestic livestock in the Karoo, for example, has been widely associated with a decline in the productivity of the vegetation (Roux, undated, Archer, 2004; Roux and Vorster, 1983). The prevailing argument is that livestock grazing through its deleterious effects like trampling and overgrazing have affected the biological and ecological composition of the system through the removal of amongst other organisms, microbiotic soil crusts and an overall compromised species diversity, as already been argued above, to bring about rangeland degradation (Roux, undated). Similarly, in contrast with earlier expositions of the causes of land degradation in the Karoo, indigenous species are increasingly being understood to have been more naturally endearing and beneficial to the rangelands from a natural capital point of view (Milton *et al.*, 2003; Roche, 2008). According to Milton *et al.* (2003: 251), the restoration of natural capital in rangelands in southern Africa is "socially, economically, and ecologically desirable" from the point of view of: 1) nature tourism and the wildlife industry; 2) restoring ecological processes; and 3) arresting poverty, dealing with water crises and managing alien weeds invasion in rangelands.

2.2.7 Conclusions

This section has highlighted that wild animals or game do have a set of biological and physical competencies over domestic livestock on the environment which, when properly harnessed, could help in alleviating the degradation problems that exist in semi-arid to arid rangeland ecosystems, particularly if the game animals used are natural capital in these ecological niche areas. From the above analysis, it is also evident that this could be achieved through the gradual re-introduction of the relevant keystone species (natural capital) in natural ecosystems, which could stimulate a gain in biodiversity thus benefiting the various natural ecological processes that are necessary for rangeland ecosystems health. One might then conclude that intensifying springbuck ranching, in Graaff-Reinet, could likely impact ecological restoration in a positive way and jump-start the much needed rangelands reclamation process.

2.3 Economic Theory and Rangelands Use

Often farmers convert to land uses that will improve the terminal equity of their land at the end of the planning horizon (Currie, 1981). However, as Currie (1981:50) argues, "there is likely to be some sort of trade-off." Depending on the motive behind the conversion, farmers are likely to forego income if such a behaviour help improve the value of the farm (Currie, 1981). There is consensus amongst economists that the driving factors behind land conversions include income growth, population growth or farm returns (Kuminoff and Sumner, 2002). However, other reasons are mainly environmental; for example, the need to conserve and preserve agricultural land from further degradation or the development of policies that encourage the uptake of ecologically benevolent agricultural land uses (OECD, 2009). Farmland conversions in their nature are based on the standard von Thünen model of land allocation, which is grounded on the philosophy that agricultural distribution is affected by both spatial variation and location of a resource. Such that different land use options compete for agricultural land on what can be called a von Thünen plain (Kuminoff and Sumner, 2002). For landowners to convert from one utilisation system to the next, the demand elasticies of the competing ecosystem products determine the direction of conversion. Similarly, to evaluate the direction of conversion investments, the net present value (NPV) is often used. The NPV is useful, especially in investment and decision theory, as a directive on whether to undertake a project or not (Just, Hueth, and Schmitz, 2004). If the NPV is positive, the decision is that it is profitable to undertake the project. An elaborate discussion of the NPV as a decision choice criterion is given in chapter 4.

In semi-arid rangelands, livestock farming has been the dominant land use system for many years. In the Karoo, this has been the case for over 200 years. A number of models have been developed that try to explain how rangeland owners maximise income from livestock keeping. Since in this study the farmer is thought to convert to springbuck ranching for meat production, the same models are used as guidance on how the farmer maximises his income from springbuck ranching. Moreover, given the conclusion that the contribution towards ecological cohesion differs between wild animals and domestic livestock, it is also recognised that the utilisation system chosen by the principal decision maker in the farm, is important as a source of income and as an appropriate vehicle through which the rangeland can be conserved and the realisation of constant income achieved (Quaas *et al.*, 2007). Thus, in this section, the economic theory on rangeland utilisation is reviewed with this in mind. This is explored in three parts. Firstly, a review of economic theory on range management given deterministic and stochastic rainfall on forage production assuming constant prices is presented. Secondly, the impact of rainfall variability and the effect of ecological feedbacks of high grazing pressures on rangeland vegetation and income given constant prices follow. The third part of this section deals with rangeland management utilisation given variable rainfall, ecological feedback effects and price variability and the effect of this on profits. The following review is by no means exhaustive.

2.3.1 Stochastic Range Model

In semi-arid rangelands, grazing by domestic livestock and wildlife forms the mainstay of the economic activities. For ecological-economic systems, grazing is pertinent because these systems are tightly coupled (Batabyal, 2005; 2002; 1999; Perrings and Walker, 1997, 2001, 2004). For example, green forage biomass is directly used as forage for livestock, which, in turn, is sold for income (Quaas *et al.*, 2007; Baumgartner, 2007). Livestock harvest forage biomass through grazing and browsing, and consequently influence the ecological dynamics of the rangeland in the absence of abiotic factors. Assuming that the major cause of vegetation dynamics in rangelands emanates from grazing pressure, rangeland productivity can be achieved by manipulating the number of livestock grazing the rangeland (Batabyal, Biswas and Godfrey, 2001). By further assuming that green forage biomass production[5] (F) in the rangeland can be translated into its grazing capacity s_{max} and that the amount of forage biomass φ required by a livestock unit is known, the grazing capacity of the rangeland can be calculated by dividing forage biomass production by forage biomass required by a livestock unit as shown in equation (2.1) (Hein and Weikard, 2008: 129):

$$s_{max} = \frac{F}{\varphi} \tag{2.1}$$

Animals grazing and browsing on the rangeland benefit by gaining weight and through growth in the herd numbers. For a myopic decision maker on a farm, the focus is always on the stocking rate as this is the most critical aspect of range management (Quaas *et al.*, 2007). Drawing on Perrings and Walker (2004), Hein and Weikard (2008) model the growth of the animal herd by assuming a logistic growth process:

$$\Delta s = \beta\left(1 - \frac{s}{s_{max}}\right) \cdot s \tag{2.2}$$

where s is livestock (in livestock units per hectare), Δs is livestock gain, s_{max} is the rangeland's grazing capacity and β represents a scaling parameter capturing the potential natural growth in animal population ($\beta > 0$). Assuming that the animals can be sold at price p per animal unit, and that there is a variable cost c and fixed cost c_0 per animal unit, the profit function can be written as:

$$\pi(s) = p\Delta s - cs - c_0 \tag{2.3}$$

Equation (2.3) can be re-written as $\pi(s) = p_m \Delta s \varrho - cs - c_0$, where ϱm is a dressed weight of each animal and p_m is the per kilogram price of meat per animal, to capture the profit structure when the per kilogram price is used. This equation can also be used to denote the profit derived from selling livestock products like wool (w) per kilogram at price, p_{zw}, where ϱw in this case denotes the amount of wool produced per animal head, given a population s of

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[5] Often, problems arise in measuring the amount of forage biomass produced in a rangeland at any given point in time. However, following the work of Pickup (1995) and Reeves, Winslow, and Running (2001), forage biomass production can be guesstimated using remote sensing techniques.

wool sheep. In order to optimise rangeland management, the range manager chooses the stocking rate s to maximise profits $\pi(s)$ (Batabyal *et al.*, 2001). Using a standard efficiency condition that equates marginal costs to marginal revenue and expressing it as a function of the stocking rate, the optimal stocking rate (s^*) can be modelled as (Hein and Weikard, 2008):

$$s^* = \frac{p\beta - c}{2p\beta} \cdot s_{max} \tag{2.4}$$

However, equation (2.4) ignores the effect of rainfall variability on stocking rate. For example, high rainfall in a given year can translate to increased forage production, which would in turn lead to an increase in the stocking rate and consequently improved income. Similarly, a decrease in rainfall can also affect the stocking rate by decreasing total forage productivity and thus leading to a decrease in the grazing capacity of the rangeland. To incorporate the impact of rainfall stochasticity, the assumption that forage production is given and fixed (as assumed in equation (2.1)) is relaxed by assuming that forage production is a function of effective rainfall, $r(0 < r_{min} \leq r \leq r_{max})$ (Hein and Weikard, 2008: 130). Effective rainfall refers to the net amount of rain available to plants for photosynthesis (thus forage production), after run-off and evaporation have taken place (Haan *et al.*, 1994, as cited by Hein and Weikard, 2008). Using this notion, forage biomass production (F) is denoted by $F = f(r)$, where F is assumed to be a function of effective rainfall (r) only, and not the amount of forage biomass present from the previous year. By assuming that $g(r)$ is the probability density function for effective rainfall, expected profit (π^e) can be maximised by (Hein and Weikard, 2008: 131):

$$\pi^e = \int_{r_{min}}^{r_{max}} g(r) \cdot \pi(s_{max}(r), s)dr \tag{2.5}$$

Integrating equation (2.5) above, yields:

$$\pi^e = \pi\,(s_{max}(r_{\mathrm{max}}), s) - \int_{r_{min}}^{r_{max}} \frac{\partial\pi(r_{max}(r), s)}{\partial r}\, G(r)dr \tag{2.6}$$

where $G(r) \equiv \int_{r_{min}}^{r} g(r)dr$. Hein and Weikard (2008: 147) have shown that maximising expected profits yields the first order condition:

$$s^* = \frac{p\beta - c}{2p\beta} \cdot s_{max}(r_{max})\left[\frac{1}{1 + s_{max}(r_{\mathrm{max}}) \int_{r_{min}}^{r_{max}} \frac{\partial s_{max}/\partial r}{s_{max}^2} G(r)dr}\right] \tag{2.7}$$

Conspicuous in the first order condition (equation (2.7)) is that there is an additional term, which is denoted by $[\cdot]$ from equation (2.6). If the denominator of $[\cdot]$ is large, the impact of rainfall on grazing capacity would also be large which would in turn lead to a larger variance of the distribution of $g(r)$. Similarly, if the impact of rainfall and rainfall variability increases, the optimal stocking rate decreases and *vice versa*. In the same way, if $\partial s_{max} / \partial r = 0$, equation (2.7) collapses to equation (2.6), meaning that rainfall has no effect on grazing capacity (Hein and Weikard, 2008: 148).

In equations (2.1) to (2.7), it was implicitly assumed that ecological feedbacks have no effect on range management. However, in practice little decision support is gained if the range manager does not account for rainfall stochasticity and the ecological feedback of high grazing on the vegetation.

2.3.2 Stochastic Range Model and Ecological Feedbacks

Range managers do not have direct control over climatic variables (rainfall and drought) and subsequently forage production but have control over the number and type of animals grazing and browsing the veld. This makes it difficult to model effectively rangeland utilisation because the range manager cannot manipulate rainfall variability and its effect on ecological dynamics. Another difficulty is that there are many causes of ecological dynamics other than livestock grazing and rainfall variability (see section 2.2; Crépin and Lindahl, 2009). Hein and Weikard (2008) suggest that to model effectively the stochasticity of rainfall and the ecological feedbacks of high grazing pressures on the rangeland, emphasis should be paid to the following three issues: 1) forage biomass production; 2) animal production and 3) income.

To evaluate the interaction between rainfall variability, forage biomass production and grazing and its ecological feedback effects, it is important first to consider a situation where there is no grazing on the rangeland. For simplicity, Hein and Weikard (2008) assume that forage production depends on effective rainfall (r) and rain-use efficiency (ρ). O'Connor, Haines and Snyman (2001) exposit that there is a $U-$ shaped relationship between rainfall and rain use efficiency in the semi-arid rangelands of Africa. For example, O'Connor *et al.* (2001) contend that the rain-use efficiency is an inverted U-shaped function of the rainfall. Assuming that rain-use efficiency is positive and bounded in the range (r_{min}, r_{max}), a simple relationship of rain-use efficiency and effective rainfall without grazing can be explained by (Hein and Weikard, 2008):

$$\rho_0 = \alpha(r - r_{min})\left(1 - \frac{r}{r_{max}}\right) \quad (2.8)$$

where ρ_0 captures the rain-use efficiency in the rangeland without grazing. To quantify the effect of rain-use efficiency with grazing, the following relationship can be established:

$$\rho(r, s) = \rho_0 - d(r, s) \quad (2.9)$$

where $d(r, s)$ denotes the reduction in rain-use efficiency due to grazing. Similarly, forage production can be determined by the amount of effective rainfall and the rangeland's rain-use efficiency. This means that forage biomass production F is also a function of the rain-use efficiency of rainfall $(F = \rho r)$. Recalling equation (2.2), the growth of the animal herd can be expressed by substituting equation (2.1) and $(F = \rho r)$ into equation (2.2), which yields (Hein and Weikard, 2008: 133):

$$\Delta s = \beta\left(1 - \frac{s\varphi}{\rho r}\right).s \quad (2.10)$$

Thus given equation (2.1) and $(F = \rho r)$, and the ecological feedback of grazing on rangeland productivity, the profit maximisation problem becomes (Hein and Weikard, 2008):

$$\pi^e = \int_{r_{min}}^{r_{max}} g(r) \cdot \pi(s_{max}(r, s), s)dr \quad (2.11)$$

where s_{max} is the grazing capacity expressed in terms of rain-use efficiency on rainfall and the long-term stocking rate s as shown below:

$$s = s_{max}\,(F\,(\rho(r, s), r)) \quad (2.12)$$

The above equations assume constant prices. This is not adequate since feed fluctuation as a result of, for example, droughts or in cases where there is more than enough rain, may cause prices to vary in sync to the prevailing climatic conditions (Börner *et al.*, 2007). In cases where there are droughts, feed shortages will force rangeland owners to sell-off their animals thus depressing prices. Similarly, an increase in forage because of good rains may induce farmers to hold their animals, thus prompting an increase in the price. Changes in macro-economic pointers may also lead to a change in price, regardless of the prevailing climatic and environmental conditions. It is thus necessary to also factor in price variability.

2.3.3 Stochastic Model with Ecological Feedback and Price Variability

In order to account for the effect of stochastic forage production, rainfall stochasticity, ecological feedbacks and price variability, it is important to augment the profit function with the price effect. This can be done by adjusting the profit function such that it captures the impact of either lower or higher prices because of poor and good rains, respectively. To illustrate the influence of price variability on the optimality condition for rangeland management and utilisation, the production season is divided into two discrete sub periods: years of normal or high rainfall and a drought period.

During drought, farmers receive lower prices (p_b) whereas in years of normal or higher rains, the price increases to (p_a). With that in mind, the profit function becomes (Hein and Weikard, 2008: 135):

$$\pi(r,s) = \begin{cases} -c \cdot s_{max} - c_0 + \eta(p_b - p_a)(s - s_{max}) \text{ if } s > s_{max} \\ p\beta\left(1 - \frac{s}{s_{max}(r,s)}\right)s - c - c_0 \end{cases} \tag{2.13}$$

where η is an adjustment factor that captures the effects of a sequential drought on prices and equals the fraction of drought years that are consecutive to another drought year.

Equation (2.13) shows the influence of high and low periods of rainfall on the profitability of the rangeland. They however do not explicitly consider and model the effects of rainfall variability and stochastic forage production on animal output and thus vegetation/ecological dynamics. For example, Quaas *et al.* (2007) and Muller *et al.* (2007) have shown that the stochastic rainfall and grazing pressure are major determinants of ecological dynamics. Perrings and Walker (1997, 2004) contended that optimal rangeland management involves achieving a steady balance between forage biomass production, rainfall regime and grazing pressure. Moreover, it might seem that, given the discussions in the preceding sections, there is the impact on biodiversity to consider. However, notwithstanding ongoing long-term grazing trials in other areas in the world (e.g. Charters Towers, Queensland, Australia), this study was unable to ascertain the success of such. Perrings (2001) argues that besides the effect of environmental factors, forage biomass production is also influenced by the competition effects between plants and grazing by domestic livestock and wild animals (for extensively managed rangelands). The effect of grazing on a rangeland is through the removal of forage biomass - the rate of which differs and their contribution to biodiversity differs with keystone species (wild herbivores) adding more than domestic livestock – as discussed in the preceding sections.

In order to effectively capture the effects of stochastic rainfall and grazing pressure on ecological dynamics and how they, in turn, influence or affect income, Quaas *et al.* (2007) suggest that one needs to conduct an assessment of the state of vegetation in any given rangeland. Drawing from Stephan, Jeltsch, Wiegand, Wissel and Breiting (1998), Quaas *et al.* (2007) show that this is achieved by considering the green biomass $(G^i(t))$ and the reserve biomass $(R^i(t))$ of representative grass species. Others (Richardson, Hahn and Hoffman (2005)) have used similar approaches of both perennial shrubs and annuals to model the effect of grazing pressure on income. Similarly, Higgins *et al.* (2007) and Börner *et al.* (2007) have shown that both above ground and below ground primary productivity matters in ecological modelling. The green biomass is important because it captures the reproductive part of the plant, which is also what the animals feed on. During the growing season, this part of the plant grows whilst the reserve biomass is the non-photosynthetic part of the plant. Recall that in the preceding sections, it was argued that ecological-economic systems are coupled: rainfall $(r(t))$ influences the amount of available $G^i(t)$ in a given rangeland, in any given year, and is dependent on the $R^i(t)$ and on a growth parameter w_G as shown below (Quaas *et al.*, 2007):

$$G^i(t) = w_G \cdot r(t) \cdot R^i(t) \tag{2.14}$$

In contrast to reserve biomass which is a stock variable, green biomass is a flow variable and is independent of the green biomass from preceding years. Because reserve biomass is a stock variable, its growth differs from the growth of green biomass, mainly because being a stock variable means that rainfall from previous years influences its growth (see Perrings and Walker, 1997). Hence, growth of the reserve biomass from the previous year to the next is (Quaas *et al.*, 2007: 253):

$$R^i(t+1) - R^i(t) = -d \cdot R^i(t) \cdot \left[1 + \frac{R^i(t)}{K}\right] + w_R \cdot (1 - c \cdot x^i(t) \cdot \left[1 - \frac{R^i(t)}{K}\right] \tag{2.15}$$

where w_R is a growth parameter, d is the decomposition rate of reserve biomass (and is assumed to be lower than the green biomass growth parameter, reserve biomass decomposition rate and the rainfall mean). The parameter Kcaptures the density dependency of reserve biomass whilst variable x^i captures the impact of animal grazing on the reserve biomass. The parameter c denotes the rate of reduction in biomass due to grazing. In equation (2.1), it was shown that the grazing capacity depends, largely, on the amount of total forage biomass available on the rangeland. Hence, using the same concept, the total amount of green biomass can be used to denote the carrying capacity and consequently the optimal herd size ($s^*(t)$). Re-writing equation (2.1) yields:

$$s^*(t) = \sum_{i=1}^{I} x^i(t) \cdot G^i(t) \qquad (2.16)$$

However, equations (2.14) to (2.16) require the modeller to know the amount of reserve biomass, which involves many parameters that require intensive fieldwork to obtain. An easier and effective approach that can be employed in the estimation of green biomass growth without guesstimating the parameter values is to calibrate directly models using remotely sensed data[6] (Pickup, 1995; Reeves, Winslow, and Running, 2001; Palmer, Short and Yunusa, 2010). Often, green growth is estimated through forage aboveground net primary production (ANPP). For example, ANPP is used as a measure and control of stock density in rangelands (Baeza, Lezama, Pineiro, Altesor and Paruelo, 2010: 73). According to Grigera *et al.* (2007) and Baeza *et al.* (2010), it is possible to determine the quantity of ANPP by using the amount of photosynthetically active radiation absorbed by green vegetation (APAR), and the effectiveness of that energy's transformation in aboveground dry matter. Accordingly, Grigera *et al.* (2007: 637) define APAR as the product of "incoming photosynthetically active radiation (PAR) and the fraction of photosysnthetically active radiation absorbed by ... [green vegetation] (fPAR)." The fPAR, moreover, can be defined as the energy available for primary production (Stenberg, Rautiainen, Manninen, Voipio and Smolander, 2004). This energy can be used as a proxy for primary production by converting it into an 'estimate green forage biomass' quantity. The Moderate Resolution Imaging Spectroradiometer (MODIS) sensor of the Earth Observing System (EOS)

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[6] Hellegers, Soppe, Perry and Bastiaanssn (2009) and Soppe, Hellegers, Perry, Boon, Bastiaanssen, de Wit and Pelgrum (2006) have recently shown the efficiency of using remote sensing and economic indicators to supplement the decision-making process in South African agriculture. (at the same time the recordings are happening, we cannot be absolutely sure that is the total: if animals are feeding at the same time)...

provides adequate assessment of rangeland vegetation and productivity[7] (Reeves *et al.*, 2001). These estimates of rangeland productivity necessitate the quantification of green forage biomass production (Reeves *et al.*, 2001). Since vegetation productivity is a measure of "rangeland vigour and vegetation growth capacity" which are all important aspects of rangeland management and health evaluation (Revees *et al.*, 2001: 50), MODIS provides time series data for weekly, monthly, and annual estimates of herbage production for the year 2000 onwards (Palmer and Yanusi, 2010).

Drawing from Grigera *et al.* (2007), fPAR is estimated as a non-linear function of MODIS normalised difference vegetation index[8] (NDVI), which is a "spectral index calculated from the reflectance in the red (R) and infrared (IR) portions of electromagnetic spectrum" (Baeza *et al.*, 2010: 73):

$$\mathrm{NDVI} = (\mathrm{IR} - \mathrm{R}) / (\mathrm{IR} + \mathrm{R}) \qquad (2.17)$$

NDVI is directly related (non-linear relationship) to fPAR by green vegetation (Grigera *et al.*, 2007; Reeves *et al.*, 2001) and primary production[9] (Baeza *et al.*, 2010). Using the non-linear relationship between NDVI and fPAR compensates for the so-called saturation of NDVI at a leaf area index of three or greater ($\mathrm{LAI} > 3$) and thus implies that there is a linear relationship between the simple relation index (SR) and fPAR, as shown in equation (4.2) (Grigera *et al.*, 2007):

$$\mathrm{fPAR} = \min[\mathrm{SR}/\mathrm{SR}_{\mathrm{max}} - \mathrm{SR}_{\mathrm{min}}) - \mathrm{SR}_{\mathrm{min}}/\mathrm{SR}_{\mathrm{max}} - \mathrm{SR}_{\mathrm{max}}), 0.95] \qquad (2.18)$$

where $\mathrm{SR} = (1 + (\mathrm{NDVI})/(1\text{-}\mathrm{NDVI}) = \mathrm{IR}/\mathrm{R})$ and NDVI is assumed not to absorb when there is no green vegetation due to erosion, environmental degradation or any form of bare soils, meaning that: $\mathrm{fPAR} = 0$ (Baeza *et al.*, 2010; Grigera *et al.*, 2007). The fPAR is converted into green forage biomass ($Forage_t$) production at time, t, using the following equation:

$$Forage_t = \alpha\beta - \varpi \qquad (2.19)$$

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[7] Melesse, Weng, Thenkabail and Senay (2007) give a brief but informative summary of the history of remote sensing satellites and sensors, and particularly contrast them with respect to ease of use, efficiency and availability.

[8] Reeves *et al.* (2001) justify the use of remote sensing techniques to quantify biomass by arguing that: "[t]he MODIS ... [8 days] productivity logic combines remote sensing data and daily climatalogical inputs with fundamental principles of plant growth. The remotely sensed data provides a snapshot of greenness and leaf area as daily weather information influences growth capacity. This approach permits the estimation of productivity across multiple range sites and biomes."

[9] The conceptual link on fPAR and primary production is found on Monteith (1972).

where α and ϖ are constants expressing the response of green biomass to environmental conditions of β which is an 8 day interval fPAR coefficient, that is converted into eight days' and later monthly fPAR and subsequently yearly green forage biomass production. Substituting $Forage_t$ to equation (2.16), yields:

$$s^*(t) = \sum_{i=1}^{I} x^i(t) \cdot Forage_t \tag{2.20}$$

where $x^i(t)$ captures the impact of grazing on the green forage biomass at time t. Likewise, the herd size ($s^*(t)$) kept on the farm in year t determines the farmer's income $y(t)$ in year t, as shown below:

$$y(t) = \tilde{p} \cdot s^*(t) \tag{2.20}$$

Equation (2.20) and (2.20) shows that 1) the herd size is a random variable and 2) that income is a random variable. The farmer is assumed to adopt an ecological-economic system because it is profitable (Quaas *et al.*, 2007). Note that the number of animals varies with the total amount of precipitation since the system is driven by highly variable rainfall. Similarly, the farmer varies his herd size on the chosen ecological-economic system with available green forage biomass. In other words, the carrying capacity of the farm changes as per the amount of rainfall in a given season. In domestic livestock farming, farmers can maintain the same number of animals by providing supplementary feeding in winter, whereas in game ranching, the animals use a set of biological and evolutionary competences to survive winter feed shortages. From the above analysis, it can be argued that rainfall variability imposes a great deal of risk and uncertainty on the amount of green forage biomass that can be produced from the rangeland, the herd size in the rangeland and the income (gross margins) that can be gleaned from the rangeland.

The decision making process, of whether to convert from one utilisation system to another hinges strongly on these factors. The choice of rangeland utilisation ecological-economic system by the farmer, for that reason, will depend on the pay-off of each utilisation system; where the pay-off can be looked at as the profitability of the chosen utilisation system. Thus, in the sense of Quaas *et al.* (2007) and assuming that the farmer is risk averse and non-satiated in income with a utility function that depends only on his income $y(t)$, his von Neumann-Morgenstern intertemporal expected utility function can be expressed as:

$$U = \sum_{t=1}^{\infty} \frac{\varepsilon_t u(y(t))}{(1+\delta)^{t-1}} \tag{2.21}$$

where $\delta$is a discount factor and $u(\cdot)$ is a strictly concave Bernoulli utility function of income, y, with an expectancy operator ε_t at time, t. Specifying the farmer's utility function with relative risk aversion yields:

$$u(y) = \frac{y^{1-\rho}-1}{1-\rho} \tag{2.22}$$

where ρ is a parameter that measures the degree of relative risk aversion of the farmer (Quaas *et al.* 2007) and is greater than or equal to zero ($\rho \geq 0$) since the farmer is assumed to be risk averse (Baumgartner, 2007).

According to Baumgartner and Quaas (2005), the farmer will choose the utilisation system that will maximize his von Neumann-Morgenstern intertemporal expected utility function. Hence, acknowledging the influence of risk and uncertainty on the profit structure of the farm, the mean income of the farmer, consequently, can be thought of as influenced by the utilisation system chosen (Quaas *et al.*, 2007). However, it should be qualified that the choice of a utilisation system is constrained by the subjective beliefs of the farmer, which depends on a variety of factors: including his resources, and perceptions about future states of nature. For example, a farmer can be either farsighted or myopic, depending on his subjective beliefs. A farmer, who is not concerned about the future sustainability of his rangeland (myopic), is most likely to behave rationally by choosing the utilisation system that maximises his expected utility in the short term without considering the effect of the chosen utilization system on the environment. However, a farsighted farmer (one who is forward looking and is concerned about the sustainability of his farming enterprise) chooses a utilisation system such that he obtains an ecological insurance from the ecosystem (Quaas *et al.*, 2007; Baumgartner, 2007; Baumgartner and Quaas, 2005).

No studies have used the above methods to explore the profitability of converting a sheep farm into a springbuck ranch. However, there are some studies which have sought to understand the effects of risk and uncertainty in the decision making process in agriculture. In the following section, a review of those studies that have used a combination of both economic and ecological models to explore the effects of uncertainty on the decision making process, is made.

2.4 Economic Studies on Rangeland Utilisation

A growing number of economic studies address the effects of both biotic and abiotic factors in rangeland utilisation systems. The approaches differ from one study to another depending on the fundamental objectives of each study. Objectives in themselves differ, depending on the focus of the study. Typical objectives include but are not limited to:

- identifying optimal rangeland management strategies under rainfall and price uncertainty (Higgins *et al.*, 2007; Borner *et al.*, 2007; Janssen *et al.*, 2004);
- reporting rangeland managers' actual responses to rainfall variability and biomass uncertainty and the inherent uncertainties as a result of the stochasticity of abiotic factors (Quass *et al.*, 2007; Gross *et al.*, 2006);
- assessing the effects of abiotic and biotic processes on the range management decision making process (Kobayashi *et al.*, 2009);
- examining the applicability of both the non-equilibrium and equilibrium paradigms in the sustainability of semi-arid pastoral systems (Richardson, Hahn and Hoffman, 2005);
- estimating the economic impacts of conservation in the optimal use of rangelands and how it interacts with the two paradigms (Perrings and Walker, 2004); and
- analysing the effects of trade on land use and the consequences of these on biodiversity conservation (Polasky *et al.*, 2004; Barbier and Schulz, 1997).

Evidently, no studies have explored the profitability of converting a sheep farm into a springbuck ranch. A handful of studies, however, have studied the interaction between herbivory and biomass production in the presence of uncertainty (Quaas *et al.*, 2007; Higgins *et al.*, 2007; Börner *et al.*, 2007, Muller *et al.* 2007; Janssen *et al.*, 2004). These studies modelled the effect of different grazing management systems on the income structure of the farm using simulation and dynamic programming and came out with varying results. For example, Quaas *et al.* (2007) used an integrated dynamic and stochastic ecological-economic model to analyse the choice of grazing management strategies of a risk-averse farmer and the long-term ecological and economic impact of different utilisation strategies. They identified grazing management as the crucial link between forage biomass, livestock and profitability. These authors further isolated livestock grazing as the driver of ecological dynamics and juxtaposed that stocking rate and the farmer's income, however, are influenced by the degree of rainfall variability. In their results, they reported that a myopic farmer is unlikely to consider future economic and ecological effects of any management strategy on the environment, as long as it is conservative enough to be sustainable.

Muller *et al.* (2007), on the other hand, developed a simulation-based model and used it to analyse the relevance of rest periods in non-equilibrium systems. They reported that improved farming conditions (supplementary feeding, etc.) could lead to both negative ecological as well as economic ramifications on the rangeland. Even though the authors (Muller *et al.*, 2007) explore possible solutions to rectify the situation, they did not look outside of domestic farming. This is despite the realisation by amongst others, Crépin and Lindahl (2009) that there is eminent competition between resource users in which when not factored may lead to a compromised understanding of the economic aspects of the causes of the deterioration of natural systems. Boerner *et al.* (2007) investigated the effects of deterministic and stochastic prices on the management functions of an ecological-economic system, using a simulation-optimisation model and reported that optimal rangeland management is likely to cause the system to crash thus making livestock holding unprofitable. Using a simulation model, Higgins *et al.* (2007) factored in a mix of both deterministic linkages (effect of forage biomass on animal production) and stochastic effects (rainfall on forage biomass) in analysing the sustainable management of livestock production systems and showed that opportunistic strategies of range management are not optimal. Similarly, in a bid to understand the effects of rancher and animal interactions, Kobayashi *et al.* (2009) constructed a bio-economic model and solved it using a stochastic dynamic programming (SDP) solution technique. The authors addressed the type and nature of trade-offs that ranchers would face given more proactive land treatments. Their results highlighted reasons other than economic gains that act as incentives to private landholders to adopt rangeland management treatments that are preventative.

Other studies have in one way or another explored the issue of the decision-making process under uncertainty in rangeland ecosystems. For example, Kobayashi *et al.* (2007) model the effect of stochastic rangeland use under capital constraints. Using a stochastic dynamic programming model, they concluded that capital constraints are pertinent in explaining low stocking densities in Kazakhstan. Using a genetic algorithm, Janssen *et al.* (2004) developed robust rangeland management strategies for two systems: one with highly variable rainfall and the other where the ranch manager ignores rainfall variability. By comparing the two optimal solutions, the authors illustrated that rainfall variability and its related uncertainty may lead to a reduction of the possible expected returns from grazing activity. In a stylised mathematical model by Anderies *et al.* (2002), an exploration of the effects of physical, ecological and economic factors on the resilience of a fire driven rangeland system, was undertaken. They (Anderies *et al.*) reported that the costs of shrub management, because of poor grazing decisions, have a significant effect on the stability of the ecosystem. In conclusion, they argued that the resilience of rangelands based ecosystems is highly influenced by ecological, economic, and management parameters.

A growing number of other studies have analysed the response of ecological systems under different range management strategies (Smet and Ward, 2005; Fynn and O'Connor, 2000; Perrings and Walker, 2004; Quaas *et al.*, 2007; Muller *et al.*, 2007), some of which were modelbased, whilst others were survey-based studies. These studies advocate adaptive rangeland management strategies as the ideal way to manage rangelands under rainfall and forage stochasticity. They, however, identify optimal stocking rates and grazing pressure as other factors that need to be considered in range management. The studies use a wide range of models and methods to explore the common strategies used in rangeland management and utilisation. In the semi-arid rangelands of southern Africa, however, survey based studies (Smith and Wilson, 2002; Milton *et al.*, 2003; Joubert *et al.*, 2007) isolated, *inter alia*, diminishing profitability and growing concerns over rangeland degradation in livestock based rangeland utilisation economic systems (Milton *et al.*, 2003) as a major stimulant in the uptake of game ranching by landowners.

Whilst survey based studies complement model based studies by providing further insights about the optimality of alternate rangeland management strategies, they, however, provide a less vivid picture of the decision making process when converting from livestock to game based rangeland utilisation economic systems. First, these studies focus entirely on domestic livestock farming and do not report the likely effects that evidence of profitability in game meat production for instance might have on the decision making process. They further do not explore the policy implications of the profitability of game meat production on the reclamation of degraded rangelands. One prominent argument that has been identified for this failure to look outside domestic livestock farming for solutions that will put an end to the degradation problem in natural ecosystems is what Hodgson *et al.* (2005) have termed, a "powerful economic deterrent" that prevents any innovative ideas outside of the conventional agricultural uses of natural ecosystems.

For instance, Smet and Ward (2005) compared the effects of different rangeland management systems on plant species composition, diversity and vegetation structure in a semi-arid rangeland of South Africa, and reported that systems under both livestock and game utilisation are most likely to perform better (environmentally) than livestock dominated ones. They further argued that herbivore diversity is not only good from an income point of view but that it can also act as a stabilising effect on rangeland productivity in light of rainfall and forage stochasticity, further confirming the importance of biodiversity in rangelands. However, notwithstanding their findings, these researchers did not investigate the profitability of converting from livestock farming to game ranching enterprises. Standiford and Howitt (1992: 421) have shown that the inclusion of stochasticity in range management shifts production away from livestock based utilisation to "less risky ... hunting enterprises." Baumgartner and Quaas (2005) demonstrate that ecosystem management depends on the degree of risk aversion of the decision maker and on the properties of the ecosystem. They further show that risk averse decision makers take cognizance of the value of the insurance offered by the rangeland ecosystem such that with increasing uncertainty farmers become more risk averse and they express this by looking for alternatives that will improve the quality of the rangeland (ecological insurance).

The above reviewed studies illustrate that the formation of a rangeland utilisation strategy and the set of relevant range management parameters vary across rangeland ecosystems. Moreover, they also show that the inclusion of risk in the decision making process can influence economic agents to convert into those ecological-economic systems which are potentially less risky or those that will provide them with ecological insurance. However, the results for any one study in any one rangeland do not necessarily transfer to other rangeland ecosystems.

Nevertheless, the tools of analysis are transferable; the degree to which method is suitable for a chosen rangeland depends largely on the assumptions about uncertainty and ecological dynamics of the system. Three alternative sets of assumptions are common: 1) certainty with no ecological dynamics (fixed rainfall and forage production) (Hildreth and Riewe, 1963); 2) uncertainty with ecological dynamics (Janssen *et al.*, 2004; Perrings and Walker, 2004); and 3) uncertainty with ecological dynamics and price variability (Hein and Weikard, 2008; Börner *et al.*, 2007; Muller *et al.*, 2007; Kobayashi *et al.*, 2009).

Uncertainty is often introduced by the stochasticity of rainfall (Quaas *et al.*, 2007) and through price variability (Hein and Weikard, 2008). In the literature, a group of studies that have used this set of assumptions to explore the management of a rangeland under uncertainty were reviewed (Kobayashi *et al.*, 2009; Hein and Weikard, 2008; Higgins *et al.*, 2007; Quaas *et al.*, 2007; Muller *et al.*, 2007; Richardson *et al.*, 2005; Janssen *et al.*, 2004; Perrings and Walker, 2004; Beukes *et al.*, 2002; Perrings, 2001; Perrings and Walker, 1997; Standiford and Howitt, 1992). However, based on this review, no studies were found to have used this set of assumptions in the context of assessing and comparing the profitability of converting a livestock farm into game ranch (which is the goal of this thesis). Whilst others (Perrings and Walker, 2004; Perrings, 2001; Perrings and Walker, 1997) have included wild animals in their studies, they merely abstract from them and do not explore the effects of these assumptions on the livestock farm/game ranch management decision-making process, concerning profitability and economic sustainability. This is probably because most rangeland ecosystems are traditionally used for domestic livestock, hence most researchers focus on the traditional economic systems taking place on them, than on what other ecological-economic systems are possible on these rangelands. Another explanation could be that, for a long period, game was considered a non-viable rangeland use enterprise, but has since gained much precedence in rangelands, as new evidence emanating from South Africa has shown that game ranching is in fact a viable land use option (Tomlinson *et al.*, 2002). Thus in order to develop better utilisation strategies, it is imperative that the economics of competing ecological-economic are studied to understand the influence of risk and uncertainty on their profitability and the decision making process by economic agents – which is the main goal of this study.

In a recent study by Moloney and Hearne (2009), an attempt is made to analyse the population dynamics of converting from cattle farming to Kangaroo production, in Australia. Moloney and Hearne's (2009) study, like this study, responds to the growing calls to return to natural production systems in a bid to halt continued degradation as a result of livestock farming in semi-arid to arid rangelands (both in Australia and South Africa). Whilst their (Moloney and Hearne's) study focuses on the interaction between livestock and wild animals, the gist is on population dynamics, as opposed to the profitability and economic sustainability therein – which is the focus of this study.

2.5 Conclusions

The literature reviewed has emphasised the pertinent issues that need to be considered when evaluating the relative profitability of alternative rangelands utilisation strategies. Firstly, the literature review has discussed how monotonous livestock farming has compromised biodiversity in rangelands, which has manifested in poor biological productivity of such systems. However, the review has also shown that game animals can act as a buffer to ecological resilience more especially if such animals are natural capital (keystone species) in an area. Secondly, the literature review has identified the dominant theories that govern rangeland management, and has highlighted the importance of using the appropriate paradigm in explaining the impact of different rangelands use strategies on ecological dynamics and profitability. Studies on southern African rangelands have emphasised the importance of rainfall, forage biomass production and price variability on the income structure of the rangeland utilisation economic systems. In this context of this research, the literature review revealed that because of the deleterious effects of domestic livestock on the environment, rangeland owners are increasingly switching to game ranching in an effort to improve the income structure of their enterprises. It was also argued that in semi-arid to arid regions of South Africa, such conversions are being spurred by the desire to reclaim degraded lands and halt crippling desertification. The conclusion is drawn that the potential to use and manage rangelands more efficiently by risk-averse decision makers, hinges strongly on the profitability of those ecological-economic systems that promote biological diversity given rainfall variability, forage biomass production stochasticity and price variability. To that extent, any information that would increase the potential to use rangelands in a more sustainable way (i.e. improve ecological resilience and biodiversity) whilst sustaining the livelihood of the rangeland owner, will aid the decision making process of whether to convert to game ranching.

Such information could include understanding the effects of both livestock and game grazing (browsing) pressure on forage biomass or the effect of rainfall stochasticity on forage biomass production in a given period, and how this could affect the profitability and economic sustainability of the respective enterprises. It could also entail developing a rounded feel of how risk and uncertainty would impact the profitability of domestic livestock versus game ranching utilisation systems. Moreover, continued livestock production in rangelands in semi-arid areas where there is a high degree of degradation and compromised biological diversity, and high rainfall and green forage biomass production variability in conjunction with price uncertainty may cause risk-averse decision makers to adopt those utilisation systems that will improve ecological insurance, such as game ranching. However, this is only going to happen once rangeland owners and decision makers have been convinced that such alternative economic system are more profitable than the current utilisation economic system, essentially domestic livestock farming. It can be concluded that the level of profitability of the alternative enterprise and the level of risk aversion will largely determine whether a farmer continues with livestock farming, switches to game ranching, or maintains a balance of the two. This is because livestock farming is highly dependent on prevailing weather conditions, forage biomass production and price variability.

In the next chapter, a detailed analysis of decision making under uncertainty is provided.

Chapter 3.

DECISION MAKING UNDER UNCERTAINTY

3.1 Introduction

The management of rangelands involves making decisions under a constantly changing production and economic environment (Carande *et al.*, 1995). In the previous section, it was shown that the sources of uncertainty in semi and arid rangelands derive from both abiotic (non-equilibrium) and biotic (equilibrium) factors. It was particularly shown that because of rainfall stochasticity, farmers and ranchers are faced with biomass production uncertainty, which imposes further uncertainty on the number of animals, the type of range utilisation system that the range manager can employ and subsequently the profit structure of the farming / ranching enterprise. Moreover, farmers and ranchers also have subjective beliefs about the probability of occurrence of different states of nature, which intertwined with their resources (both physical and financial), management objectives, and particularly their risk attitudes, play a pivotal role in their decision making process.

In order to access the profitability of converting a sheep farm into a springbuck ranch a basic understanding of the theory on decision-making under uncertainty is necessary. Focusing on risk is important because it "...serves to emphasize that ... the risk of any ... [alternative] has to be weighed against its profitability. Thus both profitability and risk have to be incorporated in the decision making process" (Levy, 2006: 25). Moreover, rangeland owners face many alternative rangeland utilisation choices. Such choices, however, are limited by the degree and level of risk exposure, and the subjective beliefs of the decision makers. Thus, to compare the risk and return of alternative rangeland utilisation strategies, a fundamental understanding of decision criteria, therefore, is essential.

This chapter discusses the theory on decision-making under uncertainty. It further presents the procedures that under-pin the decision-making under uncertainty. Particular procedures and empirical studies that have been used to quantify the effects of uncertainty on the decision-making process are reviewed. The chapter is concluded with a detailed discussion of the procedures that accompany the stochastic efficiency with respect to a function (SERF) and economic sustainability methods, selected to implement the empirical economic analyses of this study.

3.2 Subjective Expected Utility Hypothesis and Analysis

Decision-making under uncertainty, generally, is based on the assumptions of the subjective expected utility (SEU) hypothesis, which finds its theoretical foundations in the provisions of the utility theory (Hardaker, Richardson, Lien and Schuman, 2004ba; Anderson and Hardaker, 2003). The theory of utility and expected utility-maximising behaviour dates back to Daniel Bernoulli's 1738 seminal paper which was translated into English in 1954. In particular, Bernoulli (1954) introduced four axioms related to choices amongst risky prospects namely; ordering, transitivity, continuity and independence. Amongst others, Hardaker *et al.* (2004a: 35 – 36) have interpreted these axioms as follows. There is an ordering axiom if faced with two risky prospects, a_1 and a_2, the decision-maker (DM) prefers one risky prospect to the other or is indifferent between the two. Transitivity implies a case where the risky prospect, a_1 is preferred to a_2 and in a similar fashion a_2 is preferred to another risky prospect a_3. In the continuity axiom, the DM is assumed to prefer a_1 to a_2 and a_2 to a_3 and that there exists a subjective probability $P(a_1)$, not zero or one, that makes the DM indifferent to a_2 and a lottery yielding a_1 with probability $P(a_1)$ and a_3 with probability $1 - P(a_1)$. Lastly, the independence axiom relates to a case where the DM prefers a_1 to a_2 and, a_3 is any other risky prospect, such that the DM will prefer a lottery yielding a_2 and a_3 when $P(a_1) = P(a_3)$.

These four axioms are the building blocks of the Bernoulli principle, otherwise known, after the work of Leonardo Savage (1954), as the subjective expected utility (SEU) hypothesis. The axiomatic conditions imply that there exists a utility function $U : A \rightarrow R$ for which: if $a_1, a_2 \epsilon A$[10] $a_1 < a_2$ holds, then $U(a_1) < U(a_2)$, such that the DM's utility function can be specified as a function of the possible decisions (Ladanyi, 2008: 148):

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[10] Where $a_j (a_j \in A$, the set of all possible choices) denotes one of the decisions between which the decision maker must choose, the uncertain states of nature by S_i $(i \in I, j \in J, I$ and J are sets of indexes) and their (subjective probability with $P(S_i)$. X_{ij} denotes the consequences of the jth act given the state S_i (Ladanyi, 2008: 148).

$$U(a_j) = \sum_i U\,(A_j|S_i) \cdot P(S_i) \text{ for discrete probability or}$$

$$U(a_j) = \int U(a_j|\,S) \cdot P(S) \text{for continuous probability} \qquad (3.1)$$

The SEU hypothesis states that the utility or index of relative preferences, of a risky prospect is the decision maker's expected utility for that prospect (Anderson and Hardaker, 2003: 171). This basically implies that, faced with a choice amongst alternative risky prospects, it is hypothesised that the decision maker will opt for the prospect with the highest expected utility (Kim, 1991: 253). This hypothesis is particularly appealing because of its three intrinsic properties. The first property highlights the importance of utility values under uncertainty, and shows that they can be used to rank risky prospects – with the one having the highest utility being the most preferred. The second property pertains to the utility of a risky prospect and postulates that it is its expected utility. The third and final property affirms that a given utility function can be defined only up to a positive linear transformation – meaning that: "it makes no sense to say that one risky prospect yields 20% more utility than another, since a shift in the origin or scale will change the proportional difference" (Hardaker *et al.*, 2004a: 35 - 36).

As a rule of thumb, "[r]isk assessment requires coming to grips with both probabilities and preferences for outcomes held by the decision maker" (Hardaker *et al.* 2004b: 253; Anderson and Hardaker, 2003: 171). As a provision, the SEU hypothesis requires that, for the assessment of risky alternatives, the decision-maker's utility function for outcomes be specified. This is because, in the SEU sense, the shape of the utility function reflects an individual's attitude towards risk or his preference for actions (Anderson and Hardaker, 2003). In practice, however, this is seldom the norm. For example, in order to put the SEU hypothesis to work in the analysis of risky prospects in agriculture, Anderson and Hardaker (2003) contend that there is need to elicit the decision maker's utility function. This is despite the realisation that empirical evidence exists that "functions obtained [in this way] are vulnerable to interviewer bias and to bias from the way questions are framed" (Anderson and Hardaker, 2003: 173).

For this reason, Rabin and Thaler (2001) and Rabin (2000) assert that the SEU hypothesis is a flawed theory of choice. They argue that its analysis is not enough in explaining the behaviour of decision makers faced with uncertainty (Rabin, 2000; Rabin and Thaler, 2001). As an illustration, Allais (1984) as cited by Hardaker *et al.* (2004b: 254) criticized the SEU hypothesis because of its long-standing history of inconsistency with theory in certain risky choice situations. One of the major problems in using the SEU hypothesis in analysing risky alternatives in agriculture is the difficulty faced when attempting to elicit an individual's utility function (Anderson and Hardaker, 2003). Hardaker *et al.* (2004b: 254) posit that where it has been tried, the results have been rather "scanty and unconvincing". Another setback with expected utility values for decision analysis is that they are difficult to understand and do not present an opportunity to assess the magnitude between alternatives, as opposed to using, for instance, the certainty equivalents of risky prospects (Hardaker *et al.*, 2004a).

Partly to stay away from the need to obtain a specific single-valued utility function, methods under the caption of stochastic dominance criteria have been developed.

3.3 Stochastic Dominance Criterion

Hardaker *et al.* (2004b: 254) defines a stochastic dominance criterion as a "decision rule that provides a partial ordering of risky alternatives for DM whose preferences conform to specified conditions about their utility functions (preferences for consequences)". It is a much more discriminating version of the subjective expected utility analysis. Stochastic dominance rules and other investment rules (e.g. the mean – variance rule) employ partial information on the DM's preferences. Because of this, they tend to produce only partial orderings as opposed to complete ordering. This makes it near impossible to know the precise shape of the utility function (Levy, 2006: 49). According to McConnell and Dillon (1997), the stochastic dominance criteria is particularly appealing and attractive because 1) it does not require the elicitation of the decision maker's utility function, 2) it bases its comparisons on direct full probability distributions of outcomes, and 3) it is easier to use: it only requires a computer and compatible software.

Essentially, stochastic dominance methods entail pairwise comparison of alternatives, thus with a larger number of alternatives, the potential number of comparisons also increases exponentially thus increasing chances of an inefficient analysis (Hardaker *et al.*, 2004a). For instance, in reality, DMs often face a wide range of investment alternatives (Levy, 2006). These make the feasible set (FS). An example of such a set would be a DM who is faced with various rangeland utilisation alternatives ranging from wool sheep farming (A), springbuck ranching for venison production (B), mutton sheep farming(C), beef cattle farming (D) or goat farming for mohair (E) and has to choose amongst them. Assuming that the decision-maker faces these five alternatives only, the decision making process would entail first dividing these alternatives into two sets: one efficient, and the other inefficient. For illustration purposes, the five feasible alternatives (called the feasible set) as shown in Figure 3.1, are divided into two mutually exclusive and comprehensive sets, called the inefficient set (IS) and the efficient set (ES), as depicted by equation (3.2);

$$ES\ U\ IS\ =\ FS \text{ (where } U \text{ denotes union)} \tag{3.2}$$

Figure 3.1 demonstrates the division of the feasible set, FS, into the two sets IS and ES. Particularly, in this example, the FS consists of the five feasible alternatives A, B, C, D and E. Each alternative included in the feasible set must either be in the EF or in the IS. Given the utility function U' denoted by $U' \geq 0$ and assuming that the only information available is that $U' \geq 0$, consequently, $U \in U_{\mathbf{i}}$ if $U' \geq 0$ where U_{i} is the set of all non-decreasing utility functions.

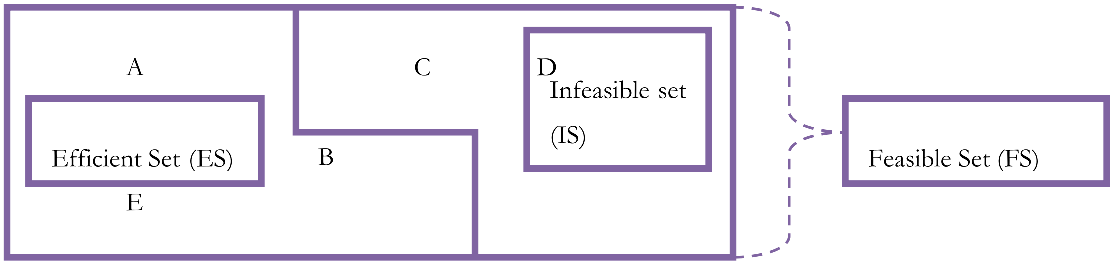

Figure 3.1: The Feasible, Efficient and Inefficient Sets (Source: Levy, 2006: 50).

To demonstrate how the concept of the efficient set works, Levy (2006: 50) introduces the following definitions:

Dominance in $\mathrm{U_I}$: means that alternative I dominates alternative II in U_I for all utility functions such that if $U \in U_I, E_1U(x) \geq E_{II}U(x)$ and for at least one utility function $U_0 \in U_I$, there is a strict inequality.

Efficient set in U_t: means that an investment is included in the efficient set if there is no other alternatives that dominates it. The efficient set includes all undominated alternatives. As shown in Figure 3.1, alternatives A and B are efficient. Neither A nor B dominates the other meaning that there is a utility function $U_1 \in U_I$ such that:

$$E_{\mathrm{A}}U_1(x) > E_{\mathrm{B}}\ U_1(x) \tag{3.3}$$

and there is another utility function, $U_2\ \in U_i$ such that

$$E_{\mathrm{B}}\ U_2(x) > E_{\mathrm{A}}\ U_2(x) \tag{3.4}$$

This basically means that neither A nor B is the "best" for all DMs included in the group $U\ \in\ U_i$. In other words, it implies that some DMs may prefer A whilst some may prefer B, and that there is no dominance between A and B.

Inefficient set in U_1: the inefficient set includes all inefficient risky alternatives. An inefficient set can be defined as a set with at least one alternative in the efficient set that dominates it. Figure 3.1 shows that the investment alternatives C, D, and E are inefficient. This consequently implies that we may have the following relationships:

$$E_A\ U(x) > E_C\ U(x) \tag{3.5a}$$

$$E_A U(x) > E_D\ U(x) \tag{3.5b}$$

$$E_B U(x) > E_E\ U(x) \tag{3.5c}$$

For all $U\ \in\ U_1$.

Equation 3.5a and 3.5b indicate that the efficient alternative A dominates alternative C and D, while equation 3.5c indicate that the efficient alternative B dominates E. However, cognisance should be taken to the fact that once an alternative has been dominated by one efficient set; that alone is enough to relegate it to the inefficient set – as opposed to having it dominated by all efficient alternatives (Levy, 2006: 51). This can be shown by bringing in another function which introduces or shows that E is above A which adds no weight to the partial ordering because E is already dominated by B (as shown in equation 3.5c above) and hence no DM will select it as it is already in the inefficient set; as shown below (Levy, 2006: 51):

$$E_A U(x)\ > E_E\ U(x)\ \text{ For all U} \in U_1 \tag{3.6}$$

In essence, the partition of the feasible set, FS, to the efficient set (ES) and inefficient set (IS) will entirely depend on the data set available. As shown in the above example, Levy (2006: 49 - 52) explains that any other assumptions made on the utility function would have to change the given utilities to a new set of utilities corresponding to the assumed information. Moreover, in generic terms, the DM is always better off if the efficient set is smaller relative to the feasible set. As it shall be shown later, the strength of the stochastic dominance criterion is improved if more assumptions or information on preferences or on the distribution of returns are introduced thus giving a more restricted efficient term (Levy, 2006).

This realisation highlights one of the main disadvantages of investment choices with partial information (hence partial ordering): they involve two decision stages. The first stage involves the consultant or investment expert and is known as the objective decision. The objective decision comprises the partial ordering and screening of investments and is concluded by dividing the FS into the ES and IS. Whereas, the other decision making stage is at a personal level and is mainly concerned with the individual DM and is known as the subjective decision. The subjective decision is made up of the optimum investment choices emanating from the DM. It is called the subjective decision because it is dependent on the DM's preferences and is based on the contents of the ES (Levy, 2006: 52).

However, various forms of stochastic dominance analysis that particularly vary as per the available information based on the subjective preferences of DMs are available. These methods also depend on the type and strength of assumptions made about the functionality of the "utility function and the risk attitudes implied" (Hardaker *et al.*, 2004a: 147). As already mentioned, stochastic dominance or efficiency methods are based on the subjective expected utility maximisation principle, wherein alternative risky prospects are on the main compared in terms of probability outcomes, thus yielding a more meaningful output than would have been otherwise. In the following subsection, a detailed description of the various forms of stochastic dominance are reviewed and their strengths and weaknesses given.

3.3.1 First degree stochastic dominance

The concept of first degree stochastic dominance (FSD) is well known in economic literature, and was first introduced by Hadar and Russell (1969), as a way of solving the problem for the unusual case of $r_1(x) = -\infty$ and $r_2(x) = +\infty$ (Hardaker *et al.*, 2004a: 255). Levy (2006: 55) defines the FSD rule as a criterion that can be used to assess whether an investment dominates another investment when the available information is limited. Consequently, in stochastic dominance criterion, information is considered limited if $U \in U'$ given that $U' \geq 0$ and that U is in the range $U' > 0$ and this assumption is adopted to avoid the trivial case of U' coinciding with the horizontal axis. The weak assumption on preference is adopted because of the idea that DMs prefer more wealth than less - conforming to the monotonicity axiom (Levy, 2006).

Consider two investment alternatives; wool sheep farming (F) and springbuck ranching (G), with a stochastic (uncertain) outcome x, which is bounded in the range $[a, b]$, the cumulative probability distributions (or cumulative distribution functions (CDFs)) of these two alternatives can be denoted by $F(x)$ and $G(x)$. F is said to dominate G by FSD if and only if $F(x) \leq G(x)$ for all x, with a strict inequality for at least one value x_0. "FSD expresses the fact that under $F(x)$ the random variable is "bigger" than under $G(x)$" (Meyer, 2001: 11). If F dominates G by FSD, then all DMs with non-decreasing utility functions (concave, convex, or with both concave and convex segments) prefer F over G. Thus, it can be argued that the FSD criterion corresponds to all types of utility functions as long as they are non-decreasing in wealth and twice differentiable (Levy and Levy, 2001: 235; Levy 2006: 55 – 59). In a graphical illustration, this means that the CDF curve of the dominating risky prospect (in this case F) must always lie below and to the right of the risky prospect being dominated (G) and that for a risky prospect to dominate another in the first degree sense, their CDF curves must not cross each other, as shown in Figure 3.2. However, in practice, as it shall be shown later, it is possible to rank alternatives even though their curves cross each other. This shows that the FSD has limited discriminatory power (Hardaker *et al.*, 2004b: 147 – 149).

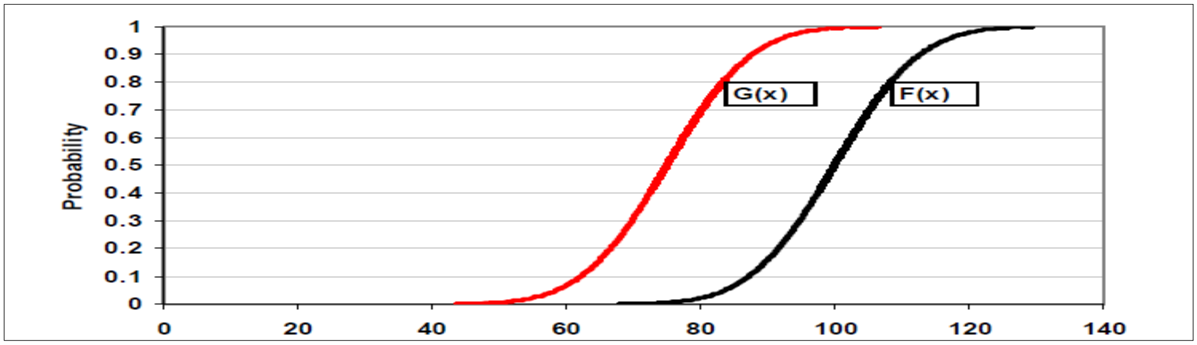

Figure 3.2: Illustration of First Degree Stochastic dominance (Source: Richardson and Outlaw, 2008: 215).

3.3.2 Second Degree Stochastic Dominance

Hadar and Russell (1969), introduced Second Degree Stochastic Dominance (SSD), as a technique of forecasting a decision maker's preference among specified pairs of risky alternatives in the absence of concrete information about a decision maker's utility function apart from the fact that it exhibits risk aversion properties. By giving necessary and sufficient conditions on a pair of risky prospects, the SSD makes it possible for decision makers who are risk averse to choose amongst a pair of risky prospects (Meyer, 1977: 477). One of the advantages of the SSD is its ability to characterise the pairs of risky prospects for which risk averse decision makers are unanimous in choosing one over the other. In particular, *F* is said to dominate *G* by SSD for all non-decreasing risk averse utility functions (i.e. all functions with decreasing marginal utility), if and only if (Hadar and Russell, 1971: 294)

$$\int_a^y [\mathrm{G}(x) - \mathrm{F}(x)] \; dx \geq 0 \text{ for all values of } y \tag{3.7}$$

with at least one strict inequality. Just like in FSD, "SSD indicates that the variable is bigger and or less risky under $F(x)$ than $G(x)$" (Meyer, 2001). Hardaker *et al.* (2004b: 255) agree that it is possible to order alternatives for decision makers who prefer more wealth to less and have absolute risk aversion with respect to wealth by using the FSD, between the bounds $-\infty < r_a(w) > r_a(w) + \infty$, whilst for the SSD the risk aversion bounds changes to $0 < r_a(w) > r_a(w) + \infty$, since it is assumed that such decision makers are not risk preferring. This has been argued to imply that the SSD takes cognisance of the possibility that some decision makers may possess an absolute risk aversion parameter that is so large that "the utility of a small difference at the lowest observation is extraordinarily important" (Hardaker *et al.*, 2004b: 255).

However, empirical work has suggested that these two forms of analysis are not adequately instructive to yield outcomes that can be considered as useful in making concrete decisions, particularly because the size of the efficient set is considered too large to be easily manageable (King and Robinson, 1981). In particular, Meyer(1977a) argues that the problem with the FSD and SSD criterion is that they fail to adequately capture and describe objects of choice of a group of decision makers or agents. Interestingly, allowing for extreme risk aversion is unrealistic particularly in relation to loss aversion. However, as Meyer (1977a) shows, a case can be made to base analysis on a more restricted range. It was on this basis that Meyer (1977b) introduced a more restricted procedure to circumvent the inefficiencies of the first and second degree stochastic dominance decision rules.

3.3.3 Stochastic Dominance with Respect to a Function

Stochastic dominance with respect to a function (SDRF) allows for tighter restrictions on risk aversion (Hardaker *et al.* 2004b: 255). Meyer (1977a) hypothesises that the general problem studied under the stochastic dominance heading is that of finding necessary and adequate conditions on cumulative distribution functions [$F(x)$ and $G(x)$ for $F(x)$] to be preferred or indifferent to [$G(x)$] by all DMs in a particular group of DMs. As already alluded to, DMs are assumed to have their preferences represented by an expected utility function $u(x)$ which is increasing and twice differentiable (Meyer, 1977a: 327; Meyer, 1977b: 477; Norstad, 2005: 2). However, Meyer (1977a: 327) argues that this has tended to direct work done on stochastic dominance to describe DMs in terms of the properties of their utility functions – which is not very convenient. Meyer (1977a) contends that since the utility function is not a unique representation, any positive linear transformation of it also represents the same preferences. He proposed that to restrict a group of DMs being considered by imposing restrictions on $u(x)$, cognisance that such restrictions should not only be met by $u(x)$, but should also be met by all positive linear transformations of $u(x)$, should be taken. For example, up until then, available literature tended to focus on restrictions that paid emphasis on the sign of the second and third derivatives of $u(x)$, thus risking the possibility of not defining some groups of DMs - bearing in mind that the thesis of whether a decision maker belongs to a group of DMs or not is entirely dependent on the particular representation of [his] preferences being used (Meyer, 1977a: 327).

In a way, to circumvent against this intricacy, Meyer (1977b) posited that using restrictions on a decision maker's preferences or $r(x)$, a case could be made to define a group of agents or decision-makers. Pratt (1964) illustrated that $r(x)$ uniquely represents an agents' preference, while Pratt and Arrow (1971) defined the function $r(x)$ as a quantification of a decision maker's absolute aversion to risk. Meyer (1977a: 328) contends that imposing restrictions on $u(x)$ can be likened to specifying a lower and upper bound on risk aversion for the DMs in the set being considered. By amalgamating the ideas behind the FSD, SSD and the SSD with respect to a function, Meyer (1977b:479) described the objects of choice of DMs by introducing an all inclusive class of agents or DMs $U\ (r_1(x),\ r_2(x))$ and showed that by identifying a utility function $u(x)$ which minimises:

$$\int_0^1 [\mathrm{G(x)\text{-}F(x)}]\ \mathrm{u}'(\mathrm{x})dx \geq 0 \qquad (3.8)$$

and satisfy the restrictions on $r(x)$ which are

$$r_1(x) \leq \frac{u''(x)}{u'(x)} \leq r_2(x) \qquad (3.9)$$

where $r_1(x)$ and $r_2(x)$ are random functions which give the lower and upper bounds on the measure of risk aversion, and qualifying it with the assumption that all utility functions are in line with the dictates of the von Neumann – Morgenstern utility functions which are decreasing and twice differentiable. Hence $u''(x)/u'(x)$ is defined for all x (Meyer, 1977b, 478). Consequently, a concept called Second Degree Stochastic Dominance with Respect to a Function, denoted by SSD (k) where $F(x)$ stochastically dominates $G(x)$ in the second degree with respect to $k(x)$ ("F SSD(k) G") if and only if (Meyer, 1977b: 479):

$$\int_0^y [\mathrm{G}(x) - \mathrm{F(x)}]\ dk(x) \geq 0$$

(3.10)

where the integration is with respect to the function $k(x)$. However, this is not a convenient way of characterising risk. According to Pratt (1964), a more suitable and corresponding depiction is to consider the set of all $u(x)$ such that $u(x) = v(k(x))$ where $v(\bullet)$ is a concave and increasing function and $u(x)$ satisfies the following condition:

$$\frac{k''(x)}{k'(x)} \leq \frac{-u''}{u'} \qquad (3.11)$$

Meyer (1977b: 480) shows that a more consistent representation of equation (3.11) can be made by relating a group of DM who are more averse to risk denoted by the function U(-$k''(x)/k'(x)$, ∞) to SSD(k) such that:

$\int_0^y [\mathrm{Gx} - \mathrm{F(x)}]\ dk(x) \geq 0$ for all values of *y* if and only if

$$\int_0^1 u(x)dF(x) \geq \int_0^1 u(x)dG(x) \text{ for all } u(x) \in U\left(\frac{-k''(x)}{k'}, \infty\right) \qquad (3.12)$$

In words, equation (3.12) states that the cumulative distribution $F(x)$ stochastically dominates $G(x)$ in the second degree with respect to $k(x)$. Furthermore, this is the same as $F(x)$ being chosen or indifferent to $G(x)$ by all DMs more risk averse than a DM with the utility function $k(x)$. Moreover, in the presence of uncertainty on how to predict a DM's choice between a pair of risky prospects, $F(x)$ and $G(x)$, the prediction can be made using the SSD

(k) if the DM's measure of risk is greater than $-k"(x)/k'(x)$. For instance, if $F(x)\ SSD\ (k)$ G(x), then it can be deduced that the DM prefers or is indifferent between $F(x)$ and $G(x)$, moreover, if $F(x)$ does not stochastically dominate $G(x)$ with respect $k(x)$, many probable outcomes are possible given that the DM's preferences are not fully known. Hence, this can be interpreted to mean that: 1) $G(x)$ is preferred to $F(x)$; and 2) $F(x)$ is preferred to $G(x)$. Concisely, this means that, when trying to predict the DM's choice among risky alternatives, the use of the information contained on the DM's lower bound can be explored by use of SSD (k) (Meyer, 1977b: 480).

However, equation (3.12) assumes that only one bound is considered on the measure of risk aversion - the lower bound. Thus, in a case where the decision maker is less risk averse than $k(x)$ (that is, only an upper bound on his degree of risk aversion is known), equation (3.12) becomes inefficient in quantifying their risk averseness. Recalling the condition that must be satisfied by $u(x)$ in equation (3.13b), a group of all DMs who are less risk averse than $k(x)$ can be defined by imposing a new but opposing condition that must be satisfied by $u(x)$:

$$\frac{-u''}{u'} \leq \frac{k''(x)}{k'(x)} \tag{3.13a}$$

According to Meyer (1977b), a more suitable and corresponding depiction is to consider the set of all $u(x)$ such that $u(x) = v(k(x))$ where $v(\bullet)$ is a concave and increasing function and the group of DMs is denoted by $U(-\infty, -k"(x)/k'(x))$, by employing Hadar and Russell's (1971) SSD concerning utility function. Thus, the problem to predict the DM's choice between pairs of risky prospects can be given by (Meyer, 1977b: 482):

$$\int_y^1 [\mathrm{Gx} - \mathrm{F(x)}]\ dk(x) \leq 0 \text{ for all values of } y \text{ if and only if}$$

$$\int_0^1 u(x)dF(x) \leq \int_0^1 u(x)dG(x) \text{ for all } u(x) \in U\ (-\infty, \frac{-k"(x)}{k'}) \tag{3.13b}$$

In words, equation (3.13b) shows that a DM will choose $G(x)$ over $F(x)$. Moreover, given limited knowledge of the DM's preferences, his choice between $F(x)$ and $G(x)$ can then be predicted if equation (3.13b) holds. The equation also shows a DM's choice between a pair of risky alternatives assuming that the upper bound on his risk aversion measure is known, as well as a categorisation of those pairs of risky prospects that DMs whose risk aversion property is less than $k(x)$ are most likely to it choose over the other (Meyer, 1977b: 482).

Furthermore, combining equations (3.13a) and (3.13b), the following sets of cumulative distribution are obtainable:

$$\int_0^y [\mathrm{G(x)} - \mathrm{F(x)}]\,\mathrm{dx} \geq 0 \qquad \forall y \epsilon [0,1] \text{ and} \tag{3.14}$$

$$\int_0^1 [\mathrm{G(x)} - \mathrm{F(x)}]\,\mathrm{dx} \geq 0 \qquad \text{implies} \tag{3.15}$$

$$\int_y^1 [\mathrm{G(x)} - \mathrm{F(x)}]\,\mathrm{dx} \geq 0 \qquad \forall y \epsilon [0,1] \tag{3.16}$$

Meyer (1977b: 483) has shown that subtracting equation (3.14) from (3.15) yields (3.16). Hence, what equations (3. 14) to (3.16) mean is that a risk neutral DM is equally well-off between $F(x)$ and $G(x)$ if $F(x)$ is preferred or equally well-off to $G(x)$ by all DM who are more risk averse than the risk neutral DM. Accordingly, the risk neutral DM can consequently be defined in a way as some margin between DM who prefer $F(x)$ to $G(x)$ and *vice versa:*

$$\int_0^y [\mathrm{G(x)} - \mathrm{F(x)}]\,\mathrm{dk(x)} \geq 0 \qquad \forall y \epsilon [0,1] \text{ and} \tag{3.17}$$

$$\int_0^1 [\mathrm{G(x)} - \mathrm{F(x)}]\,\mathrm{dk(x)} = 0 \qquad \text{only if} \tag{3.18}$$

$$\int_y^1 [\mathrm{G(x)} - \mathrm{F(x)}]\,dk(x) \leq 0 \qquad \forall y \epsilon [0,1] \tag{3.19}$$

Introducing the utility function $k(x)$ on equations (3. 14) to (3.16) yields the equations (3.17) to (3.19) which basically mean that all DM with the utility function $k(x)$ are equally well-off between $G(x)$ and $F(x)$. Further, the equations demonstrate that, if $F(x)$ is preferred or equally well-off to $G(x)$ for a group of DMs who are more risk averse than $k(x)$, where $k(x)$ is indifferent between $F(x)$ and $G(x)$, then $G(x)$ is preferred or indifferent to $F(x)$ by all agents less risk averse than $k(x)$. Hence, $k(x)$ can be viewed as a boundary function setting a group of DMs who prefer F to G apart from a group which prefers G to F (Meyer, 1977b: 483). Meyer (1977b: 483) has further revealed that it is possible to find $k(x)$ for a particular pair of risky prospects ($F(x)$ and $G(x)$) such that they are in line with the assumptions of equation (3.19) above. In particular, this can be done by determining whether the DM is more or less risk averse than $k(x)$ - since the value of $k(x)$ that satisfy the assumptions of equation (3.19) also partially characterises those DMs who prefer G to F and *vice versa.*

3.3.4 Conclusions

Meyer's (1977b) SDRF has been criticised for its inability to blend well with most risk quantification software, with Hardaker *et al.* (2004a) and Hardaker *et al.* (2004b) arguing that the computing task in it is very tedious and complicated and leads to compromised understanding to its users. According to Hardaker *et al.* (2004b: 255), the SDRF is also inefficient in that it relies on finding a subset of dominated alternatives, as opposed to identifying, for example, utility efficient prospects for ranges of risk attitudes. What this means is that the SDRF will only identify pairwise dominated alternatives, hence, faced with a smallest possible efficient set, a pairwise dominated alternative may not be able to pick and isolate such a set.

In the next section, a more discriminating and transparent method of risk quantification is introduced and explained. This method is called the Stochastic Efficiency with Respect to Function (SERF) and forms the most recent development in ranking risky alternatives in agriculture. The SERF can be viewed as an augmentation of the SDRF, in that it simplifies what Meyer (1977b) set out to do (Hardaker *et al.*, 2004a: 153; Hardaker *et al.*, 2004b: 255). The availability of easy to use software to quantify and simulate risk in agriculture that comes with SERF makes it even more appealing.

3.4 Stochastic Efficiency with Respect to a Function

The stochastic efficiency with respect to a function (SERF) method was first presented and illustrated by Hardaker and Lien (2003) and formally introduced and proven by Hardaker *et al.* (2004b). Like the SDRF, SERF also finds its theoretical basics in Bernoulli's (1954) four axioms (see section 3.1). Recall in section 2.3, it was argued that the decision maker is assumed to choose an alternative that maximises his expected utility function. Hardaker *et al.* (2004b: 257) and Hardaker and Lien (2003: 8 – 9) have independently shown that the SERF method works by ordering a set of risky alternatives expressed in certainty equivalents (CE), and calculated for ranges of risk attitudes. In particular, Hardaker *et al.* (2004a: 105) demonstrated some of the advantages obtained in using CE's of alternative risky prospects as opposed to their expected utility values in decision analysis. Firstly, they argued that CEs are easy to understand, and present a more transparent approach to assess the magnitude between alternatives (through comparison of the CEs). Secondly, they proved that results could be interpreted simply and directly since the comparing of independent alternatives entails the expression of one CE as a proportion of another, or obtaining the difference between two CEs.

The CE of a risky prospect is defined as the: "sure sum with the same utility as the expected utility of the prospect" (Hardaker *et al.*, 2004b: 257). Drawing on Richardson (2004), Grové, Nel and Maluleke (2006) define a certainty equivalent as the minimum cash ransom that a decision maker would accept as payment for him to be indifferent between the CE and the future payment of a risky prospect. Grové *et al.* (2006: 53) further add, "the level of the CE is determined by the decision maker's expected utility function and the level of risk aversion." Landányi (2008: 148) defines a CE as "the value 'for sure' that would make the DM indifferent to facing the risky prospect or to accept the value 'for sure' with $\min_{\mathrm{i}} (X_{ij}) < \max_{\mathrm{i}} (X_{ij})$".[11] The essence of CEs is to be at a point where the DM is indifferent between the value and the risky outcome. Risky prospects are expressed in CE under the supposition that for the rational DM, the CE is characteristically lower than the expected money value (EMV) and greater than or equal to the minimum value. Thus by computing the difference between the EMV and the CE, the risk premium can be obtained (Hardaker *et al.*, 2004a). Since the information available from the DM is always limited, partial ordering of alternatives by CE is the same as partial ordering them by utility values. Moreover, converting the utilities to CE values by taking the inverse of the utility function is ideal and convenient because it allows for the direct explanation of the CE values as premium than as utility values. The utility values are converted to CE values by (Hardaker *et al.*, 2004a: 154; Hardaker *et al.*, 2004b: 257):

$$\mathrm{CE}\ (x, r_a(x)) = U^{-1}\ (x, r_a(x)) \tag{3.20}$$

and depending on the utility function given, the CE can be calculated by assuming an exponential utility function (Hardaker *et al.*, 2004b: 257) and a discrete distribution of x (Grove 2008: 33) as (Hardaker, *et al.*, 2004a: 154; Hardaker *et al.*, 2004b: 257):

$$\mathrm{CE}\ (x, r_a(x)) = \ln\ \left\{\left(\frac{1}{n}\sum_i^n e^{-r_a(x)x_i}\right)^{\frac{-1}{-r_a(x)}}\right\} \tag{3.21}$$

---

[11] Where i and j are sets of indexes and X_{ij} are the consequences of the jth act given the state S_i

where U is utility, r_a is the relative risk aversion coefficient, assumed constant[12], $r_a(x)$ represents the intensity of absolute risk aversion and n describes the magnitude of the random sample of risky alternative x. Moreover, McCarl and Bessler (1989) have also shown that the risk aversion coefficient (RAC) values can be calculated by dividing 5 by the standard deviation. To determine the relationship between risk aversion and CE, an evaluation of equation (3.21) over a range of $r_a(x)$ is performed[13]. By similarly repeating it for different risky prospects, the relationship for several prospects can be obtained. By means of a graphical representation of the outcomes, the CE and the risk aversion can be weighed against each other and the alternative with the highest CE is chosen given the specific magnitude of risk aversion (Hardaker *et al.*, 2004b: 257 – 8). This is particularly so because, at each $r_a(x)$ "only the alternative that yields the highest CE is efficient" and all other alternatives are "dominated in the SERF sense" (Hardaker *et al.*, 2004b: 258).

This can be illustrated graphically as shown in Figure 3.2, which elucidates the case of being dominated in the SERF sense further. Unlike the SSD or SDRF, Figure 3.2 actually shows that even though the various curves are crossing each other at different risk aversion levels, it is possible to pick up the most efficient alternative, at any given level of assumed risk aversion. Figure 3.2 further shows that alternative one is the dominating prospect since it has the highest CE to all the other prospects (two and three) for the risk aversion magnitude $r_a(x)_L$, $r_a(x)_1$ and $r_a(x)_2$, whilst alternative two is the prospect of dominance for the risk aversion magnitude of $r_a(x)_2$ and $r_a(x)_U$. Using the SERF criteria, alternative 3 is not utility-efficient given the fact that it is dominated in every level of risk aversion, which offers relief, since the SDRF would eliminate none of the three alternatives from the efficient set given the fact that each curve is crossed by at least one of the other two alternative curves.

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[12] Following on Anderson and Dillon (1992) the risk attitude of the farmer with respect to wealth (or gains and losses) can be categorised into five different classes of relative risk aversion: 0.5 = hardly risk averse at all; 1.0 = somewhat risk averse (normal; rather risk averse = 2.0; very risk averse = 3.0 and extremely risk averse = 4.0.

[13] Risky outcomes (x) can also be expressed as gains and losses as opposed to being expressed in terms of wealth (w) only (Hardaker *et al.*, 2004a).

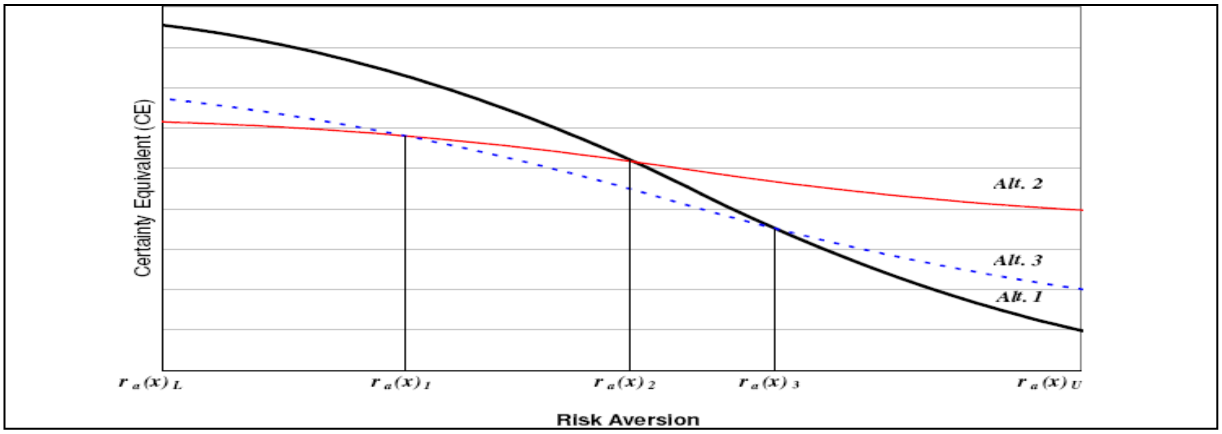

Figure 3.3: Illustration of a stochastic efficiency with respect to a function (SERF) for comparing three alternatives over risk aversion levels $r_a(x)_L$ to $r_a(x)_U$. (Source: Hardaker *et al.*, 2004b: 258).

The SERF method allows for simultaneous comparison of risky alternatives – unlike the SDRF, SSD or FSD, which only permit pairwise comparisons (Hardaker *et al.*, 2004b; Hardaker and Lien, 2003). By using graphical presentation of SERF results, alternative rankings for DMs with different risk preferences may be presented. Because risky alternatives are calculated in terms of CE – which is equal to the amount of money an individual would require to be equally well-off between a certain payoff and a risky prospect, the SERF method allows for the computation of CE values over a range of absolute risk aversion coefficients (ARACs), thereby availing the opportunity of representing the DM's level of risk aversion (Hardaker *et al.*, 2004b: 255 – 259). Decision makers are risk averse if ARAC > 0, risk neutral if ARAC = 0, and risk preferring if ARAC < 0. The main advantage of SERF over SDRF is that "the utility efficient set is obtained directly, and so is potentially smaller than SDRF efficient set" (Hardaker *et al.*, 2004a: 155). Hardaker and Lien (2003) present a detailed comparative analysis of the SDRF and SERF methods.

3.4.1 Risky Premiums

Decision makers often assign certain premiums or pay-offs to risky alternatives that will leave them equally well-off between the risky alternative and the pay-off of the preferred alternative. These pay-offs are called risky premiums (RP) and denote the sure amount of money that will leave the decision maker equally well-off between the risky alternative and the preferred alternative. To calculate the risky premium, consider the amount of money (CE) such that the decision maker is indifferent between an alternative yielding the amount of money, π, and the CE. Since a risk averse agent would be willing to pay or be paid a certain premium that will make him to be indifferent between the risky prospect and its expected utility $E\pi(f)$, the risk premium (RP) is calculated by:

$$RP = E\pi(f) - CE \tag{3.22}$$

Note that $E\pi(f)$ can also denote the expected money value (EMV), such that re-writing equation (3.22) yields:

$$RP = EMV - CE \tag{3.23}$$

According to Hardaker *et al.* (2004a:101), the risky premiums are negative and "measure the costs of the combined effects of risk and risk aversion". For example, under risk aversion, the risk premium is subjective to the appropriate moments of income distribution (Di Falco and Chavas, 2009).

3.4.2 Economic Studies on SERF

Although relatively new, SERF has been used extensively to rank risky alternatives for a number of farm businesses and projects in agriculture around the world, ever-since Hardaker *et al.*'s (2004a) seminal paper. Lien, Hardaker and Flaten (2007a) used SERF to analyse the economic sustainability of organic and conventional cropping systems in Eastern Norway. Whilst Lien, Stordal, Hardaker and Asheim (2007b) applied SERF to evaluate optimal tree replanting replacing on an area that was previously forest land. Clancy, Breen, Butler, Thorne and Wallace (2008), showed the practical use of SERF in comparing returns from two alternative land use strategies (willow and miscanthus) with those from conventional agricultural enterprises, in Irish agriculture. In Greece, Tzouramani, Karakinos, and Alexopoulos (2008) have used SERF to compare and explore the economic viability of organic and conventional cropping systems with respect to profitability and risk behaviour. In South Africa, Grové (2008); Grove (2006) and Grové, Nel and Maluleke (2006), have used the SERF method in the analysis of alternative agricultural water use and deficit irrigation practices, respectively. Watkins, Highnight, Beck, Anders, Hubbell, and Gadberry (2010) evaluated the profitability and risk efficiency of grazing stocker steers on conservation tillage winter wheat pasture, in Arkansas using simulation and SERF. Other recent international studies that focused on comparing the net profitability and risk efficiency of various land use enterprises have employed the SERF method, in one way or another. These include (but are not limited to) studies by Watkins, Hill, and Anders (2008); Archer and Kludze (2006); Evangelista and Lansigan (2007); Ascough, Fathelrahman, Vandenberg, Green and Hoag (2009) and Carlberg (2010).

All the above studies have shown that the trend in stochastic efficiency with respect to a function analysis is that of using certainty equivalents (CEs) to distinguish among risky alternatives while assuming a specific utility function. In particular, they highlight the ability of SERF to rank alternatives for risk efficiency. Through stochastic simulation, alternatives that are profitable and risk efficient can be identified and compared. While there are studies that analyse and compare the profitability of alternative livestock enterprises (Watkins *et al.*, 2010), there are no studies, in as far as the literature reviewed is concerned, that have applied SERF to compare and analyse the profitability of converting from livestock farming to springbuck ranching – which is the goal of this study.

3.4.3 Incorporating Risk into Budgeting Models

Lien (2003) developed procedures that can be used to evaluate the financial feasibility of different investments and management strategies on a farm. Lien emphasised the importance of accounting for risk in farm planning and, in particular, argued that since deterministic budgeting models fail to incorporate the stochasticity of estimates (uses point estimates) of uncertain variables (see section 3.3), consequently, they fail to capture the future of investment and management decisions on the farm[14] (Lien, 2003). According to Lien (2003) and Lien *et al.* (2007a), improved farm planning flexibility can be achieved by using stochastic budgeting. For example the "stochastic budget approach may give more realistic and more useful information about alternative decision strategies" (Lien, 2003: 411).

Pouliquen (1970) posits that risk and uncertainty in decision-making can be accounted for by employing risk analysis techniques. In the preceding sections, it was shown that risk and uncertainty are incorporated into budgeting models by attaching probabilities of occurrence to

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[14] This is because the probability distributions of the outcomes are usually skewed and non-normal (Lien, 2003: 411).

the "key variables in a budget, thereby generating the probability distribution of possible budget outcomes" (McConnell and Dillon, 1997: 278). The process or act of attaching the probabilities is commonly known as stochastic budgeting (Lien, 2003). Basic farm planning requires developing forecasts of the coming years' yields, prices and costs based on personal opinion or published data (Lien, 2003). These forecasts simplify the decision making process by presenting the decision-maker with an opportunity to determine *a priori* the most profitable farm enterprise combinations that will maximise his/her profits.

Stochastic budgeting is appealing for a number of reasons. Firstly, it is an improvement on the traditional budgeting approach where the focus is on the deterministic elements of the budget. Secondly, stochastic budgeting incorporates both the deterministic and stochastic elements in developing an apt measure of financial performance (Lien, 2003). In other words, it takes cognisance of the fact that, in reality, "events and conditions planned for will not turn out as assumed" (Lien, 2003: 403). Lien (2003: 403) shows that the stochastic elements need to be introduced into the budget by specifying probability distributions for the key variables assumed to be affecting the "riskiness of the selected measure of financial performance."

Stochastic budgeting is often used, interchangeably and with much about the same meaning as stochastic simulation (Hardaker *et al.*, 2004a). Typically, stochastic budgets comprise a deterministic component in a form of a conventional budget with given or fixed variables (assumed certainty) whilst a stochastic simulation model may or may not have the deterministic component. However, in practice, stochastic simulation commences from the deterministic equivalent to the stochastic one. In short, as Hardaker *et al.* (2004a: 157) write, "stochastic budgeting can be regarded as a sub-category of stochastic simulation." The advent of stochastic simulation software has made the stochastic simulation process much easier than it was in the late 1960s and early 1970s. Particularly, the development of specialist stochastic simulation add-ins for spreadsheet software such as Microsoft Excel has made the practice and adoption of stochastic simulation much easier and quicker. The simulation software Simulation and econometrics to analyse risk (Simetar®) has gained much popularity following the advent of the SERF method.

Richardson, Schumann and Feldman (2008: 1) define simulation as the "process of solving a mathematical ... [replication] model representing an economic system for a set of exogenous variables." Apland and Hauer (1993) note that mathematical programming techniques form the centre focus in the analyses of decision-making and economic behaviour under risk. Essentially, mathematical programmes make it possible for the modeller to mimic the real world system, through a set of equations and parameters. Risk programming and simulation models are particularly popular in agriculture because of the pervasive nature of risk (Richardson, Lien and Hardaker, 2006). These models are used to analyse the "what-if" questions about the real world (Hardaker *et al.*, 2004a: 158), given that perfect knowledge is not feasible. They do this by mimicking the relationships that exist between inputs and yields in the real world system, thus presents an opportunity for the easy exploration of the impact of change on the decision variables (Hardaker *et al.*, 2004a), including that of risk and uncertainty on the system.

One of the major difficulties faced by the farm/ranch manager in managing rangelands ecosystems involves, *inter alia*, the difficulty or inability of knowing *a priori* what the outcome of his management decisions would be on the rangeland (see chapter 2: section 2.3). However, through a stochastic simulation model, the decision-maker is able to develop a rounded feel of what might happen in the farm because of his management actions. For this to happen, a stochastic simulation model representing the complexity of the various input variables, interactions, non-linearities, uncertainties and variability must be developed and applied empirically. For example, such a stochastic simulation model should include all the key variables of interest in the system under study. Using stochastic simulation, the DM can establish the probability distributions of consequences for alternative decisions. By developing the probability distribution function, the DM can then assess the effect of his management actions on the farm (in this case on farm profitability) and consequently weigh various management alternatives so as to arrive at a superior and knowledgeable preference. One way of doing this is to simulate the consequences of a range of alternative decisions so that a comparative analysis of the outcome distributions can be made (Hardaker *et al.*, 2004a).

3.4.4 Stochastic Simulation and Sampling Procedures

Stochastic simulation involves generating random numbers and repeated sampling from a specified input distribution (Hardaker *et al.*, 2004a). The most common and basic form of sampling used in stochastic simulation is Monte Carlo sampling which was developed by von Neumann and Ulam in the early 1940s (Rubinstein, 1981; as cited by Vose, 2008). According to Vose (2008), Monte Carlo sampling is the least sophisticated and widely understood stochastic sampling method. "It satisfies the purist's desire for an unadulterated random sampling method. It is useful if one is trying to get a model to imitate random sampling from a population or for doing statistical experiments" (Vose, 2008: 59). A key concept to understanding Monte Carlo sampling is the cumulative distribution function (CDF). A CDF $F(x)$, can be thought of as a function that yields the probability P that the variable X will be equal to or less than x such that (Hardaker *et al.*, 2004a: 165):

$$F(x) = P(X \leq x) \tag{3.23}$$

where $F(x)$ is between zero and one. In order to use Monte Carlo sampling, the inverse function of equation (3.22) is specified as follows (Hardaker *et al.*, 2004a: 165):

$$x = G(F(x)) \tag{3.24}$$

Using this inverse function, values of x on the horizontal axis can be generated "with the frequency that, given a large sample, will represent the original distribution" (Hardaker *et al.*, 2004a: 165). The sampling procedure is described by Hardaker *et al.* (2004a: 165 – 166) as follows. Given uniformly distributed values, u $(0 \leq u \leq 1)$ (meaning that every value of u between 0 and 1 has an equal chance of being observed), a conceptual sample can be generated by selecting u and feeding it to equation (3.23) for $F(x)$ to solicit the matching value of x or (Hardaker *et al.*, 2004a: 165):

$$x = G(u) \tag{3.25}$$

This necessitates the sampling of CDF values of u on the vertical axis, thus generating the corresponding x value on the horizontal axis, as shown in Figure 3.3. By performing adequate iterations, the distribution can be recreated using Monte Carlo sampling. Monte Carlo sampling further allows for the random selection of sample means across a range of distributions. However, the randomness of its sample means is also its weakness. For instance, Monte Carlo sampling has a tendency of over-and under sampling from various parts of the distribution (Vose, 2008; Richardson *et al.*, 2008).

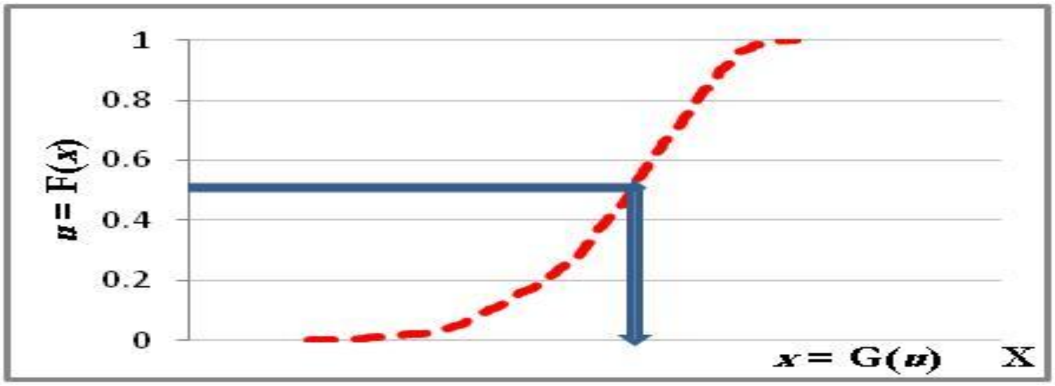

Figure 3.3: The Principle of Monte Carlo sampling using the inverse CDF (Source: Vose, 2008: 58)

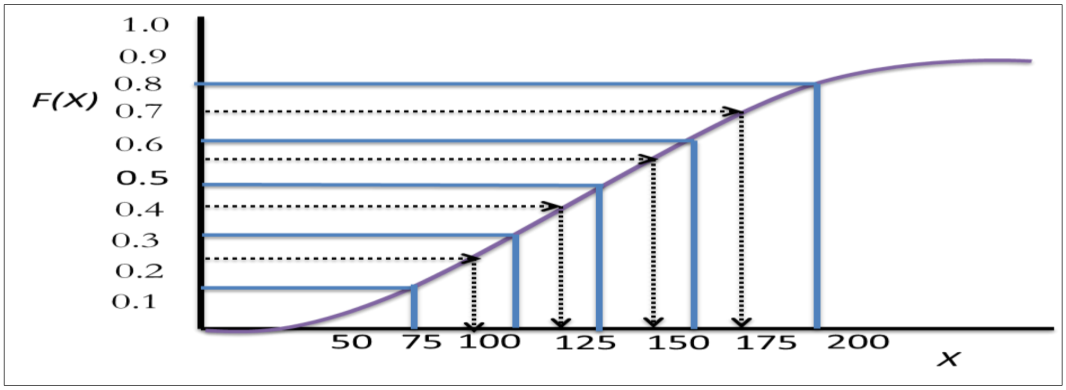

Figure 3.4: The principle of Latin Hypercube sampling (Source: Hardaker *et al.*, 2004a:167)

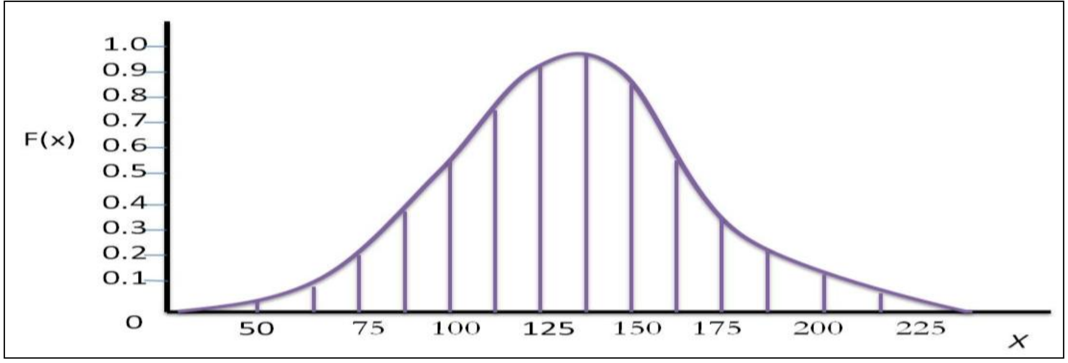

Figure 3.5: The effect of stratification on Latin Hypercube sampling (Source: Vose, 2008: 60)

This compromises its trustworthiness when replicating the input distribution's shape unless a very large number of iterations are performed. Simulation focuses on a model's ability to reproduce a set of given inputs as close to their distribution functions as possible. Hence, for simulation to be correct, emphasis should be directed at getting correct cumulative distribution functions. Because of this, a need to reproduce the sample means with greater efficiency than

Monte Carlo sampling arises. Latin Hypercube sampling provides a method of sampling that "*appears* random" with an added benefit of being able to reproduce the "input distribution with much greater efficiency than Monte Carlo sampling" (Vose, 2008: 59).

In Latin Hypercube sampling (LHS) a "stratified sampling technique" (Hardaker *et al.*, 2004a: 167) which has been identified by Vose (2008: 59) to be "without replacement" is used in simulation modelling. LHS involves the separation of the CDF into n intervals of the same probability, with n being the number of iterations that must be executed on the model (Hardaker *et al.*, 2004a; Vose, 2008), as shown in Figure 3.4. According to Vose (2008: 59 – 60) and Hardaker *et al.* (2004a: 166 – 167), each iteration can be viewed as occurring in a two-step process, where the first step involves the selection of one of the n intervals using a random number generator. To achieve this, the cumulative probability scale is divided into n equi-probable intervals (for example in Figure 3.4 $n = 5$ intervals).

The dashed arrow lines show the boundaries of the intervals, whereas the thick solid (blue) lines show the corresponding location of $F(x)$. In the second step, the generated random integer (1, 2..., n(where $n = 5$ in this case)) is allowed to pick an interval, which is immediately followed by the generation of another random number that helps establish the location of $F(x)$ within the interval. x is calculated the same way as in Monte Carlo sampling (i.e. obtain value of $F(x)$ and substitute it into $x = G(u)$).

This procedure is repeated continuously for the required number of iterations, through a method that makes sure that once an interval has been chosen, it is automatically excluded from the sampling process (Vose, 2008). This yields a stratified distribution as shown in Figure 3.5, which further demonstrates that Latin Hypercube sampling has a much greater ability and efficiency to recreate the original distribution than Monte Carlo sampling. Thus, for stochastic simulation analysis, Latin Hypercube sampling is superior in that it offers the modeller increased sampling efficiency and faster run times due to smaller samples (Hardaker *et al.*, 2004a).

3.5 Stochastic Dependency

A common problem that - in most cases - is neglected in stochastic simulation is "the question of dependency between variables" (Hardaker *et al.*, 2004a: 168). According to Lien *et al.* (2007), stochastic simulation requires vigilance on the stochastic dependency between variables. Stochastic dependency can in most cases lead to biases in the results, hence, to avoid such, it is important to cater for first-order autocorrelation (i.e. inter-temporal correlation) between years as well as cross correlation (Lien *et al.*, 2007). For example, in this study, it is important to account for the stochastic dependences between all the variables (rainfall, forage biomass, springbuck output, wool sheep output, and lamb output, as well as the price of mutton, venison and wool, exchange rates, interest rates, and inflation). Assuming them is not enough since it might be a source of erroneous results in the analysis. In order to allow for an appropriate stochastic dependency representation, joint distributions of all the related variables must be specified. However, Monte Carlo or Latin hypercube sampling is not possible from such joint distributions. Nonetheless, by specifying a correlation matrix, stochastic dependency can be dealt with (Hardaker *et al.*, 2004a).

Correlation is an important tool in the measuring of stochastic association between variables. However, in agriculture, correlation often fails to yield a more robust picture of the causes of stochastic dependency encountered. In essence, "[c]orrelation coefficients measure the overall strength of the association, but give no information about how that varies across the distribution" (Venter, 2002: 69). For example, correlation matrices tend to reveal dependency in terms of first order co-moments even though the dependency can also be explained in terms of higher order co-moments (notwithstanding the fact that they (higher order co-moments) rarely occur). Yet, as Hardaker *et al.* (2004a: 170 – 171) write: "[t]he limited capacity of correlations to characterise stochastic dependency is analogous to the limited characterisation of some marginal distributions by only their means and variances. Nevertheless, ... for marginal distributions, ... the story may be told by the lower co-moments... and because of the difficulties in measuring and accounting for all aspects of dependency, it is common in stochastic simulation work to restrict the representation of such dependency to correlations."

Alternative methods that try to capture co–dependency in light of the realisation that correlation is a compromised measure of stochastic dependency have been considered. In a way, these methods eliminate the limitations of using correlation as measure of co-dependency by augmenting it (correlation) with other techniques. One such technique involves the use of *copulas* to account fully for dependences in a robust manner. A *copula* is a function that brings together two or more marginal distributions. Drawing on Embrechts, Lindskog and McNeil (2001), Hardaker *et al.* (2004a: 172), define a *copula* as a "multivariate distribution function defined on the unit cube, with uniformly distributed margins." According to Venter (2002), a *copula* not only separates the individual variables of the joint distribution into marginal distributions, it also separates the joint distribution based on the interdependency of the probabilities. They further provide "an alternative way to model joint distributions of random variables with greater flexibility both in terms of marginal distributions and the dependence structure" (Vedenov, 2008: 4). Hence, *copulas* provide the basis for undertaking a full exploration of stochastic dependency amongst marginal distributions.

There are many advantages of using *copulas* in modelling; one such is that upon specification, the *copula* can be used for many other modelling requirements that may come up. For example, they can be applied to any pair of marginal distributions beyond those specified by the original distribution (Vedenov, 2008). In the midst of the many examples of *copulas* in agricultural economics problems, is a practical method that was developed by Richardson, Klose and Gray (2000) to solve agricultural economics research problems. Known as a multivariate empirical (MVE) probability distribution analysis, it necessitates the simulation of random values from a frequency distribution that comprises actual historical data. This procedure is an extension of the work of Richardson and Condra (1978; 1981) who presented a *copula* for simulating intra-temporally correlated non-normally distributed random prices and yields and van Tassel, Richardson, and Conner's (1989) method for simulating inter-temporally correlated random variables from non-normal distributions. Van Tassel *et al.*'s (1989) method was, however, inefficient when it came to manipulating random deviates to correlate variables from one year to the next for problems greater than three years (Richardson *et al.*, 2000). Richardson *et al.*'s (2000) method has been shown appropriately to correlate random variables based on their historical correlations. According to, amongst others, Pendell, Williams, Rice, Nelson and Boytes (2006), the MVE distribution is, like any other *copula* based method, particularly useful in cases where the data observations are too few to warrant estimation for another distribution, as is the case in this study. Richardson *et al.* (2000) further show the necessary steps that ought to be followed to specify a proper MVE distribution. The MVE provides full correlations of non-normally distributed stochastic variables.

In recent years, this method has formed the basis for any correlation work done in stochastic simulation in agricultural economics, and it shall be employed to correlate the various variables in the present study.

3.6 Economic Sustainability

Decision makers are also interested in an economic system that will be able to meet its financial obligations throughout the entire planning horizon without compromising the land used (Lien *et al.*, 2007a). However, achieving sustainability is a challenging goal, especially in ecological-economic systems that are driven by highly variable rainfall. In economics, Commons and Perrings (1992) formalized sustainability as relating to both the ecological and economic aspects of ecological-economic systems. Beukes *et al.* (2002:222) state that a fundamental aspect of any sustainable biological system is that "[its] long-term capacity ... to produce forage from rainfall must be maintained, and the system must produce an acceptable financial return for the owner". This view is shared Solow (1993: 18) who envisions sustainability as an "obligation to conduct ourselves so that we leave to the future the option or the capacity to be as well off as we are". Thus, given that to sustain, is to keep in existence, there are key features that need to be considered in any sustainability measure. These range from an understanding that the system that one is dealing with is *stochastic* or *changing over time*, that it can *fail* at some *future date* and that the ability of such a system to survive into the future can be best expressed as a probability (Hansen and Jones, 1996: 186 - 187).

An economic system is usually set up to accomplish an intention. Such intentions may range from deriving profits from the system or satisfying some subjective goal like a way of life etc. However, a sustainable economic system is one that has the potential to continue into the future. A system that fails to satisfy the continuity condition can be seen as having failed to fulfil its purpose (Hansen and Jones, 1996). By implication, this requires that the preferred ecological-economic system's ability to be biologically and economically productive into the future needs to be considered. Essentially, the notion of sustainability can be used to quantify the capability of various alternatives to meet specific required financial and environmental thresholds into the future. The assumption that if an ecological-economic system is able to honour all its future financial obligations without compromising the sustainability of the land it depends on, is important to form an opinion on the benevolence of a chosen ecological-economic on the environment. Batabyal (1999:4) who notes that "the continuance of economic activities such as ... grazing depend on the ability of the ecosystem to support these activities" – meaning that ecosystem health is fundamental for their survival. Hansen and Jones (1996: 185) used this notion to define the economic sustainability of a farming system as "its ability to continue to the future." This view is also shared by Lien *et al.* (2007a) who conclude that agricultural systems are only economically sustainable if they:

- Survive financially into the future and,
- Do not destroy the very resource in which they depend on – the land itself.

From this discussion, it is clear that economic sustainability is concerned with the ability of a system to survive financially[15] into the future. However, it is also true that, at that future date, failure or a loss is irreversible (Hanson and Levy, 1996; Lien *et al.*, 2007a).

This makes the time taken to failure, T_F, to be a random variable with a probability density function, f_{TF}, and a cumulative probability distribution, $F_{TF}(t)$, which occurs only to the (possible) time paths of systems behaviour (Hansen and Jones, 1996). Here t can be seen as a time variable whereas T can be understood as representing a time horizon such that for the time period (0, T); economic sustainability, S, is defined as (Hansen and Jones, 1996):

$$S(T) = 1 - F_{T_F}(T) \qquad (3.26)$$

This implies that in order to estimate economic sustainability, it is mandatory that the probability of occurrence of successful outcomes is modelled (Hansen and Jones, 1996). Often, simulation procedures are used to quantify economic sustainability. Such that economic sustainability $\hat{S}(T)$ is defined as the product of the number of simulated non-failures $n(T)$ at

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[15] It can also be taken to mean time period to failure (Hansen and Jones, 1996; Lien *et al.*, 2007)

the end of the planning horizon T and the total number of iterations (N) used in the simulation model (Lien *et al.*, 2007a):

$$\hat{S}(T) = \frac{n(T)}{N} \tag{3.27}$$

SUMMARY

This chapter discussed the different stochastic efficiency techniques: their foundation and major assumptions. It also illustrated how they can be used to aid decision-making process in agriculture. It was shown that the most effective and latest method in stochastic efficiency analysis is the SERF procedure, which involves ordering of risky alternatives calculated over a range of risk attitudes and expressed in certainty equivalents (CEs). The advantages of using the CEs of alternatives as opposed to their utility values ranges from ease of interpretation and understanding of results to an ability to compare independent alternatives graphically. In order to apply the SERF method, it is important to conduct a stochastic budget – which helps in developing and presenting more information about alternative strategies, which further aids in the incorporation of risk. However, in stochastic budgeting it is also important to account for the stochastic dependency between variables. This can be done by specifying a multivariate empirical (MVE) distribution, which is fundamental in estimating and simulating farm-level risk assessment and policy analysis – which was developed by Richardson *et al.* (2000).

In the next chapter, a detailed discussion of the application of the above discussed methods in the quantification and analysis of converting a sheep farm into a springbuck ranch in Graaff-Reinet whilst overtly considering risk is given.

Chapter 4.

DATA AND METHODS

4.1 Introduction

This chapter illustrates the procedures used to quantify and compare the profitability of alternative rangelands utilisation scenarios and how that information is used to explore the main objective of assessing the profitability of converting a 5 000ha sheep farm into a springbuck ranch in Graaff-Reinet. The chapter discusses the stochastic budgeting procedure required to explore the profitability of converting a sheep farm into a springbuck ranch, whilst overtly considering risk. In order to simulate the financial statements, a multivariate empirical (MVE) probability distribution framework is used. This general framework requires specific functional forms, discussed in this chapter. Accordingly, the chapter starts with a discussion of the stochastic variables used to specify the MVE probability distribution. This is followed by a description of the procedure that is used to combine animal yield, stochastic forage biomass, and stochastic rainfall with output price variability to simulate intra- and inter-temporally correlated risk matrices for the stochastic simulation model. A discussion of the financial statements and SERF analysis follow. The chapter is concluded with an explanation of the procedure used to quantify economic sustainability.

4.2 Stochastic Variables

In order to convert from sheep farming to springbuck ranching and maximise expected utility, the decision maker (DM) needs to consider production and output risk brought about by forage biomass production, rainfall variability, output yield and price variability. The stochastic variables for the sheep and springbuck enterprises are annual forage biomass production, annual rainfall, wool, mutton, springbuck meat (venison), wool price, mutton price, and venison price.

4.2.1 Forage Biomass

In this study, forage biomass production is estimated using remote sensing techniques. The forage biomass is used as a proxy for the carrying capacity, such that the correlation between the total amount of available edible biomass on the ranch and the total numbers of animals kept and culled in the historical period and planning horizon is similar. Accordingly, green forage production in the historical period is calculated from the fraction of photosysnthetically active radiation absorbed by green plants (fPAR). The fPAR is estimated as a non-linear function of MODIS normalised difference vegetation index (NDVI) (Baeza *et al.*, 2010: 73):

$$\mathrm{fPAR} = \min[\mathrm{SR}/\mathrm{SR}_{\max} - \mathrm{SR}_{\min}) - \mathrm{SR}_{\min}/\mathrm{SR}_{\max} - \mathrm{SR}_{\max}), 0.95] \tag{4.1}$$

and

$$\mathrm{SR} = (1 + (\mathrm{NDVI})/(1\text{-}\mathrm{NDVI}) = \mathrm{IR}/\mathrm{R}) \tag{4.2}$$

where SR is the simple relation index, R denotes the reflectance in the red whilst IR is the infrared and NDVI is zero when there is no green vegetation due to erosion, environmental degradation or any form of bare soils such that: fPAR = 0 (Baeza *et al.*, 2010; Grigera *et al.*, 2007; Chasmer *et al.*, 2008). The fPAR is converted into green forage biomass ($biomass_t$) production at time, t, using the following equation (Vetter and Palmer, Personal Communication):

$$Biomass_t = 27.694\beta - 190.92 \tag{4.3}$$

where β is an 8 day interval fPAR coefficient, which is converted into eight days' then monthly fPAR and subsequently yearly green forage biomass production[16]. For the purpose of this study, the green forage biomass ($Biomass_t$) is used as a proxy for the actual carrying capacity[17] (s_{max}) of the farm since the farming system is forage/grass-based. This is calculated by specifying the following equation as discussed in chapter 2:

$$s_{max} = \frac{Biomass_t}{\varphi} \tag{4.4}$$

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[16] Palmer *et al.* (2010) provide a detailed explanation of this method.

[17] Palmer and Ainslie (2007) used a similar method and equation to qualitatively describe the condition of communally managed rangelands in the former Transkei of South Africa, using GIS and high resolution near-infrared imagery. Recently, Yang *et al.* (2008) have shown that near and shortwave hyperspectral reflectance has a great potential for estimating fPAR, which has helped improve the precision with which above ground productivity is estimated.

where φ is the average annual amount of forage biomass required by one livestock unit (LSU). LSU is used to bring both the springbuck and the sheep under a shared denominator. Since the farmer kept both sheep and springbuck, this study assumes that the number of sheep and springbuck is in equilibrium with the forage produced in the ranch. Furthermore, the amount of green forage biomass produced using equation (4.3) is assumed to be adequate to maintain an economic number of sheep in summer and springbuck throughout the year, since the farmer adapts the stocking rate to the available green forage biomass and as per the chosen utilisation strategy[18]. However, cognisance is taken that sheep and springbuck will consume different parts of the forage biomass, at different rates. Important to note is that since remote sensing was used to estimate the forage biomass data, its limitation was that it also considered green growth that is not available to the animals as well as that which is unpalatable. In addition, some of the biomass is lost to trampling and senescence, which reduces the amount of forage biomass available to the animal. To correct for this, an availability factor of 35% of the total biomass produced was used, based on expect opinion[19].

4.2.2 Rainfall

Rainfall influences biomass production, which in turn influences the number of animals that the rangeland can support and consequently the total income that can be obtained from the rangeland. Precipitation amount in the planning horizon was calculated based on a time series of 60 years of monthly rainfall, ranging from January 1950 to December 2010. These data were obtained by application from South African Weather Services. Difficulties are often experienced in as far as forecasting precipitation data is concerned. Drawing from New *et al.* (2002), the seasonality of rainfall is simulated by using monthly time steps, where the monthly mean of rainfall and the coefficient of variation are used to simulate mean monthly rainfall as a Gamma random number, using MATLAB® R2010a. Because of the existence of zero observations in

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[18] This is done through systematic culling to ensure that the total number of sheep and springbuck kept is equivalent to what the rangeland can support. The carrying capacity through the total biomass produced is used to capture that.

[19] This was based on personal communication to A. R. Palmer (Agricultural Research Council, Grahamstown)

the monthly observations, a Pearson distribution was used instead[20]. Annual rainfall is modelled through the individual summation of monthly means in a year to obtain annual rainfall observations from 2011 to 2025. These annual observations are used in the MVE as mean values for the annual rainfall values.

To forecast the amount of biomass in the planning horizon, the forecasted monthly rainfall data from 2011 to 2025 were used to estimate the amount of biomass produced in a month in the planning period. This was done by using an ordinary least squares (OLS) regression model, where green forage biomass was specified as a function of rainfall. The forecasted monthly forage biomass was subsequently paired with the rainfall data in each month to estimate the amount of forage biomass produced in a season. For simplicity, the years were divided into four different seasons: rainy season (November to January); mild rainy season (February to April); dry season (with incidence of winter rains) (May – July) and; mild dry season (August to October). The total seasonal forage biomass production in a month was calculated by adding together all the biomass in a season. The seasonally produced forage was added together to calculate the annual total biomass and this was done for every year in the planning horizon.

4.2.3 Yield

The stochastic yield of wool sheep shorn, wool sheep culled for mutton and springbuck output are simulated from their historical deterministic means. The historical yields exhibited no trends, which necessitated the use of the historical means as the deterministic means in forecasting the yield values in the planning horizon. Specifically, yield varies with the amount of precipitation and green forage biomass production on the farm. In the empirical distribution, the yield variability is assumed to grow linearly at 2% per year over the planning period, denoting greater uncertainty (of weather and other factors that may affect production in the area) with time. Because of this, the variability of the future yield values is expected to be higher than their historical ranges.

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[20] A Pearson distribution is essentially a Gamma distribution with an offset to account for zero numbers.

4.2.4 Prices

Price data were acquired from different sources. Wool price data were obtained from Cape Wools, whereas data for mutton were obtained from Statistics South Africa online. Springbuck meat (venison) price data were obtained from Camdeboo Meat Processors. Since there are no price forecasts for wool, mutton and springbuck prices in South Africa from 2011 to 2025, the deterministic mean prices used as forecast values in the simulation analysis were forecasted linearly using an inflation rate for consumer prices. The Bureau for Economic Research[21] (BER) provides annual forecasts for most economic data in South Africa for 15 years. Specifically, the prices were tested for the presence of trends, and were found to exhibit a trend. Using an ordinary least squares (OLS) time regression, the variables were regressed against time to de-trend them and were adjusted for inflation, using 2007 prices.

4.2.5 Other Economic Variables

Other economic variables also influence decision making in farm level management. These include rates of inflation, interest and exchange rates, which all affect the financial structure of the business at any time. These variables are specified in the MVE probability distribution together with the output variables, to simulate the behaviour of the real system. Economic outlook data from 2011 through to 2025 for interest rates, inflation (consumer price index and producer index) rates, exchange (Rand / US$) rates are available from the BER. Historical data for the variables were obtained from Statistics South Africa online and covered the period 2000 to 2010. The BER 2011 baseline projected rates of inflation, interest rates and exchange rates were used as forecasted mean values for the simulation of these variables.

4.3 Specifying the Multivariate Empirical (MVE) Probability Distribution

All the above variables were used to specify the MVE probability distribution used to perform the simulations. The procedure proposed by Richardson *et al.* (2000) was used to

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[21] The BER is attached to the University of Stellenbosch and provides economic outlook data for a range of macroeconomic indicators.

specify a MVE probability distribution. Fundamentally, this procedure requires that the future variables are correlated the same way as they were in the past. Richardson *et al.* (2000: 302-308) propose that to specify a MVE probability distribution, it is essential to first work out the correlation matrix ($M_{k\times k}$) for the k variables of the historical distribution. Using the Cholesky decomposition matrix, the M matrix is factored to get an $\mathrm{R}_{k\times k}$ matrix such that $M = RR'$. The $R_{k\times k}$ matrix is correlated within each year and amongst years of the simulation period by multiplying it with a vector of independent standard normal deviates (ISND). This produces intra and inter-temporally correlated standard normal deviates (CSND). Specifically, the intra-temporal correlation matrix is calculated by specifying the following equation[22]:

$$\rho_{ij} = \begin{bmatrix} \rho_{(\hat{e}_{it},\hat{e}_{it-1})} & \rho_{(\hat{e}_{it},\hat{e}_{it-1})} \\ 0 & \rho_{(\hat{e}_{it},\hat{e}_{it-1})} \end{bmatrix} \tag{4.5}$$

where $\hat{e}_{it}$ is the random component for each random variable X_{it} in year t. This is necessary since it precludes biasing the results by allowing for first-order autocorrelation. In the same way, the inter-temporal correlation of the random variables is specified by following equation (4.6):

$$\rho_{i(t,t-1)} = \left\{ \begin{matrix} 1 & \rho_{(\hat{e}_{it},\hat{e}_{it-1})} & 0 \\ & 1 & \rho_{(\hat{e}_{it},\hat{e}_{it-1})} \\ & & 1 \end{matrix} \right\} \tag{4.6}$$

The rest of the simulation process is performed by following equation (4.7), which is a simplification of the requisite steps necessary in simulating an MVE probability distribution (Lien *et al.* 2007: 544):

$$\tilde{X}_t^q = \bar{X}_t^q + \sigma_t^q \times CSND_t^q \times E^q \tag{4.7}$$

where $\tilde{X}_t^q$ is the mean of each variable q in the model at time t; σ_t^q denotes the standard deviation of variable q at time t whilst $CSND_t^q$ is a cross and auto-correlated standard normal deviate for the variable q at time t. E^q is a variance expansion factor for variable q. It captures assumptions regarding the relative variability of the stochastic variable q over the planning horizon.

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[22] Equation 4.5 demonstrates an intra-correlation matrix for a 2 x 2 matrix.

4.4 Wool Production

Wool production in the planning horizon is calculated from the simulated total wool sheep shorn on the farm multiplied by a constant wool production coefficient per sheep on the farm throughout the planning horizon[23]. Drawing on Kobayashi, Hewitt and Jarvis (2003), wool production ($Wyield_t$) at time, t, is modelled using wool output of a representative ewe and or yearling. This is achieved by multiplying wool output per average sized ewe (BW_1) and yearling (BW_2) with the total number of ewes and yearlings shorn, respectively. Based on the principal decision maker's experience[24] on wool production per animal on the farm, a coefficient of 75% clean wool production coefficient was assumed per ewe weighing 45kg (also see Olivier and Roux, 2007); the following equation was used to estimate the aggregated (clean and greasy fleece) wool output[25]:

$$Wyield_t = \sum_{v=1}^{2} (0.75\lambda_1 BW_1 * x_1 + 0.75\lambda_2 BW_2 * x_2) \quad (4.8)$$

where λ is the average wool output per average sized ewe (BW) (v = 1) or yearling (v = 2) , and x_1 is the simulated number of wool sheep shorn. Yearlings (x_2) were assumed to comprise 25% of the ewe (x_1) population[26] (Janssens and Vandepitte, 2003). One quarter was assumed to necessitate the calculation of the number of yearlings in the herd.

4.5 Wool Income

The simulated amount of wool produced, $Wyield_t$, in time, t, of the planning horizon was multiplied with the simulated probability distribution of inflation adjusted historical wool price at time, t, to calculate the wool total revenue per year, in the planning horizon. Specifically, this study used a simplified version of the wool cheque calculation method devised by the Queensland Department of Agriculture in Australia, which calculates the wool cheque (WC) as the total amount of wool produced (Kg all grade average) × weighted yield (%) × 0.75 (% of

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[23] This method is similar to the one used by D'Haese *et al.* (2001), in cases where there is not enough data.

[24] The farm manager's (principal decision maker) experience is used because wool output per animal varies from one farm to the next and across studies.

[25] The final output of wool per sheep was based on an aggregated output of clean wool and greasy wool.

[26] Rams are not considered because they do not form part of the farmer's management plan on the farm.

wool clean) × 0.905 (after selling costs) × clean price (c/kg clean). However, since this study uses an aggregated clean and greasy fleece, the Australian method was modified to suit available data. The wool income (y_t) is therefore calculated as:

$$y_t = Wyield_t \times \tilde{P}_t \tag{4.9}$$

where $Wyield_t$ is as defined in equation (4.8) and $\tilde{P}_t$ is the empirically distributed deflated price (R/kg) of wool.

4.6 Mutton and Venison Output Estimation

Mutton and venison output were estimated from the total number of simulated wool sheep and springbuck culled in the farm, respectively – as per the various scenarios. This was accomplished by specifying the following equations:

$$Y_m Yield_{it} = \psi \cdot BW_m \cdot \gamma_{it}\ ; \tag{4.10}$$

$$Y_v Yield_{it} = \psi \cdot BW_v \cdot x_{it}\ ; \tag{4.11}$$

where $YYield_{it}$ is the average annual (t = 1, 2, 3,…15 years) output of mutton (equation 4.10) and venison (equation 4.11) produced at time, t, on the farm, i denotes 500 iterations, whilst γ_{it} and x_{it} is the total simulated number of sheep and springbuck culled respectively; ψ denotes a dressing weight percentage of 50% for sheep and 56% for springbuck (Skinner *et al.*, 1986). The average body weight of a culled ewe is denoted by BW_m whereas that of springbuck is denoted by BW_v.

4.7 Mutton and Venison Income

To calculate mutton or venison income (y_t), the simulated annual output of mutton ($Y_m Yield_{it}$) (equation 4.11) and venison ($Y_v Yield_{it}$) (equation 4.11) were substituted into equation (4.12) and multiplied by the inflation adjusted meat (mutton or venison) empirically distributed price ($\tilde{P}_t$) (R/kg) in the planning horizon:

$$y_t = YYield_{it} \cdot \tilde{P}_t \tag{4.12}$$

Since the springbuck have a 56% dressing weight which reduces the carcass of a springbuck measuring an average weight of about 30kg to an average dressed weight of 16.8 kg per animal. An average weight of 14.5 kg was assumed based on the records of the principal decision maker, and given that weight differs depending on the season and number of animals on the rangeland. Furthermore, the dressed weights of the springbuck carcasses were assumed to decrease to 13 kg, in the last 5 years of the planning horizon[27]. For a culled ewe, a bodyweight of 45kg was assumed (which gives a dressed weight of 22.5kg, but because bodyweight varies from one animal to the next, a dressed weight of 20kg was used for all culled ewes instead). For the wool sheep enterprise, income was assumed to come from wool and mutton sales only. Similarly, some springbuck are culled through trophy hunting; however, because the farmer did not keep any records, it is assumed that all the money for the springbuck enterprise comes from venison production and where applicable wool and mutton.

4.8 Simulating Net Returns Variability

In order to simulate stochastic net returns, the stochastic budgeting model generated from the MVE distribution, based on the three alternative scenarios, was used. To construct the distribution of net returns ((NR) equation (4.13) was used (Watkins *et al.* (2010: 10):

$$NR_{ijk} = \sum_{k=1}^{3}[((\tilde{P}_{ijk} \cdot \tilde{Z}_{ijk}) - (VC_{ijk} + \widetilde{W}_{ijk}))] \qquad (4.13)$$

where NR_{ijk} are the simulated net returns for iteration i, and scenario j (in rands); ($\tilde{P}_{ijk} \cdot \tilde{Z}_{ijk}$) is the total revenue, ($VC_{ijk} + \widetilde{W}_{ijk}$) denote input costs (including costs of winter-feeding in sheep farming); i = 500 iterations; j = 1 to 3 scenarios; k is the output, 1 to 3 (1= wool, 2=mutton, 3 = venison). $\tilde{P}_{ijk}$ represents empirically distributed deflated and de-trended prices of output k, for iteration i, scenario j (in rands). $\tilde{Z}_{ij}$ is the empirically distributed output ($YYield_{it}$) for iteration i, scenario j (kg/animal head). VC_{ijk} is the output dependent variable cost for scenario j output k (R); and $\widetilde{W}_{jk}$ denotes winter feeding costs for scenario j, output k (R/year).

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[27] This observation was informed by an extensive interview held with the Meat Processor, who argued that as the number of animals increased in one ranch, the total output in Kg of venison, decreased substantially. It is easy to guess that this may have been because of competition for forage on the farm, since springbuck have been documented to be territorial (Conroy, 200).

VC_{jk} were calculated by abstracting the variable costs for the current enterprises from the farmer's financial statements. These were then estimated as per the simulated stocking rate in the respective scenarios. The costs of winter feeding ($\widetilde{W}_{jk}$) were calculated from the product of the total number of animals fed during winter or otherwise and their daily forage biomass intake (φ) in the farm on scenario j for output k. In the case of sheep farming, revenue comes from both wool sales and mutton sales. For the springbuck enterprise, however, revenue comes from venison sales.

Using stochastic budgeting, the information on output and all economic variables assumed pertinent in the operations of a 5 000ha farm in Graaff-Reinet were programmed on Excel®. Simetar© (Richardson *et al.*, 2008) was used to simulate the financial statements (discussed in section 4.9) for the specific alternative scenarios, using Latin Hypercube sampling.

4.9 Financial Statements

This section describes how the financial statements were attached into the MVE distribution to quantify the annual farm income variability of the alternative scenarios. Figure 4.1 illustrates how the stochastic variables and all the assumptions of the MVE distribution were attached to the financial statements. It further summarises the association between variables costs, control variables and output and key output variables (KOVs). The financial statements were developed for all the three alternative scenarios, in the four cohorts and incorporated into the financial model. Through the financial statements, is attached the assumptions made in each of the alternative scenarios.

4.9.1 Income Statement

The income statement measures the financial performance of the various alternatives over the planning horizon. This is achieved through a summary of how the business generates income and expenses through its various operations, in a given year of the planning horizon. In essence, the income statement is also known as the profit and loss statement because it shows the net profit or loss of an enterprise over time. Total market receipts for the various enterprises were calculated by adding the alternative scenarios' enterprise receipts (total output produced multiplied by output selling price) and interest earned receipts. More specifically, total annual receipts for the wool sheep enterprise were calculated by summing the wool output receipts (product of total wool output multiplied by wool selling price in that given year. Particular attention is paid to the fact that different wool grades are possible from one year to the next – which is modelled using an all grade wool average price, as discussed in section 4.3 above. The receipts for the mutton enterprise come from the mutton sales, whilst those for springbuck come from the venison sales as already discussed in the preceding sections. For each of the scenarios, the wool, mutton and venison incomes are then summed together with the interest receipts to work out the total income for that scenario.

Interest earned was calculated by multiplying surplus cash reserves with interest rates, whereas variable costs are added to interests' costs to come up with total expenses for the enterprises. Stochastic variable costs for supplementary feeding were obtained by multiplying the total amount of feed required per production season by the price of feed per ton. The variable costs are different across the scenarios, throughout the years, in all the cohorts. The method of calculation is, however, the same. Since the focus of this study is on converting an already existing sheep farm into a hypothetical springbuck ranch, the following assumptions were made relating to land investments costs. The farmer is assumed to continue paying outstanding initial capital loan interests costs, which are calculated using a fixed payment amortisation (Richardson *et al.*, 2008). For converting the sheep farm into a springbuck ranch, the farmer was assumed gradually to allow springbuck into his sheep farm in a very systematic fashion. This study captures that by introducing three scenarios based on the current ecological-economic system on the ranch and three hypothetical scenarios (see chapter 1 and 5 for their definition) to adequately model the type of investments that the rancher would have to make.

Remaining costs (and especially costs for supplementary feeding and veterinary care where necessary) are financed using an operational loan from the bank. Subsequently, the interest costs for this loan were calculated by multiplying the sum of all variable costs by the projected interest rates. The difference between the total receipts and total expenses yields the net cash income, which was then subjected to a tax rate after removing the costs of depreciation (Lau, 2004).

4.9.2 Cash Flow Statement

In this study, Lien *et al.*'s (2007) procedure of incorporating stochastic features by specifying probability distributions for key uncertain variables was followed. The study adopts a recursive budgeting model over a period of 15 years to evaluate the financial performance of the three alternative scenarios in the four cohorts. This means that the ending cash balance from the previous year transforms to the beginning cash balance for the following year, such that the beginning cash balance for 2011 to 2025 is equal to the ending cash balance from the previous year.

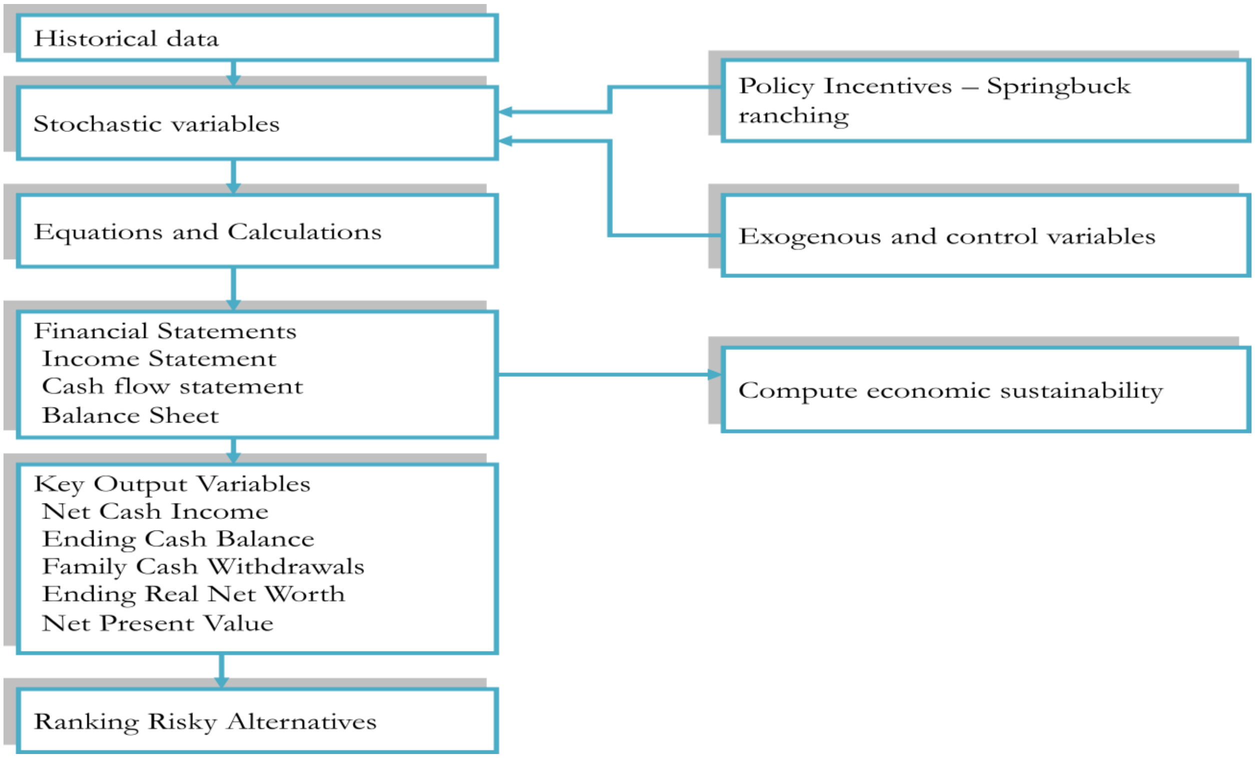

Figure 4.1: Diagrammatic Illustration of Simulation Model (Source: Lau, 2004: 103)

Total cash income for the alternative scenarios is calculated by summing the cash balance for the previous year with the net cash income for that year. Total cash outflows represent the money leaving the business in the planning horizon. These are calculated by summing the total loan repayment costs, repayment of cash deficit, annual fence replacement costs, miscellaneous expenses, income taxes paid (where necessary) and family withdrawals paid. Family cash withdrawals are set at a fixed R120 thousand a year growing at 5% per annum throughout the planning horizon. A corporate tax consistent with the South African Revenue Services tax codes was imposed. Essentially, in South Africa, farmers are taxed in terms of section 26 of the Income Tax Act 58 of 1962.

Moreover, The South African environmental conservation tax law (Price Waterhouse Coopers, 2009) as stipulated on section 37C of the 2009 Income Tax Act accord farmers some tax incentives if they incorporate or introduce those land use initiatives that promote environmental conservation. This law came into effect in 2009 and is in accordance with, or aims to put into action, the objectives of the Biodiversity Management Act (Act 10 of 2004). It details a series of costs that can be deducted if land is used for conservation purposes that will simultaneously promote biodiversity. In the scenarios that explore the effect of policy incentives (income tax breaks and a restoration subsidy) on the profitability of the farm, this was taken into effect, as springbuck ranching does promote biodiversity and environmental management (see chapter 2). To quantify the impact of tax deductions[28] on the gross margins, the model is programmed in such a way that it does not deduct income tax in the scenarios where tax breaks are assumed to be introduced, whilst a fixed restoration subsidy of R13/ha is introduced on a per hectare basis. This subsidy was carefully calculated based on its influence on the net income structure of the 5 000ha farm.

Ending cash balance was obtained by subtracting the net cash inflow from net cash outflow. The whole-farm stochastic simulation model is programmed in such a way that if ending cash balance is negative, the farmer is allowed to borrow money from the bank, and similarly if the ending balance depicts that the farm made a loss, no taxes are paid, until there is a profit and *vice versa*. Similarly, if the ending cash balance is positive, the model automatically allows the surplus income to earn interest in the bank. This is applicable to all the 15 years in the planning horizon.

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[28] Note that all tax calculations are programmed into the financial analysis.

4.9.3 Balance Sheet

The enterprises' balance sheet is made up of assets, liabilities and equity (Lau, 2004). Unlike in most balance sheets, the assets are made-up of cash balance and inventories. Land is deliberately left out of the balance sheet because of the assumption that, in the event the rangelands become completely degraded, financiers would not be able to recover their money, as the land would have lost all its agricultural economic value. The balance sheet for the various alternative scenarios is actually different from one cohort to the next. For the sheep enterprise, depreciation for machinery was calculated using a standard depreciation method. For machinery used in all the enterprises, e.g. tractors and vehicles, a straight-line method of depreciation is used to depreciate them. Similarly, shearing machinery was depreciated in the same way as the tractors and vehicles. Land and buildings were not considered in this study[29]. Instead, the focus is on other assets like cash in bank, stock inventories, machinery (shearing machinery) tractors and vehicles in the various scenarios.

To calculate total liabilities, short term and long-term liabilities were summed together. In the event that there are any cash deficits in the planning horizon, they are recorded as short-term liabilities, whereas the annual ending balance for machinery and vehicles debt constitutes the long-term liabilities. Operational capital requirements also differ from cohort one to cohort four and amongst the scenarios in the cohorts. Whilst scenario one in cohort one is a true depiction of what is happening on the ground (currently), scenarios two and three are only hypothetical and all the other scenarios in the three other cohorts are also hypothetical.

Lastly, equity or net worth is the difference between total assets (excluding land and buildings) and total liabilities. Real net worth was used in evaluating the financial soundness of the enterprise. A deflation factor was used to deflate the nominal net worth into real net worth.

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[29] In the Karoo, farmers seldom build new houses on their properties. Farms are handed over from one generation to the next, including buildings in them. Land is not considered because of the degradation question in the Karoo. The reasoning is that, in the event that desertification was to be a reality, financiers would lose out anyway. Accordingly, this study focuses on income wealth.

4.9.4 Key Output Variables

Key output variables (KOVs) form the centre focus of any stochastic simulation analysis (Richardson *et al.*, 2007a; Richardson *et al.*, 2007b, Outlaw *et al.*, 2006; Richardson *et al.*, 2006). In order to compare the various alternative scenarios in terms of profitability, this study simulates a group of common financial indicators or key output variables, as shown in Figure 4.4. These include:

- Net cash income (NCI);
- Ending cash balance (ECB),
- Real net worth (RNW) and
- Net present value (NPV) future returns of the alternative scenarios, in the different cohorts.

The annual net income (NCI) constitutes the total revenue or total farm receipts less all expenses and depreciation costs. Annual ending cash balance (ECB) is computed by considering only those costs, which impact the business before borrowing - so it does not take into account any borrowing costs. The real net worth (RNW) is the sum of the net worth in the last (15th) year of simulation period, discounted to 2010 using an assumed discount rate of 9%. Lastly, the NPV is selected as a proxy for profitability. It is calculated over the 15-year planning horizon using equation 4.14 (Richardson *et al.*, 2007: 204):

$$NPV = - Beginning\ net\ worth\ \sum_{t=1}^{15} (Family\ withdrawals_i + \Delta Net\ Worth_i)/(1 + r)^{15} \qquad (4.14)$$

where r is the discount rate through which future returns are discounted with to express them in today's money's worth. Since the NPV is used as a proxy for profitability of every scenario, this study follows Richardson and Mapp (1976), who argued that economic success of a project is best analysed using the Net Present Value (NPV). However, for this study, a positive NPV is defined to mean that the rate of return of the project is greater than its discount rate making it a profitable initiative. It is further used as a directive to decision-makers whether to convert from sheep farming to springbuck ranching. Thus far, it is used as a foundation to formulate a judgment about how converting a 5 000ha sheep farm into a springbuck ranch will perform in a given time period.

Consequently, for this study, a negative NPV (NPV below zero) means that the rate of return of the project is lower than its discount rate hence it is not economically profitable. According to Lau (2004), the NPV is but one of many available rules for decision-making. It is, moreover appealing because of its ability to give decision makers a synopsis of how the project will perform *a priori* (Lien *et al.*, 2007). Lau (2004: 109) terms this the "value of flexibility" and draws from Hardaker *et al.* (2004) to argue that it is particularly pertinent in instances where risky alternatives possess a degree of uncertainty that cannot be resolved before a decision is taken - as is the case in this study. The NPV also has the property of presenting a risk-free assessment of risky alternatives (McLellan and Carlberg, 2010) and as such is employed, in this study, to explore the question of whether converting to springbuck ranching is an economically profitable alternative to sheep farming or not, in Graaff-Reinet.

4.10 Ranking Risky Alternatives

In order to rank the alternative scenarios with respect to profitability, this study applies the SERF analysis to the NPV. This is done to allow for an apt comparison of the various alternative scenarios on a range of risk preferences for the decision makers. Particularly, for each risky alternative, a utility function, U, for wealth (monotonicity axiom) is calculated by evaluating it on a range of lower and upper absolute risk aversion coefficients (ARACs) levels, $r_a(x)$ and distribution of wealth, w (as denoted by the NPV) by specifying equation (4.15) (Hardaker *et al.*, 2004b: 257):

$$U(w, r(x)) = \int U\ (w, r(x))f(w)dz \ \approx \ \sum_{n=1}^{n} U(w_n, r(x)P(w_n) \qquad (4.15)$$

where $r(x)$ denotes the selected values of risk aversion bounded within lower, $r(x)_L$, to upper, $r(x)_U$, ranges of risk aversion. Drawing from McCarl and Bessler (1989), the upper ($r(x)_U$) and lower risk aversion coefficients $r(x)_L$are calculated by specifying the following equation:

$$RAC \ = \frac{5}{Std\ Dev} \qquad (4.16)$$

where RAC is the risk aversion coefficient and $Std\ Dev$ denotes the standard deviation. For this study, the RACs are bounded between a (lower) limit of zero and a positive (upper) limit to capture the decision making process of a risk neutral and risk averse decision maker, respectively. A RAC of zero signifies a decision maker who is risk neutral, whereas that of above zero denotes a risk averse decision-maker.

The second term in equation (4.15) denotes the continuous case, whereas the third term is a "discrete approximation for computational purposes" (Lien *et al.*, 2007: 543 - 4). Since this study uses Monte Carlo stochastic simulation to develop distributions for all the key output variables, $P(w_n)$ denotes the probability of returning iteration n in the simulation. The utility function is bounded between $U' > 0$ and $U'' < 0$, because decision-makers are assumed to prefer more income to less or simply that they are naturally inclined to choose an investment that yields more income. To simulate the decision maker's utility values for income, the following equation is used:

$$U\,(w) = \;(1 - r_a(x)^{-1}\,w^{1-\,r_a(x)} \tag{4.17}$$

where $r_a(x)$ is the calculated absolute risk aversion coefficient of the relative risk aversion function with respect to income, $r_a(w)$, w denotes the income the farmer obtains from the various alternative scenarios.

The utilities are subsequently converted into certainty equivalents (CEs) by taking the inverse of the utility function U (Hardaker *et al.*, 2004: 257b):

$$\text{CE}\;(x, r_a(x)) = U^{-1}\;(x, r_a(x)) \tag{4.18}$$

The CEs are easy to interpret by converting the utility values into money terms as opposed to using them raw - as utility values - which are less instructive. Specifically, Simetar® calculates the CEs using the following equation:

$$\text{CE}\;(x, r_a(x)) = \ln\;\left\{\left(\frac{1}{n}\sum_i^n e^{-r_a(x)x_i}\right)^{\frac{-1}{-r_a(x)}}\right\} \tag{4.19}$$

where U is the utility, $r_a(x)$ is the calculated value of absolute risk aversion coefficient, and n captures the magnitude of the random sample of risky alternative x. Once the risky alternatives have been ranked, using their CE values on the SERF analysis, the minimum amount that decision makers would want to be paid to convert from the preferred alternative scenario (P) to a less preferred alternative scenario (L) based on the absolute risk coefficient (ARAC) is calculated by specifying equation (4.21):

$$RP_{P,L}r_a(x) = CE_P, r_a(x) - \;CE_L r_a(x) \tag{4.20}$$

where RP is the utility weighted risk premium, $CE_P, r_a(x)$ denotes the CE of the preferred scenario and $CE_L, r_a(x)$ is the CE of the less preferred scenario.

4.11 Economic Sustainability

Economic sustainability of the three alternative scenarios in the four cohorts is investigated by simulating the probability of occurrence of successful outcomes by specifying the following equation (Lien *et al.*, 2007a):

$$\hat{S}(T) = \frac{n(T)}{N} \tag{4.21}$$

where $n(T)$ denotes the number of simulated non-failures at the end of the planning horizon, T, and N is the total number of iterations used in the simulation model. The economic sustainability measure is linked into the financial model. Specifically, this is achieved by specifying a Bernoulli function - consistent with Roy's safety-first rule - for economic sustainability in the Monte Carlo financial statements, which is either 0 for failure or 1 for success and is simulated for 500 simulations for every year in the planning horizon. The economic sustainability of an alternative scenario is determined using

$$Es_{ij}^{t} = 1, \text{ if } \left[\left\{ \frac{VC_{ij}^{t}}{TR_{ij}^{t}} \right\} > \frac{mxt}{100} \right] \tag{4.22}$$

$$0, \text{ otherwise,}$$

where Es_{ij}^{t} denotes economic sustainability of scenario j, iteration i (i=500) at time t, VC_{ij}^{t} are the total variable costs for scenario j, iteration i at time t. TR_{ij}^{t} represents the total revenue from scenario j, iteration i at time t, and mxt is the maximum threshold of variable costs to total income as shown in Table A1 of Appendix A. To avoid biasing the results, the value for mxt in the wool sheep dominated cohorts differs from that of the springbuck dominated cohorts, as shown in Table A1.

To conduct sensitivity analysis, the variables costs, yield and price for wool, mutton and venison of each scenario in each cohort (cohort one and cohort three) were weighted against the NPVs of each scenario in the same cohorts, using Simetar®.

4.12 Summary

This chapter discussed the procedures used to quantify the profitability of converting a 5 000ha sheep farm into a springbuck ranch in Graaff-Reinet. Firstly, the technique used to quantify green forage biomass data used to specify the effect of green forage biomass stochasticity on output was discussed. An explanation of the processes followed when forecasting rainfall data and biomass data using as a function of rainfall was also discussed. Secondly, an explanation of the MVE probability distribution procedure used to quantify risk and ensure that the historical observations are correlated the same way in the future as they were in the historical distribution, was given. This allowed for the conversion of the deterministic means into stochastic variables, required for the stochastic budgeting simulations and economic sustainability measure. The chapter also contains a discussion of the financial statements used to measure the profitability of the various scenarios, in the various cohorts. A stochastic efficiency procedure, namely SERF procedure, was used to rank and isolate economically profitable scenarios.

In the next chapter, the results of all the three scenarios in the four cohorts are given.

Chapter 5.

EMPIRICAL RESULTS

5.1 Introduction

In this chapter, the results of the simulations of the multivariate empirical (MVE) probability distributions, stochastic budgeting simulations, SERF analysis and economic sustainability analysis are reported. For ease of exposition, the results are presented in three parts. In the first part a detailed explanation of the simulation and descriptive statistics results of the stochastic variables is given. Part 2 simultaneously reports the results of the stochastic budgeting simulations and the SERF analysis of each of the 3 scenarios, in the four cohorts. Part three focuses on the results of the economic sustainability analysis of the alternative scenarios in the four cohorts in a bid to answer the main objective of this study, which was to access the profitability and economic sustainability of converting a sheep farm into a springbuck ranch, whilst overtly taking risk.

5.2 Diagnostic Tests and Stochastic Variables Results

Before conducting the analysis, the simulated variables were subjected to a variety of diagnostic tests by comparing them to their historical values. This was done for two reasons: firstly, to ascertain how close the stochastic values are to their historical counterparts, and secondly, as a way to authenticate the model. To achieve this, the multivariate distribution means, variance and correlations were tested against their historical means, variance and correlations, respectively. The means of the simulated multivariate distribution were compared to their historical means by using the Hotelling's T-Squared Test, whereas Box's M Test was used to test their variance. The Student t-test was used to test the correlations of the simulated variables against those of their historical distribution.

Specifically, the Hotelling's T-Squared Test conducts concurrent tests that determine the statistical relationships between the simulated vector means and the vector means of the historical distribution (Richardson *et al.*, 2006; Vose, 2008; Vose, 2000). Simetar® uses the Two Sample Hotelling's T-Squared Test to ascertain whether the simulated vector means for the multivariate distribution are statistically equivalent to the vector means for the original distribution or not (Richardson *et al.*, 2008). Accordingly, the results of the Hotelling's T-Squared tests illustrated that at the 0.05 significance level, most of the simulated vector means were statistically equal to their historical means. This was expected as some of the simulated means were assumed to follow the distribution of the historical means. Variance was tested using Box's M Test (Box, 1953) for homogeneity, which checks for consistency in the variation amongst variables (Richardson *et al.*, 2008; Richardson *et al.*, 2006; Vose, 2008; Vose, 2000). To perform Box's M test, the covariance of the simulated multivariate distribution were tested against the covariance of the original multivariate distribution, with the intention of checking if the was equality in the variables of the two distributions (Richardson *et al.*, 2008). The results for the for Box's M tests for homogeneity confirmed that the variance of the simulated distribution was similar to the variance of the historical distribution at the 0.05 significance level - thus authenticating the model and confirming that the stochastic variables simulated the variability of the historical distribution.

5.2.1 Output and Prices

The simulated means for wool sheep output, mutton output, springbuck output, wool price, mutton price, and venison price for the year 2011 to 2025 are presented on Figure 5.1. The simulated output for springbuck and culled wool sheep increases annually during the course of the planning horizon, whereas that of wool sheep was decreasing throughout the planning horizon. This is because the farmer was leaning more on springbuck in terms of output than he was on wool sheep. Because of this, it was generally assumed in this study that this trend was expected to continue in the planning horizon[30]. This assumption is line with the outcomes of an unstructured interview held with farmers in the area, as part of this study, which revealed that, whilst farmers were reluctant to take up springbuck ranching as a premier ecological-economic system in their rangelands, they, however, often looked to it for improving their net returns.

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[30] For example, data from Camdeboo Meat Processors shows that the output of springbuck in the area was generally increasing.

This can be chiefly attributed to a growing cost-price squeeze in livestock farming in South Africa, especially in the Karoo, which has left farmers in financial hardships. To circumvent going into financial ruins, farmers have been keeping more springbucks on their farms. This result is line with the observations of Nel and Hill (2008) who reported similar findings with regard to game ranching and livestock farming in the Karoo.

Furthermore, the simulated means show that the amount of mutton produced on the farm, nevertheless, was increasing. This is a rather ambiguous result since, it is expected that as the population of springbuck on the ranch increases, the number of sheep should subsequently fall. However, recalling that the historical dataset is based on the actual number of wool sheep sheared, culled or sold as mutton sheep in the past 11 years, it then becomes less confusing. What it means is that as the decision maker consciously allows the population of springbuck on the ranch to increase, the number of wool sheep culled and subsequently sold as mutton, increases. This simultaneously means that the number of wool sheep actually shorn on the ranch subsequently decreases, as the mutton and venison output increases: hence, the evident decrease in wool output. [31]Table A3 in Appendix A presents a comprehensive illustration of the summary statistics of all the simulated stochastic variables used in this study. They include the mean; standard deviation (StDEV), coefficient of variation (CV), minimum, and maximum values for wool sheep, sheep for mutton, springbuck, wool price, mutton price, and venison price. The CVs are stable and unwavering from 2011 through to 2025. Not surprisingly, the means of the simulated stochastic price variables are higher than their historical deterministic means. The reason for this was that the variability of the forecasted mean prices was assumed to increase linearly for all means from 2011 to 2025.

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[31] Furthermore, it should be recognized that the output for mutton can only increase for so long, after which if the parent stock has been sold there would be no sheep kept on the ranch which would consequently mean that there would be no wool or mutton produced. This is also true for springbuck output, which can only increase if there is available space to produce more, otherwise the output fluctuates as per the carrying capacity of the farm.

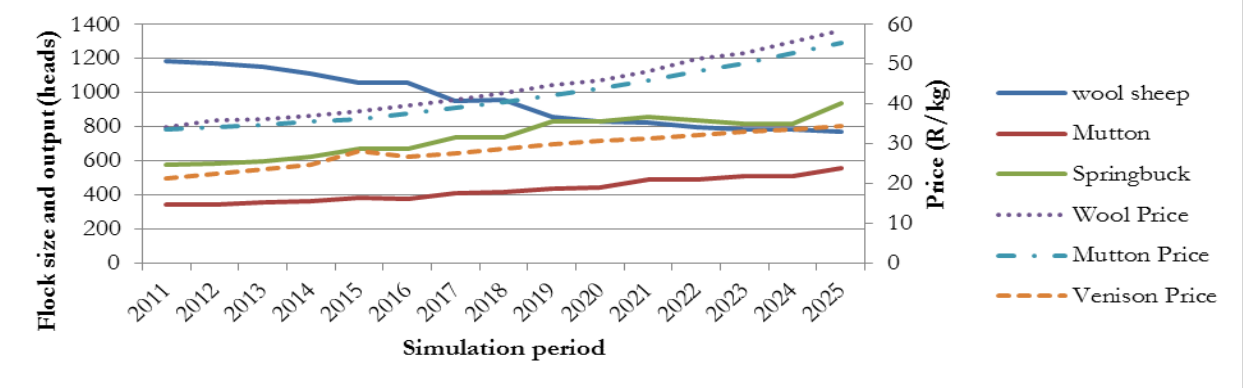

Figure 5.1: Simulated yearly mean values for wool sheep, mutton, springbuck, wool price, mutton price, and venison price from 2011 to 2025.

Similarly, the mean output for mutton and venison was increasing. This is in line with projections from the OECD-FAO Outlook (2011), which predicts that the world consumption of meats and its products is expected to increase up until 2020. The mean price for mutton and venison was, using the consumer price index, assumed to increase linearly from 2011 to 2025. The price of mutton and venison grew by between R33.66 to R55.48 and R21.37 to R34.57 per kilogram in 2011 and 2025, respectively. This is only true in as far as local production and consumption of mutton and venison is concerned. This increase in price supposedly attracts or cause more landowners to convert their sheep farms to springbuck ranches. Because there is only a single buyer of springbuck carcasses in Graaff-Reinet, it was assumed that, even though in international markets the per kilogram price of venison might be increasing, it would decrease in the area as supply out numbers the processor's capacity. Because of this, ranchers react by finding another buyer, who - at the present moment - is many kilometres away from Graaff-Reinet, which further increases harvesting and transportation costs, thus undermining any lucrative prices that the new buyer might be offering[32]. The price of mutton increases because of the assumption that there will be an increase in the world demand of sheep meat (OECD-FAO, 2011), but such an increase is only applicable to the world price of mutton not in Graaff-Reinet. Thus, as many farmers continue progressively to convert their sheep farms to springbuck ranches, it was assumed that the price of mutton would decrease, and to capture this, a price wedge that restricts the price from increasing was introduced. Primarily, the mutton price wedge

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[32] This justifies the assumption that throughout the planning horizon, there will only be one buyer.

prevents the price from increasing, because of the assumption that the conversions continue throughout the planning horizon and that no single farmer converts to 100% springbuck ranching over a production season or during any time of the planning horizon. It should be noted that this observation only holds under the assumption that ranchers gradually convert their sheep farms to springbuck ranches, which means there is an oversupply of mutton. This was subsequently assumed to cause the price of wool to become more attractive as wool output decreases, in favour of springbuck ranching: an occurrence that was assumed to continue from 2016 of the planning horizon to 2025.

In the same way, the mean price of wool increases by between R34.23 to R58.62 per kilogram from 2011 to 2025, respectively. This assumption was informed by the observation that the Karoo is a significant wool-producing region in South Africa (NDA, 2010). Hence if land were to be converted, *en masse*, for ecological-economic systems that do not favour wool production, the expectation is that the wool output in South Africa would drop substantially, which would - in the long run - lead to an increase in the nominal price of wool. This should, however, be understood within the context of this study, as it does not necessarily mean that, because of the conversion from sheep farming to springbuck ranching in Graaff-Reinet, the world wool price would be affected. Rather it means that for South Africa, because of a decrease in output in the Karoo, buyers might be willing to pay a slightly higher price than they would have been willing had the output been increasing or significantly not changing over time.

5.2.2 Correlations

In stochastic simulation, stochastic dependency is a crucial concept. In preceding chapters, it was mentioned that to account for stochastic dependency amongst variables it is important to determine the correlation structure of the historical variables, which was achieved through a correlation matrix. A correlation matrix is a table containing a group of numbers describing the relationship between all possible pairs of variables in a distribution.

Table 5.1: Intra and Inter-Temporal Correlations and Summary Statistics of Wool Sheep, Mutton, Springbuck, Wool Price, Mutton Price, Venison Price, Rainfall and Biomass

	OUTPUT			**PRICE**			**OTHER**	
	Wool Sheep	Mutton	Springbuck	Wool	Mutton	Venison	Rainfall	Biomass
OUTPUT[a]								
Wool Sheep	1.00	-0.83	0.41	-0.29	-0.62	0.61	0.54	-0.26
Mutton		1.00	-0.16	0.64	0.82*	0.62	-0.54	0.15
Springbuck			1.00	0.33	0.33	0.21	-0.19	-0.66
PRICE								
Wool Price				1.00	0.76*	0.70*	-0.27	0.07
Mutton Price					1.00	0.54	-0.64	-0.24
Venison Price						1.00	-0.33	0.43
OTHER								
Rainfall							1.00	0.54
Biomass								1.00
Inter-temporal[b]	0.44	0.44	0.48	0.10	0.07	0.08	0.41	0.12
Mean[c]	953	657	595	36.86	37.94	14.21	305.77	1,880.47
StDev	221	129	115	7.41	7.63	6.16	59.74	364.08
CV	23.23	20.57	19.34	20.09	20.10	9.40	19.54	19.36
Min	767	444	403	24.74	25.62	7.65	204.82	1,261.77
Max	1,223	874	789	48.88	50.50	25.63	406.50	2,503.98

[a] Animal heads

[b] One year Correlations

[c] Mean restricted to sheep dominated enterprise

*Significant at 0.05 level (t-critical = 1.98)

To test for correlation, the correlation matrix of the original or historical distribution was tested against that of the simulated distribution to investigate if the variables in the simulated distribution exhibited the correlation of the historical variables. To perform this test, the Student t-test was used to evaluate each of the coefficients in the correlation matrix (Richardson *et al.*, 2008; Vose, 2008). Specifically, the Student t-test tests the significance of the correlation matrix of the historical distribution against those of the simulated distribution. The results of the tests evince that the correlation matrix for the simulated distribution was statistically not different to the historical correlation matrix at the 0.05 level, indicating that the simulation model was proficient in replicating the historical correlations amongst all the variables.

Table 5.1 presents the correlation matrix for the historical observations for wool sheep, mutton, springbuck, wool price, mutton price, venison price, rainfall and biomass. All variables are intra-temporally correlated with one or more variables at the 0.05 significance level. A high negative correlation was observed between the number of wool sheep sheared on the ranch and the wool sheep culled as mutton (-0.83), the price of mutton (-0.62) and the price of venison (-0.61). Likewise, the number of wool sheep culled for mutton showed a high correlation with the price of wool (0.64), price of mutton (0.82), price of venison (0.62) and rainfall (0.54). The correlation between springbuck culled in the farm and green forage biomass was negative and significant (-0.66), whereas the correlation between the price of wool and price of mutton (0.76) and the price of wool and venison (0.72) was positive and highly significant. Wool sheep sheared for wool showed a significant but negative correlation with the rainfall amount in a year (-0.54), whilst the correlation between biomass and rainfall (0.54) was positive. Mutton price produced a negative and significant correlation with rainfall (-0.64).

The inter-temporal correlation matrix depicts a moderately weak correlation for wool sheep sheared (0.44), wool sheep culled for mutton (0.44) and springbuck culled for venison (0.48). The correlations between output and prices were positive but weak, with the price of wool having the highest inter-temporal correlation (0.1) amongst the three, followed by the price of venison (0.08) and the price of mutton (0.07) was last. Rainfall had a positive and moderate inter-temporal correlation (0.41) whilst biomass yielded a positive but weak inter-temporal correlation (0.12).

5.3 Simulation Results for Alternative Scenarios

The study analyses three alternative ecological-economic systems, categorised into four cohorts. Table 5.2 gives a concise illustration of the various ecological-economic systems and summarises their grouping as per the decision maker's preferences. The study was interested in knowing if it would be profitable for the principal decision maker to continue as today (Cohort 1) or convert the farm to a springbuck ranch by making springbuck ranching the leading ecological-economic activity on the ranch by means of setting aside more land for it (Cohort 3). Moreover, the study also wanted to explore the effect that incentives would have on springbuck ranching considering its assumed potential to promote ecological cohesion (through biodiversity restoration, see chapter 2). Because of this, Cohort 2 scenarios investigate the impact of incentives on farm profitability if the farmer continues as today with all the assumptions of

Cohort 1, but with the option of getting incentives for springbuck ranching[33]. The last option is to follow the assumptions of Cohort 3 with the possibility of getting incentives for springbuck ranching (Cohort 4). Currently, the premier ecological-economic system on the farm is sheep farming.

Hence, Table 5.2 also shows whether the farmer receives incentives or not. The share of land used relates to the portion of the 5 000ha farm assumed to be used for the various alternatives in the different scenarios, respectively. It is perhaps, worth mentioning that, in Cohort 1, alternative WLS NI SF (wool mutton springbuck, no incentives, sheep farming) is a true depiction of what is happening on the study farm at the present. Moreover, also important to note is that the share of land used was specifically introduced for ease of computation in this study. In practice, springbucks are naturally occurring in farms in Graaff-Reinet; meaning that they also share the rangelands with sheep. There are no incentives on livestock farming in South Africa, neither are there any subsidies. They, however, are used here to explore the income boosting policy measures that the government of South Africa would have to initiate to ensure the sustainable use of rangelands in Graaff-Reinet. This would be in response to the continued degradation of rangelands because of livestock farming but also given the constitutional goal of wanting to conserve natural ecosystems for the benefit of future generations.

5.3.1 Simulation Results for Cohort One Scenarios

In Table 5.2, it is shown that in cohort one there are three possible scenarios of how the principal decision maker can utilise the rangeland, under the assumptions of this study. The decision maker can either continue as today, by using the rangeland chiefly for sheep farming (SF) with the sole purpose of producing wool (W) and mutton (L). The decision maker, however, harvests free and naturally occurring springbucks (S) on the ranch which are sold to the Meat Processor for a per kilogram dressed weight price. In scenario two, the study assumed that the decision maker decreases the sheep stock in favour of springbuck ranching, whilst in scenario three the study assumed that there would be an increase in springbuck output by up to

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[33] Because it is assumed that the rancher gets incentives for springbuck ranching, even though he does not get them for sheep farming the prices are also expected to be influenced, largely, by what is happening in other farms.

30 percent. The financial statements were simulated as discussed in the preceding chapter and the key output variables (KOV's) were compared to each other in an endeavour to solicit an understanding of how the various alternatives affect the profitability of the ranch.

Table 5.2: Groupings of Scenario Contents Assumed for Study Analysis

Cohort	Abbreviation	Ecological system	Share of land used	Incentives
Cohort 1	WLS NI SF*	Wool Mutton Springbuck	7:2:1	No
	WS NI SF	Wool Mutton Springbuck	5:3:2	No
	WL NI SF	Wool & Springbuck	7:3	No
Cohort 2	WLS YI SF*	Wool Mutton Springbuck	7:2:1	Yes
	WS YI SF	Wool Mutton Springbuck	5:3:2	Yes
	WL YI SR	Wool & Springbuck	7:3	Yes
Cohort 3	SLW NI SR#	Springbuck Mutton Wool	7:2:1	No
	SW NI SR	Springbuck Mutton Wool	5:3:2	No
	SL NI SR	Springbuck & Wool	7:3	No
Cohort 4	SLW NI SR#	Springbuck Mutton Wool	7:2:1	Yes
	SW NI SR	Springbuck Mutton Wool	5:3:2	Yes
	SL NI SR	Springbuck & Wool	7:3	Yes

*SF,#SR = premier ecological-economic system is sheep farming and springbuck ranching, respectively.

5.3.1.1 Net Cash Income

The estimated average yearly net cash incomes in thousands of South African rands (R) for each of the cohort one scenarios are presented in Figure 5.2. The results show that the estimated average annual net cash incomes are positive throughout the planning horizon, for all the 3 scenarios. Notwithstanding, for WLS NI SF (scenario 1) they indicate that the net cash income is smallest throughout the planning horizon. After 2011, the net cash income gradually decreases in all the scenarios because, even though the prices show an upward trend, a benefit that is over-shadowed by an equal increase in production costs – which prevents any realistic gains from wool price increases to be realised. This is somewhat expected since, in this cohort, wool production is the premier ecological-economic system and thus there is a high number of wool sheep kept implying a high sheep retention ratio and thus high winter feeding costs. The net cash income received from scenario 2 (WS NI SF) and 3 (WL NI SF) was higher than in the WLS NI SF scenario illustrating the influence of springbuck meat production on the income structure of the family farm. However, like in the WLS NI SF scenario, feeding and production costs in winter were increasing during the entire course of the planning horizon. This made the net cash income to decrease throughout the planning horizon. The WS NI SF scenario had the highest income in 2011 and outpaced by the WL NI SF scenario in 2016, an expected result considering the high costs of winter-feeding, that were increasing throughout the planning horizon in wool sheep farming. In the WL NI SF scenario, and because of the high number of springbuck harvested, the net cash income was highest from 2016 right through to 2025 – justifying that a more diversified rangeland could potentially yield higher income returns than monotonous wool sheep farming. This is partially because of the increase in income obtained from springbuck production as well as the reduced costs of feeding as more land is set aside for springbuck ranching. However, such a net income is equally constrained by an equivalent increase in production costs, as the farmer tends to use the money from the springbuck enterprise to supplement the sheep enterprise.

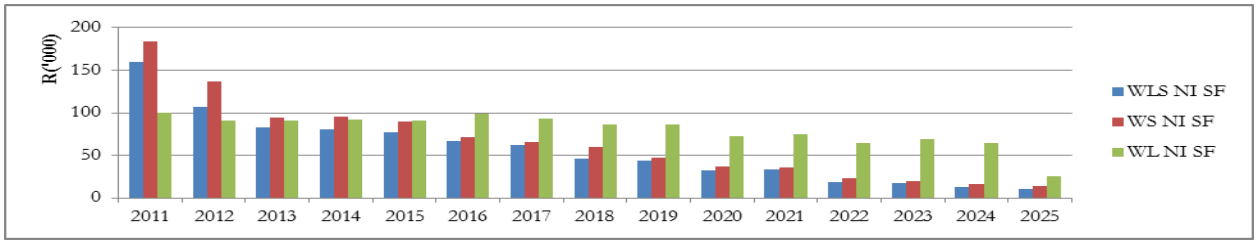

Figure 5.2: Estimated yearly Net Cash Income for a 5 000ha farm producing wool as a premier economic activity without incentives.
See Table 5.2 for a detailed explanation of acronyms.

The net cash income for the three (WLS-, WS- and WL NI SF) scenarios in 2011 was about R159 thousand, R183 thousand, and R100 thousand, respectively. For WLS NI SF, the probable net income decreases from R159 thousand in 2011 to R8 thousand in 2025, whereas for WS NI SF, it decreases from R183 thousand to R24 thousand in 2025, as shown in figure 5.2. There is a 10% chance that the net cash income in the WLS NI SF scenario would be negative in 2025. The WS NI SF scenario returned the highest net cash incomes in all the scenarios up until 2015 where after it was over taken by the WL NI SF scenario in 2016, suggesting that a combination of 70% wool production and 30% venison might yield higher returns in the long-term. The WL NI SF scenario starts with an average net cash income that is smallest in all the three scenarios in 2011 and continues in this trajectory up until 2015. In 2016, the WL NI SF scenario returned average net cash income that is higher than that of the WS NI SF scenario. These results show that scenario 3 (WL NI SF) yields more average yearly net cash income than the WLS- and WS NI SF scenarios, respectively, towards the end of the simulation period. From 2013 through to 2025, the net cash income for all the scenarios except the WL NI SF scenario is below the R100 thousand mark, demonstrating the effects of production costs, especially winter feeding on the net returns. However, scenario one and two failed to yield a net cash income above R50 thousand from 2018 to 2025, indicating the influence of an increase in production costs on net farm returns.

Figure 5.3 shows the fan graphs of the probable yearly net income risk for the 5 000ha farm, under the assumptions of cohort 1. These fan graphs illustrate the range and risk of the simulated probable yearly net incomes for all the three scenarios in cohort 1. The probable yearly net income risk is bounded between 5 lines coloured in five distinct colours. The dark red (uppermost) line and red (lower) line contain 90 percent of the simulated values, whilst the black (middle) line shows the estimated yearly mean, over the planning horizon. The inner lines: blue (second from bottom) and green (second from top) contain 50 percent of the simulated values. Table B1 in the appendix presents the mean, standard deviation, coefficient of variation, minimum, and maximum values of net cash income for the three scenarios.

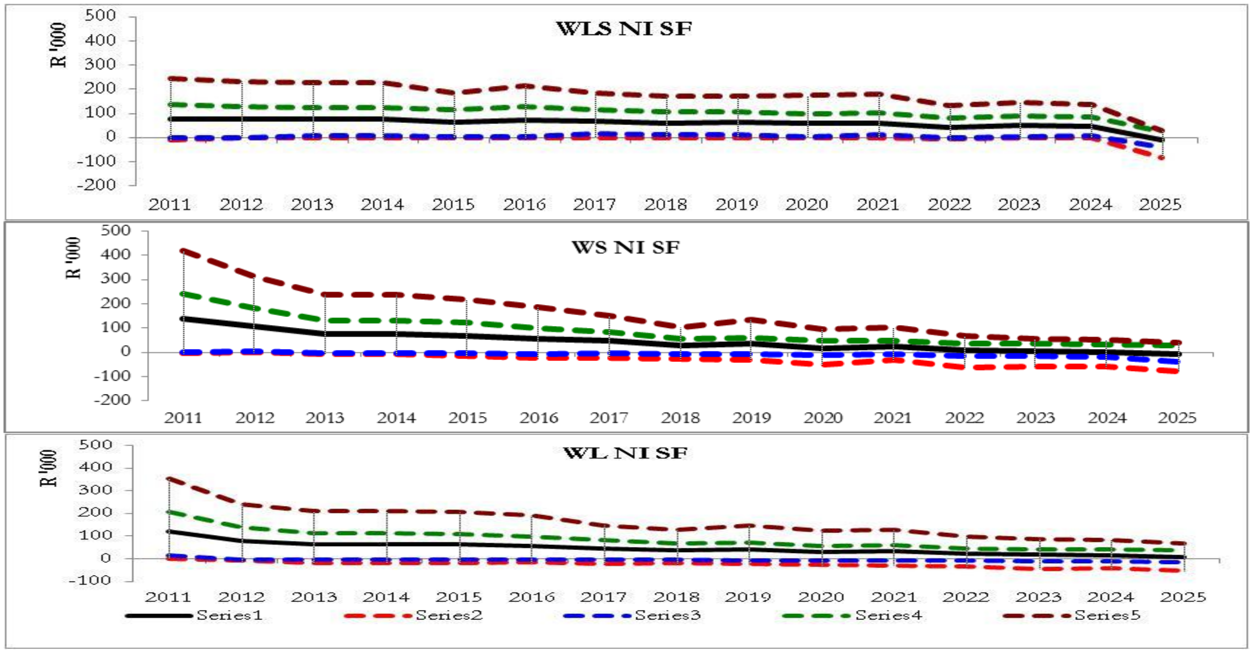

Figure 5.3: Fan Graphs showing estimated yearly net income risk for a 5 000ha Farm in Graaff-Reinet, producing wool as a premier economic activity without incentives.
See Table 5.2 for a detailed explanation of acronyms.

Important to note is that the estimated yearly net cash incomes range and risk for scenario one was constant whilst both scenarios two and three had a decreasing variability throughout the planning horizon. This variability is shown by the dark red lines in the two graphs, and by the coefficient of variation (CV) in Table B1 of Appendix B. In scenario three, the net cash income stays constant – with constant variability - throughout the entire planning horizon. In these scenarios, the probability of obtaining negative average net cash income increases towards the end of the simulation period – owing to high feeding costs in the sheep enterprises.

The range of net income was highest in the WS NI SF with a 50 percent chance that the net cash income would lie between R175 thousand and R55 thousand throughout the planning horizon. In this scenario, 90 percent of the simulated estimated average yearly net income fell between R186 thousand and (R6) thousand in 2016. Moreover, with 90 percent of the simulated estimated average yearly net income falling between R216 thousand and (R4) thousand - in the same year, the WL NI SF scenario had the thinnest range of net income amongst the three scenarios. In 2025, the WS NI SF scenario produced the biggest range and this was supported by 90 percent of the simulated average yearly net income falling between (R76) thousand and R38 thousand. The WL NI SF scenario had 90 percent of its simulated average yearly net income falling between (R53) thousand and R68 thousand, in 2025. There was a 50 percent chance that the WL NI SF scenario would yield an income between R153 thousand and R59 thousand throughout the entire planning horizon.

5.3.1.2 Ending Cash Balance

In chapter 4, the ending cash balance (ECB) was defined as that portion of income that affects the business before borrowing. For the Cohort 1 scenarios, this is shown in Figure 5.4, which displays the estimated average yearly ending cash balances in thousands of rands. The ending cash balances for all the scenarios are positive throughout the year and follow the same pattern as the net cash incomes. The ending cash balances are highest in 2011, and decrease gradually throughout the planning horizon as costs for production increases. The WLS NI SF scenario returned the smallest average ending cash balance in 2011, followed by the WS NI SF scenario. As expected, given the high ending cash balances, the WL NI SF scenario, yielded the highest ending cash balance at bank. For WLS NI SF, the ending cash balance starts from R213 thousand in 2011, drops to a low of R103 thousand in 2019 and gradually decreases until it reaches R65 thousand in 2025. The reason for the decrease in ending cash balance can be attributed to high production costs in this cohort that affected the ending cash balances at bank for this scenario, as farmer had to use more income to finance feeding costs given an increase in production costs. Figure 5.4 also shows that for the WS NI SF and WL NI SF scenarios, the ending cash balances start from R242 thousand and R261 thousand in 2011, and like the WLS NI SF scenario, drops to R89 thousand and R118 thousand in 2019 whence they decrease gradually to R87 thousand and R109 thousand in 2025, respectively.

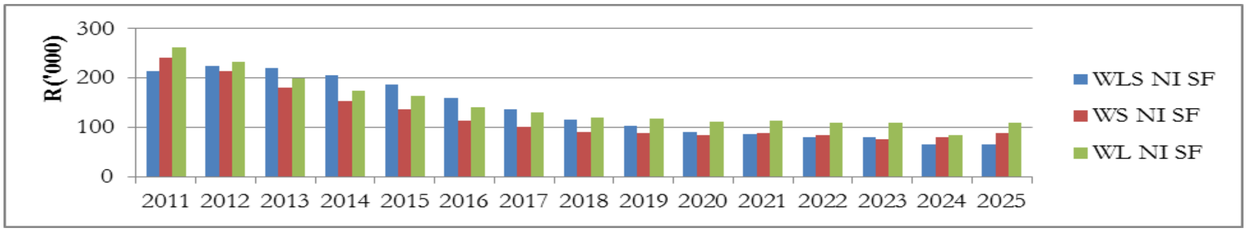

Figure 5.4: Estimated yearly ending net cash balance for a 5 000ha Farm in Graaff-Reinet, producing wool as a premier ecological-economic activity without incentives.
See Table 5.2 for a detailed explanation of acronyms.

The ECBs for the entire three scenarios further reflect the influence of increasing springbuck output on the ending reserves of the business. For example, the WLS NI SF has the lowest ending cash balance in 2011, whilst the WL NI SF scenario has the largest. Similarly, in 2025, the WL NI SF scenario yielded the lowest ending cash balance in contrast to the other two alternative scenarios. This is clearly a result of increasing income sourced from springbuck ranching, which increases the farm income thereby increasing the amount of money available to accumulate interest in the bank.

The estimated yearly ending cash balances' range and risk for all the alternative scenarios in cohort 1 are presented in Figure 5.5. The range and risk for the WLS NI SF, WS NI SF and WL NI SF scenarios show that the variability of the ending cash balances from 2018 to 2025 are constant and moderately thin - ranging between R4 thousand and R196 thousand and R4 thousand and R112 thousand, respectively. There is a 50% chance that the net cash income for the WLS NI SF scenario would be greater than R100 thousand in the first 5 years. The CV for this scenario is highest in 2011 at 52% and gradually decreases to 16.56%, in 2025. For the WS NI SF the variability remains relatively constant after 2018 and only decreases moderately to 18.34% in 2025. The ending cash balance ranges between R12 thousand and R336 thousand, in

2011 and R8 thousand and R112 thousand in 2025, reflecting decreasing variability around mean towards the end of the planning horizon, for the WLS NI SF scenario. Furthermore, the scenario has a 50% chance that the ending cash balance would be between R134 thousand in 2011 and R45 thousand in 2025. However, the ending cash balance for the WL NI SF scenario is the largest in this cohort. In 2011, the estimated ending cash balance range and risk for the WL NI SF scenario is between R7 thousand and R360 thousand and decreases to R4 thousand and R194 thousand, in 2025. There is a 50% chance that the ending cash balance for the WL NI SF scenario would be bounded between R153 thousand and R75 thousand in 2011 and 2025, respectively.

Table B3 in Appendix B also presents the mean, standard deviation, coefficient of variation, minimum, and maximum values of the estimated ending cash balance for the three scenarios.

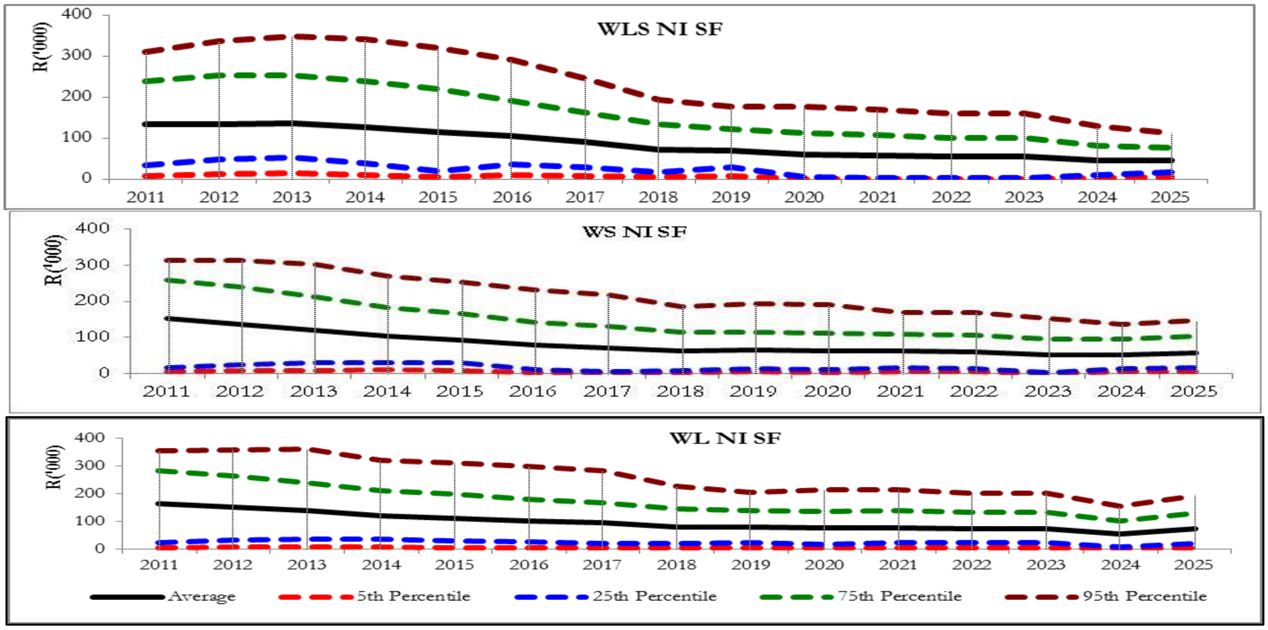

Figure 5.5: Estimated yearly net ending cash balance risk for a 5 000ha Farm in Graaff-Reinet, producing wool as a premier ecological-economic activity without incentives.

See Table 5.2 for a detailed explanation of acronyms.

5.3.1.3 Real Net Worth

The net worth can analyse the financial soundness of any enterprise in two ways. First, it can be used in nominal or current (rand) money terms, or as real money (rands). In real money (rand) terms, the net worth is called the real net worth and is calculated by adjusting the nominal net worth for inflation to find the real value of the enterprise in today's rands using a deflation factor. In this study, the real net worth assesses the financial soundness of the various enterprises over a period of 15 years. Figure 5.6 presents the estimated yearly average real net worth for the 5000 ha farm, whereas Table B4 in the appendix presents the mean, standard deviation, coefficient of variation, minimum, and maximum values for real net worth for all the scenarios, in cohort 1.

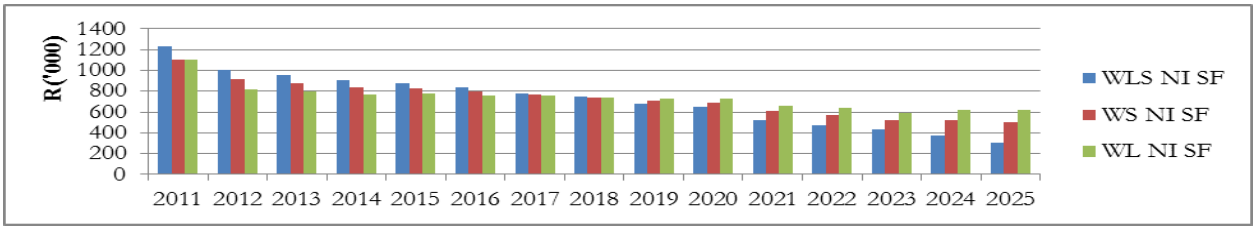

Figure 5.6: Estimated yearly real net worth for a 5 000ha Farm producing wool as a premier ecological-economic activity without incentives.
See Table 5.2 for a detailed explanation of acronyms.

The real net worth for the three scenarios starts out just above R1 million in 2011 and decreases throughout the 15 year planning horizon, such that it is at its lowest in 2025. The estimated average yearly real net worth is equal for both scenarios 2 and 3, in 2011, whereas in 2025, WL NI SF had the highest real net worth for all the three scenarios. In all the scenarios, the real net worth decreases because of the influence of the deflation factor used to deflate the nominal net worth – which decreases throughout the planning horizon. Moreover, it also decreases because of high borrowing costs and liabilities that the family farm faces throughout the planning horizon. The real net worth in 2011 was R1.2 million for WLS NI SF and R1.1 million for the WS NI SF and WL NI SF scenarios. In 2025, however, the real net worth for the three scenarios stood at R307 thousand for WLS NI SF, R500 thousand for WS NI SF and at R624 thousand for WL NI SF. The WL NI SF scenario showed the highest real net worth than all the other two scenarios because of the high income received from springbuck ranching. The higher real net worth was a result of lower borrowing costs as income sourced from venison production, in this scenario, was used partly to finance the wool sheep enterprise. This result suggests that a lower sheep retention ratio might in the long-run lead to a profitable enterprise. The portion of land used for wool sheep was 70 percent whilst the remaining 30 percent of land went to springbuck ranching. Notwithstanding, the results further shows that none of the cohort 1 scenarios looks promising as all of them have a declining net worth.

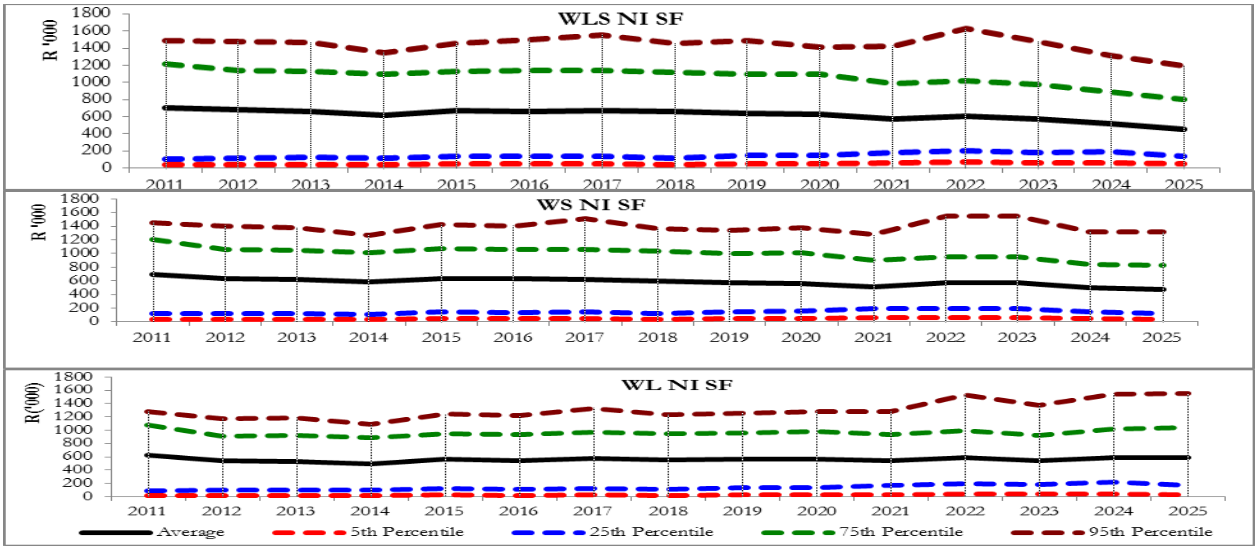

Figure 5.7: Estimated yearly real net worth risk for a 5 000ha Farm producing wool as a premier ecological-economic activity without incentives.
See Table 5.2 for a detailed explanation of acronyms.

The fan graphs of the real net worth of the cohort one scenarios are shown in Figure 5.7. Despite the WS NI SF scenario showing the thinnest real net worth range in 2011, it has the second largest range in 2025, after the WL NI SF scenario. For example, 90% of the real net worth values for the WS NI SF scenario are bounded between R32 thousand and R1.173 million in 2011. This is in contrast to the WLS NI SF and WL NI SF scenarios, which had 90% of the simulated real net worth values fall between R40 thousand and R1.48 million and R34 thousand and R1.55 million, in the same year, respectively. In 2025, moreover, the WLS NI SF scenario has the thinnest real net worth range with 90% of the simulated estimated yearly real net worth falling between R45 thousand and R1.197 million. This is in contrast to a range of R86 thousand and R1.311 million for the WS NI SF scenario, in 2025. There is a 50% chance that between 2011 and 2025, the net worth will range between R680 thousand and R455 thousand, R636 thousand and R480 thousand, and R546 thousand and R600 thousand for the WLS NI SF, WS NI SF and WL NI SF scenarios respectively.

5.3.1.4 Net Present Value

In chapter 4, the usefulness of the NPV as a yardstick to gauge the financial soundness of a project, was discussed. It was emphasised that the NPV is often a valuable tool in cases where a decision on whether to invest or not is sought. Lau (2004: 135) adds that an "NPV of a capital budgeting project … [can also act as a directive especially when the desire is on developing a rounded understanding of] the expected impact of a project on the value of the firm and its income earning potential." In this study, the NPV is used as a proxy for profitability. According to Lien (2003), risky strategies are best evaluated using their cumulative distribution functions (CDFs). A CDF graph of the NPV, as Lau (2004: 135) continues: "represents the risk of simulated NPV outcomes for visual comparison between alternative scenarios." In cohort 1, there are three scenarios, which are represented by the three CDFs in Figure 5.8. The vertical axis of Figure 5.8 measures the probabilistic outcome of the NPV whilst the horizontal axis shows the actual amount of the estimated NPV of the various scenarios.

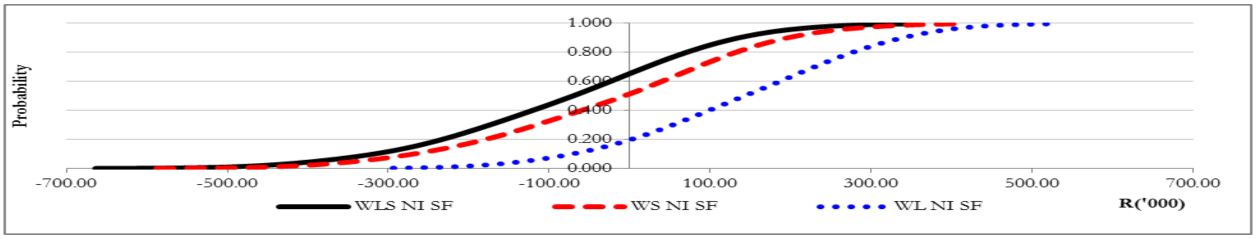

Figure 5.8: Stochastic Efficiency with Respect to a Function graph of net present value for a 5 000ha farm producing wool as the premier ecological-economic activity without incentives.

See Table 5.2 for a detailed explanation of acronyms.

The decision maker can only choose one scenario, and when he makes that choice, the other two scenarios simultaneously fall off. Since it is assumed that no specific scenario is preferred amongst the alternative scenarios in this study. The rule of thumb in mutually exclusive projects is to choose the one with the highest positive NPV (Lau, 2004). Using a positive NPV is based on the premise that a discounted stream of net returns is sufficient to meet the rate of return as dictated by the assumed discount rate – which is 9% in this study. The CDF graph results demonstrate that the probability that any scenario in this cohort will yield a negative average NPV is high, except WL NI SF. Table B4 in the appendix also shows the mean, standard deviation, CV, minimum and maximum values for the estimated average NPVs in cohort one. The probability that WLS NI SF will return a negative NPV is 62 percent, followed by WS NI SF with a 51 percent chance. However, WL NI SF has an 18.7 percent chance of returning a negative NPV. The average NPVs for the three scenarios are (R83.03) thousand, (R23.70) thousand and R137.19 thousand, for WLS-, WS- and WL NI SF, respectively. Only the WL NI SF scenario was able to produce a positive NPV albeit small.

Clearly, the WL NI SF scenario, depicted by a blue dotted line, is the most profitable option amongst the three. It is difficult, however, to tell with confidence that the WL NI SF scenario is the most profitable alternative since the CDF lines seem to be touching each other at the tails. In order to resolve this problem, the stochastic efficiency with respect to a function (SERF) method is used to rank and analyse the three scenarios. The SERF analysis complements the results of the NPV analysis by providing an unbiased weighting of the SERF graph of the alternative scenarios across a range of possible risk aversion coefficients (RACs). Recalling the importance of the risk aversion coefficient, as argued in earlier chapters, a need to specify the upper and lower limits of the RACs ranges for this study becomes eminent. Accordingly, the upper and lower risk aversion coefficients are calculated by following equation (4.23).

This study uses a lower RAC of 0 because of the assumption that the decision makers are risk averse. Therefore, the RACs are bounded between a lower limit of zero and an upper limit to capture the decision-making process of a risk neutral and risk averse decision maker, respectively. A RAC of zero signifies a decision maker who is risk neutral, whereas a RAC greater than 0 but less than 4 (Hardaker *et al.*, 2004a) implies risk averseness. A negative RAC implies risk loving or risk seeking which does not apply to this study, since the decision makers are assumed risk averse.

Thus, the study used a lower absolute risk aversion coefficient (ARAC) of 0.0 and calculated and an upper ARAC of 0.000025, such that the absolute risk aversion coefficient (ARAC) range was between 0.0 and 0.000025 for all the scenarios in cohort one. Figure 5.9 presents the SERF graph showing the CE lines for the WLS-, WS- and WL NI SF scenarios. From these CE lines, it is clear that the WL NI SF scenario is the most preferred scenario over the WS NI SF and WLS NI SF scenarios, across the various ranges of risk aversion coefficients.

However, the WLS NI SF scenario returned negative CE across the range of risk aversion coefficients, suggesting that the farmer is better off increasing his investment in springbuck ranching. Often a negative CE means that the investment is not worth it, and is better abandoned. In this case, it shows that since the farmer increases the amount of sheep from scenario one to scenario three, it would be potentially profitable to convert more land to springbuck ranching to take advantage of the positive CE values that comes with an increased investment in springbuck ranching. The WS NI SF is equally not appealing for the same reason, as it tends to yield a negative CE throughout the range of absolute risk aversion coefficients.

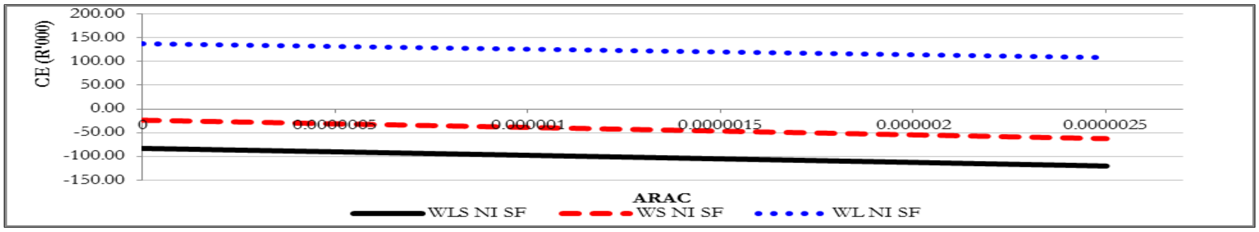

Figure 5.9: Stochastic Efficiency with Respect to a Function graph of net present value for a 5 000ha farm producing wool as the premier ecological-economic activity without incentives.
See Table 5.2 for a detailed explanation of acronyms.

This result is further confirmed by the calculated risk premiums when the decision maker exhibit risk neutral, moderately risk averse and risk averse properties, respectively, between the alternative scenarios, as shown in Table 5.3. Important to note is that the differences between CE lines also depict the risk premium that decision makers would assign to the alternatives of choice in relation to other alternatives in the same cohort. Using equation (4.24), the risk premiums were calculated and are as presented on Table 5.3. The risk premium denotes the "confidence of decision makers in a particular preferred risky alternative" (Hardaker *et al.*, 2004a: 264). The CE is the "sure sum with the same utility as the expected utility of the prospect" (Hardaker *et al.*, 2004b: 257). This suggests that the risk premium can also represent the amount of money that decision makers would be willing to accept to be equally well-off or indifferent between two alternative scenarios (Lau, 2004). The risk premium can also be defined as the amount of money that will leave the decision maker equally satisfied, in terms of utility, between two competing alternatives (Baumgartner and Quaas, 2005).

Table 5.3: Risk Premiums for a 5 000ha Farm in Graaff-Reinet, producing WLS, WS, and WL with sheep as a premier ecological-economic activity without incentives.

	Risk Neutral	Moderately Risk Averse	Risk Averse
		R	
WLS NI SF	(220 226. 94)	(277 656. 54)	(326, 208. 85)
WS NI FS	(160 894. 09)	(219, 899. 83)	(256, 440. 47)
WL NI SF	-	-	-

See Table 5.2 for a detailed explanation of acronyms.

Under the assumptions of cohort one, the results of the SERF analysis suggest that the WL NI FS scenario is preferred over all the other scenarios across all the risk aversion coefficient ranges and was used to calculate the risk premiums. For risk neutral decision makers to convert their farms from WL NI FS to WLS NI SF and WS NI SF, respectively, and still be equally satisfied, they would have to be paid R220 226.94 and R160 894.09, respectively. However, moderately risk averse decision makers would require a sure amount of R277 656.54 to convert from the preferred WL NI FS to WLS NI SF scenario. Whereas they would need R219 899.83 to convert from WL NI SF to WS NI SF. Alternatively, the risk premium also show the amount of money in utility terms that the decision makers are losing by engaging in the other two scenarios. Lastly, for risk averse decision makers to move from the preferred WL NI SF scenario to WLS NI SF and WS NI SF scenarios, respectively, and still be indifferent, they would have to be compensated with R326 208.85 and R256 440.47, respectively. This illustrates that as the farmer's absolute risk aversion coefficient increases from zero (risk neutral) to risk averse (0.000025), so does his desire for more money to be equally well-off between the preferred WS NI SF scenario and the other two scenarios.

The above results suggest that it is potentially profitable to incorporate springbuck ranching into a 5 000ha wool sheep farm in Graaff-Reinet. However, as the results demonstrate, only a conversion of at least 30 percent of the 5 000ha farm allocated to springbuck ranching for meat production would earn the farmer enough income to warrant any profitability.

5.3.2 Simulation Results for Cohort Two Scenarios

The objective of the scenarios in this cohort was to evaluate the influence of incentives on the profitability of gradually converting a sheep farm - under the assumptions of cohort one - into a springbuck ranch. However, since the size of land used by the springbuck in scenario one

(WLS YI SF) is so small[34], the farmer is assumed not to get a restoration subsidy. This is because assumption that a small number of springbuck on the ranch cannot bring about any significant restoration benefits. Moreover, the farmer gets a tax break strictly for the income obtained from springbuck ranching – as enticement into springbuck ranching. In scenarios two (WS YI SF) and three (WL YI SF), respectively, the farmer progressively increases the amount of land allocated to springbuck ranching, which sees the farmer accessing the restoration subsidy – which is paid on a per hectare basis of land reserved for springbuck ranching. A restoration subsidy of R 13/ha was carefully calculated and used for this study. The results show that the incentives do not have a significant effect on the structure of the net cash income, ending cash balances, net worth and NPV of the ranch. They, however, play a significant role in influencing the long-term behaviour of economic agents in the local market and the principal decision makers in the rangelands. For example, because of the introduction of a tax break the ranchers are stimulated to reduce the population of sheep on their farms. In the long-run, however, this depresses the local price of mutton and the wholesale price of springbuck as more and more wool sheep are culled at the end of the year to allow for more springbuck on the ranch, but simultaneously increases the price of wool, as a result of a decline in wool sheep shorn.

5.3.2.1 Net Income

Figure 5.10 presents the results for the estimated average yearly net cash incomes for all the scenarios in cohort two. The results follow the same direction as those of the cohort one scenarios. In 2011, the WS YI SF scenario returned the highest net income, followed by the WL YI SF scenario. However, unlike in the cohort one scenarios, the WL YI SF scenario overtook the WS YI SF scenario in 2013, such that by 2016, it was the leading ecological economic system in terms of net incomes. This was because of high subsidies, given the high number of springbuck harvested on this scenario throughout the year. The WLS YI SF scenario returned the lowest net income throughout the planning horizon. This was expected, as this scenario did not receive the restoration subsidy unlike the other two scenarios. The net incomes

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[34] Essentially, as already been argued in the preceding paragraphs, the springbuck share the rangeland with the sheep, since they move everywhere on the ranch.

were decreasing throughout the planning horizon because of high costs of production, which were equally increasing in the planning horizon. However, they were generally higher than the cohort one scenarios, elucidating the influence of the restoration subsidy and the tax abatements on the net income of the farm.

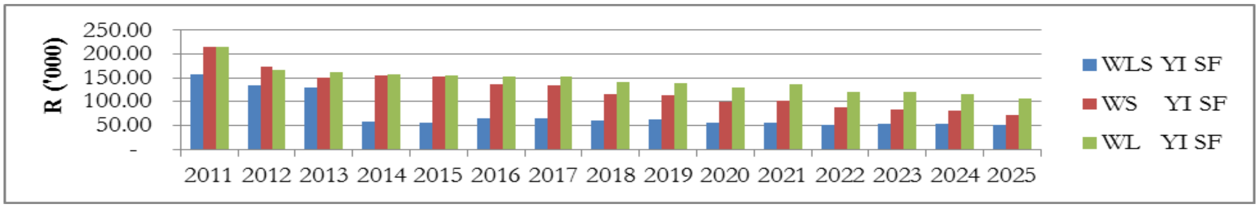

Figure 5.10: Estimated average yearly Net Cash Income for a 5 000ha farm in Graaff-Reinet, producing wool as a premier economic activity with incentives.
See Table 5.2 for a detailed explanation of acronyms.

The WS YI SF and WL YI SF scenario returned relatively higher net income than the WLS YI SF scenario. Income earned from the springbuck enterprise via the restoration subsidy and tax reduction likewise increased the average net cash income for scenarios two and three. However, at the same time, for the WLS YI SF scenario, the high price of wool was unable to improve the average net cash income. This can be attributed to rather high production costs in sheep farming such as costs for supplementary feeding – which were equally increasing - and overshadowed any benefits that the lucrative prices in the wool market, may have had. This is unlike the WL YI SF scenario, which, whilst it experienced high production costs for winter-feeding and labour, the income sourced from springbuck ranching including the incentives accorded the rancher made the net income increase progressively towards the end of the planning horizon, demonstrating the influence of springbuck meat production on farm profitability. Table B5 of appendix B shows the mean, standard deviation, CV, minimum and maximum values for the net cash incomes for the three scenarios.

In 2011 up until 2013, the WS YI SF and WL YI SF scenarios returned a net income above R200 thousand. However, for the WLS YI SF scenario, the net cash income was smallest, and continued in this trajectory throughout the planning horizon. This was because of high initial costs of feeding, and generally increasing costs of production in sheep farming throughout the planning horizon. The net income for the WLS YI SF, WS YI SF and WL YI SF was R156 thousand, R214 thousand and R213 thousand in 2011, respectively. In 2013, the net income obtained from scenario WL YI SF was R161 thousand, and gradually decreased to R106 thousand in 2025. The WLS NI SF scenario reached R57 thousand in 2017, whereas WS YI SF followed the same trajectory as the WL YI SF scenario, and was at R52 thousand in 2025. Like in the cohort one scenarios, the WL YI SF scenario yielded higher incomes throughout the planning horizon. This is because, as the farmer increases the amount set aside for springbuck ranching, the amount of income obtained from the springbuck enterprise offsets some of the costs from the sheep enterprise, thus leaving the farmer better off than in the other scenarios where is investment in springbuck ranching is substantially lower.

The range and risk for the simulated net cash income for the cohort two scenarios is presented on Figure 5.11. A quick comparison between the range and risk of the simulated net cash income for the cohort one scenarios and the cohort two scenarios reveals some differences between the two. For example, in 2011 and 2025 the 50th percentile income range for the WLS YI SF falls between R74 thousand and R43 thousand, respectively. However, for the WS YI SF and WL YI SF, there is a significant difference. The average cash income ranges between R120 thousand to R50 thousand and R109 thousand and R74 thousand between 2011 and 2025, respectively. No scenario shows a probability of yielding negative net cash incomes, as expected since incentives also improve the income structure of the springbuck ranching, and thus of all the enterprises where springbuck meat is produced. In 2011, 90 percent of the simulated net cash income values fell between R2 thousand and R181 thousand, R2 thousand and R350 thousand, and R4 thousand to R311 thousand for the WLS YI SF, WS YI SF and WL YI SF scenarios, respectively. In 2025, it decreased to R1 thousand and R128 thousand, R3 thousand and R137 thousand, and R4 thousand and R183 thousand, for the WLS YI SF, WS YI SF and WL YI SF scenarios, respectively. The variability of the range of income gradually grew from 2011 to 2015, for all the scenarios. Moreover, for the WL YI SF scenario, the CV shows constant variability between the average net cash incomes in the different percentiles, as shown in Table B5 of appendix B.

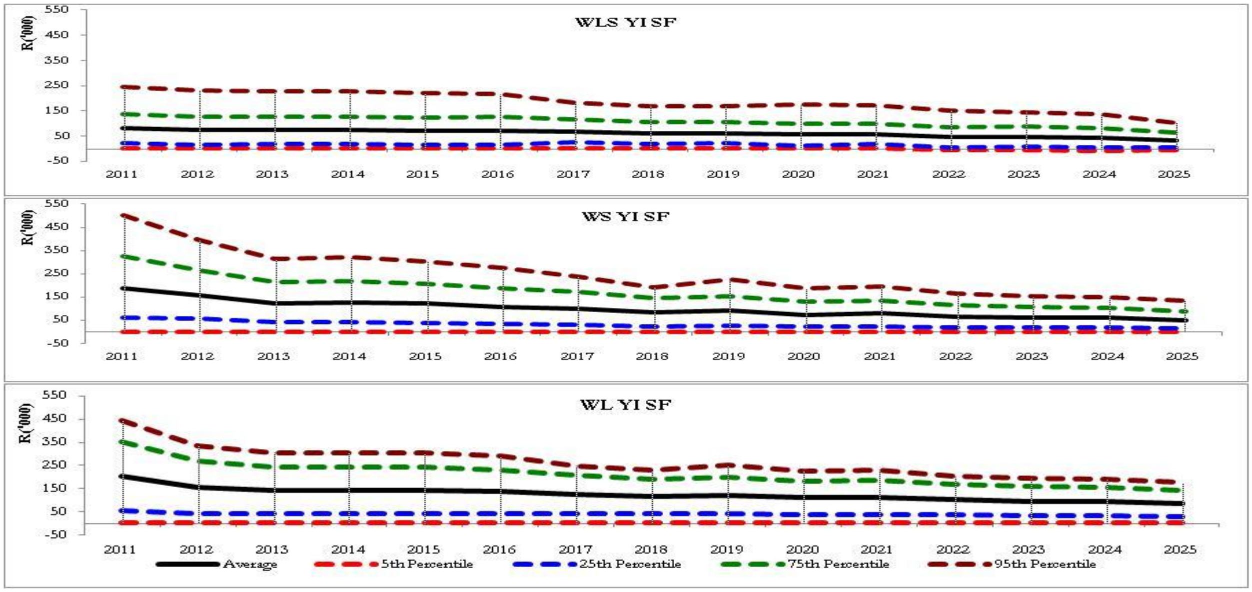

Figure 5.11: Estimated average yearly Net Income Risk for a 5 000ha Farm in Graaff-Reinet, producing wool sheep as a premier ecological-economic activity with incentives.
See Table 5.2 for a detailed explanation of acronyms.

5.3.2.2 Ending Cash Balance

The estimated yearly ending cash balance for all the scenarios in cohort two are presented in Figure 5.12, whereas Table B6 of appendix B presents the mean, standard deviation, CV, minimum and maximum values for the net cash incomes for the three scenarios. Figure 5.12 shows that the ending cash balances for all the cohort two scenarios. For the WLS YI SF and WS YI SF scenario start positive but decrease such that they become negative in subsequent years of the planning period. In 2011, the WL YI SF scenario had the highest ending net cash balance, followed by WS YI SF and WLS YI SF, respectively. The ending cash balance for all the scenarios decrease steadily from 2011 through to 2025, such that it they are lowest in 2025.

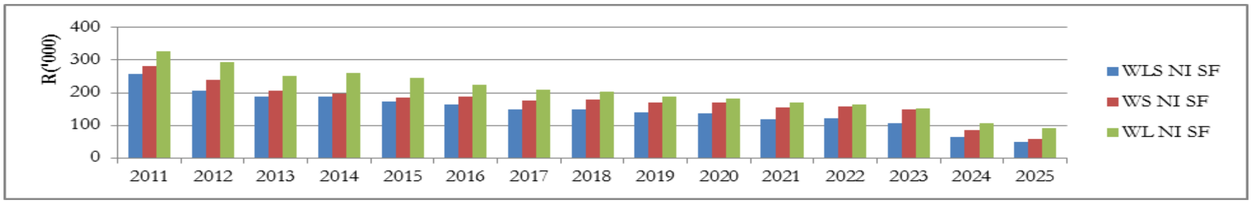

Figure 5.12: Estimated average yearly Net Ending Cash Balance for a 5 000ha farm in Graaff-Reinet, producing wool sheep as a premier economic activity with incentives.
See Table 5.2 for a detailed explanation of acronyms.

The estimated ECBs for WLS YI SF, WS YI SF and WL YI SF is R257 thousand, R282 thousand and R328 thousand in 2011, respectively. For the WL YI SF scenario, the ending cash balance decreases to R202 thousand in 2019, where after it gradually declines to R90 thousand in 2025. The decrease in ending cash balance is partially attributable to an increase in production costs, which decreases the total amount of income available at bank to fetch interest. Likewise, the ending cash balances for the WLS YI SF and WS YI SF scenarios were decreasing throughout the planning period. In 2025, the ending cash balance at bank for the WS YI SF scenario was R58 thousand, whereas the WLS NI SF scenario returned an ending cash balance of R50 thousand, in the same year. The ending cash balance for the WLS YI SF and WS YI SF were decreasing, respectively, because of the high need to provide for increasing production costs during the planning horizon.

The range and risk for the estimated ending cash balances for all the scenarios in this cohort are presented in Figure 5.13. The ending cash balance for the WLS YI SF scenario is similar to that of the WLS NI SF scenario in cohort 1 and depicts an increasing risk over the planning horizon. The range and risk for scenarios WLS YI SF and WS YI SF decreases throughout the planning horizon and is quite similar to the fan graphs for the similar scenarios in cohort 1. The variability around the mean for the WLS YI SF and WS YI SF scenarios respectively is highest in the first five years of the planning horizon. After 2015, the CV decreases gradually from 2016 to 2025. For WLS YI SF, 90% of the simulated year on year ending cash balances is between R3 thousand and R312 thousand and R4 thousand and R84 thousand in 2011 and 2025, respectively. For WS YI SF and WL YI SF, 90% of the simulated year on year ending cash balances are between R8 thousand and R329 thousand and R7 thousand and R400 thousand, in 2011 respectively, whereas they were between R2 thousand and R119 thousand and R15 thousand and R126 thousand respectively, in 2025. The WL YI SF has the largest variability amongst the three scenarios throughout the planning horizon, with a CV of 52% and 42.9% in 2011 and 2025, respectively.

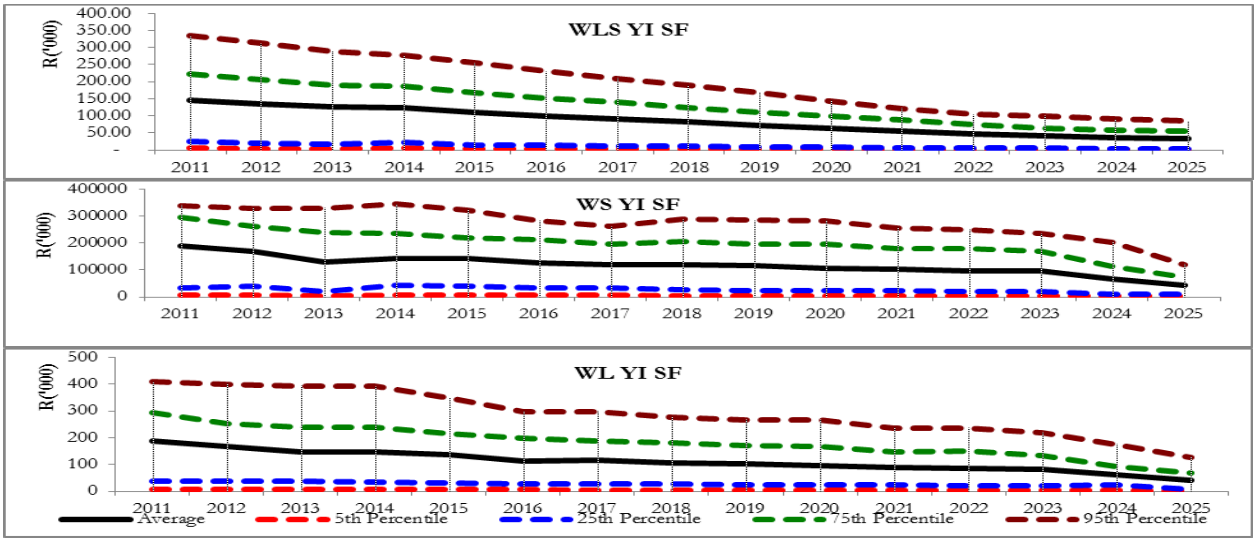

Figure 5.13: Estimated average yearly Net Ending Cash Balance risk for a 5 000ha Farm in Graaff-Reinet, producing wool sheep as a premier ecological-economic activity with incentives.
See Table 5.2 for a detailed explanation of acronyms.

5.3.2.3 Real Net Worth

The real net worth for the cohort two scenarios is presented on Figure 5.14. Table B7 in appendix B also presents a complete picture of the mean, standard deviation, CV, minimum and maximum values for the real net worth. In 2011, owing to high initial cash at hand, the WLS YI SF and WL YI SF scenarios' real net worth was R1.217 million and R1.309 million, respectively, while that of WLS YI SF stood at R1.400 million, in the same year. The real net worth was R0.587 million, R0.772 million and R0.883 million for WLS YI SF, WS YI SF and WL YI SF, respectively, in 2025.

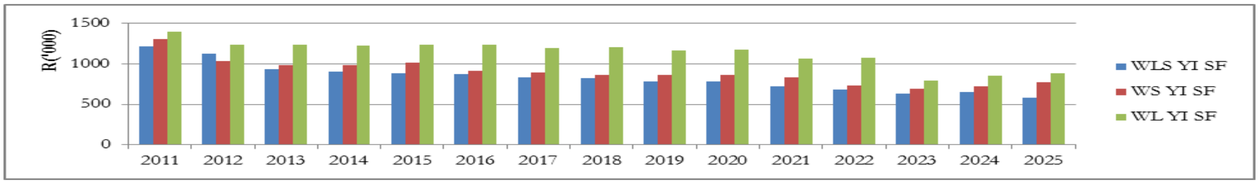

Figure 5.14: Estimated yearly real net worth for a 5 000ha Farm producing wool sheep as a premier ecological-economic activity with incentives.
See Table 5.2 for a detailed explanation of acronyms.

The year on year average real net worth was different for the scenarios in cohort two when compared to those in cohort one. Like in the cohort one scenarios, the real net worth in this scenario started at a higher value and started to decrease after 2013, because of the effect of the deflation factor. Furthermore, the real net worth for all the scenarios in cohort three was comparatively higher than the real net worth of the scenarios in cohort one and two. Notwithstanding and like in cohort one, scenario WL YI SF returned the highest real net worth and it was followed by scenario WS YI SF whilst WLS YI SF returned the lowest real net worth in the cohort two scenarios. The WLS YI SF scenario has the highest variability around the mean throughout the planning horizon, followed by the WL YI SF scenario, as shown by the CV in table B7 of the Appendix.

To confirm this, the results of the fan graphs as shown in Figure 5.15 come in handy. The graphs show the range and risk of the simulated year on year real net worth risk for all the cohort two scenarios. As already been alluded to in the preceding paragraphs, the estimated real net worth for all the scenarios is positive and decreases gradually from 2011 to 2025. For WLS YI SF and WS YI SF, the real net worth starts out high at R1.672 million and R2.583 million for the 95th percentile, respectively. In 2025, 90 percent of the simulated real net worth for scenarios WLS YI SF, WS YI SF and WL YI SF was between R20 thousand and R1.663 million, R14 thousand and R1.413 million, and R21 thousand and R1.769 million, respectively. For all the scenarios, there is a zero percent chance that the real net worth will be negative throughout the planning horizon.

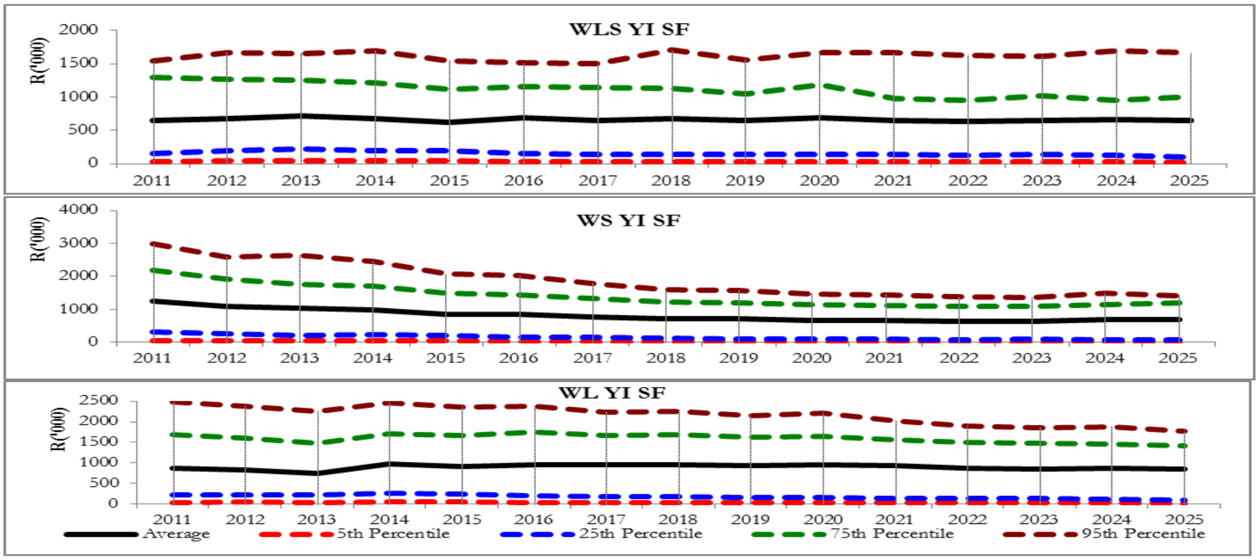

Figure 5.15: Estimated yearly real net worth risk for a 5 000ha Farm producing wool sheep as a premier ecological-economic activity with incentives.
See Table 5.2 for a detailed explanation of acronyms.

5.3.2.4 Net Present Value

The CDF graph of NPV for a 5 000ha wool sheep, mutton and springbuck farm producing wool as the premier product of focus with incentives is presented on Figure 5.16, whilst Table B8 in the appendix gives the mean, standard deviation, CV, minimum and maximum values for the NPV. The graph shows that scenarios WLS- and WL YI SF have a 70% and 31.9% chance of returning a negative NPV, respectively, whilst the likelihood that scenario WS YI SF would return a negative NPV anytime during the planning horizon is 17.5%. The estimated average NPVs for WLS-, WS- and WL YI SF are (R101) thousand, R137 thousand, and R63 thousand, respectively. Interestingly is that a comparative analysis of the NPVs of the cohort one and cohort two scenarios reveal that, even though the cohort two scenarios received incentives for the springbuck enterprises, some cohort one scenarios managed to return higher incomes when compared to their cohort two counterparts, except for the WL YI SF scenario. This scenario produced a higher NPV with a comparatively low probability of being negative than the other two scenarios in this cohort and its cohort one equivalent. This was anticipated given the influence of the tax reductions and the restoration subsidy on the income structure of the springbuck ranching enterprises. Moreover, as in the cohort one scenarios, the WL YI SF scenario shown by a blue-dashed line on Figure 5.17, returned the highest NPV in contrast to the WLS YI SF and WS YI SF scenarios, respectively.

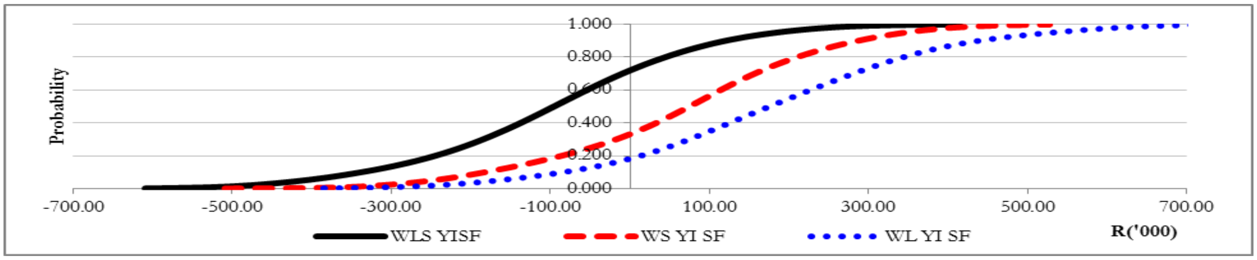

Figure 5.16: Cumulative density functions graph of net present value for a 5 000ha Farm producing wool sheep as a premier ecological-economic activity with incentives. See Table 5.2 for a detailed explanation of acronyms.

Interestingly, however, is that the results reveal that the incentives did not make any significant increase on the NPVs for the cohort two scenarios in relation to their cohort one counterparts. The WL YI SF, like the WL NI SF scenario in cohort one, returned the highest

NPV. Secondly, there were no great differences between the NPVs of the scenarios, suggesting that including incentives on the sheep dominated scenarios might not influence the profitability of farm businesses in the area. However, since the CDF graphs for the NPV are touching on the tails, it is hard to isolate the most dominated scenario with certainty.

Using the SERF analysis, the alternative scenarios can be ranked from the most preferred to least preferred across a range of risk aversion coefficients. The results of the SERF analysis demonstrate that the WL YI SF scenario is the most widely preferred scenario amongst the three. In fact, there is a slight difference in utility between the WL NI SF scenario and the WL YI SF scenario. Moreover, it also displays that the WS YI SF scenario is the next most preferred whilst WLS YI SF is the least preferred amongst the three, as shown by the CE lines on Figure 5.17. The WLS YI SF scenario had a negative CE throughout the range of absolute risk aversion coefficients calculated in this study, demonstrating the insignificance of the income from springbuck ranching in improving the profitability of the farm when springbuck ranching is about 10% of the land, given the assumption made on the land use ratios. Certainly, this shows that farmers are better off not investing on this scenario.

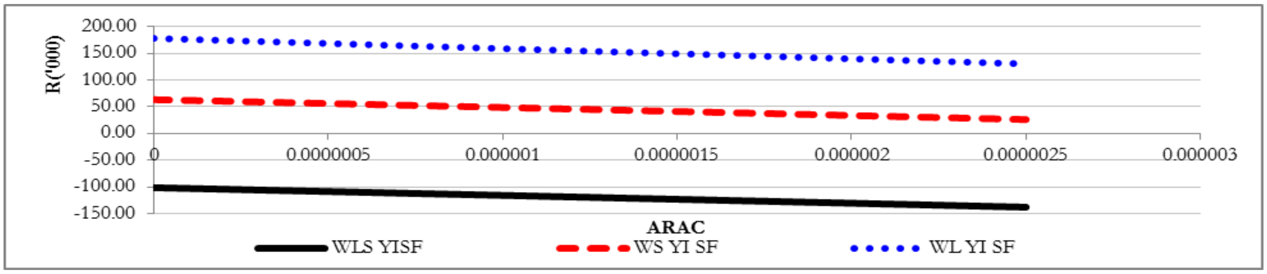

Figure 5.17: Stochastic Efficiency with Respect to a Function graph of net present value for a 5 000ha Farm producing wool sheep as a premier ecological-economic activity with incentives.
See Table 5.2 for a detailed explanation of acronyms.

Moreover, unlike in the SERF analysis results for the cohort one scenarios, in the cohort two scenarios, the WS YI SF scenario returned positive CE values across the range of absolute risk aversion coefficients, further illustrating the effects that incentives might have on increasing expected utility. In conclusion, it is clear that decision makers prefer the WL YI SF scenario followed by the WS YI SF scenario across the range of absolute risk aversion coefficients, as shown in Figure 5.17. This is an expected result considering that the WL YI SF and WS YI SF scenarios received more income in the form of tax cuts and the restoration subsidy. Table 5.4

shows the calculated risk premiums for the different absolute risk aversion coefficients for risk neutral (ARAC zero), moderately risk averse (ARAC 0.0000125) and risk averse (ARAC 0.000025) decision makers. To facilitate the calculation and comparison of the risk premiums, the study used the WL YI SF scenario, as it was the most preferred on the SERF analysis.

Table 5.4: Risk Premiums for a 5 000ha Farm producing wool sheep as a premier ecological-economic activity with incentives.

	Risk Neutral	Moderately Risk Averse	Risk Averse
		R	
WLS YI SF	(279, 670.67)	(273, 718.74)	(268, 307.41)
WS YI SF	(114, 742.58)	(109,099.86)	(104, 204.38)
WL YI SF	-	-	-

See Table 5.2 for a detailed explanation of acronyms.

The results confirm that the WL YI SF scenario is favoured over the WLS YI SF and WS YI SF scenarios, respectively, with high-risk premiums. For example, for risk neutral decision makers to convert from the preferred WL YI SF scenario and be indifferent between it and the WLS YI SF and or WS YI SF scenarios, they would have to be paid R279 670.67 and R114 742.58, respectively. Similarly, moderately risk averse decision makers would have to be paid R273 718.74 and R109 099.86 to be indifferent between the preferred WL YI SF scenario and the WLS YI SF and WS YI SF scenarios, respectively. For risk averse decision makers to be indifferent between the preferred WS YI SF scenario and the WLS YI SF and WL YI SF scenarios, they would have to be paid R268 307.41 and R104 204.38, respectively. Remarkably is that, unlike in the cohort one scenarios, the WS YI SF scenario has lesser risk premiums than the WLS YI SF scenario, exemplifying the impact of subsidies on the springbuck ranching enterprise. These premiums decrease as one moves from risk neutral decision makers to risk averse decision makers.

These results demonstrate that a 70% wool and 30% springbuck ranching (WL YI SF) for meat production scenario is the most preferred enterprise mix over the 7:2:1 wool, mutton and springbuck (WLS YI SF) and 5:2:3 wool and springbuck (WS YI SR) with sheep farming as the key ecological-economic system, respectively. The results further illustrate that such a scenario is preferred with bigger risk premiums over the other alternatives. Based on this finding, the conclusion that incorporating springbuck ranching into an existing 5 000ha sheep farm can be profitable is made. However, the results also reveal that such profitability can be highly improved by the introduction of incentives. Secondly, the net cash incomes from this scenario were decreasing throughout the planning horizon, suggesting that even though springbuck ranching would return some extra income to the rancher, the need to provide supplementary feeding for the sheep especially during winter, over and above other variable costs could, in the long-term, affect farm profitability.

5.3.3 Simulation Results for Cohort Three Scenarios

The objective of the scenarios in this cohort was to explore the profitability of converting a 5 000ha sheep farm into a springbuck dominated ranch with springbuck ranching for meat production as the premier ecological-economic system, with no incentives, in Graaff-Reinet. In this cohort, the principal decision maker explores the profitability of the 5 000ha farm under three utilisation scenarios, namely: 7:2:1, 5:3:2 and 7:3 springbuck, mutton and wool (SLW NI SR); springbuck, mutton and wool (SW NI SR); and springbuck and wool (SL NI SR), respectively – as shown in Table 5.2. In this cohort, the assumption made was that the rancher invests substantially in boundary fences, and keeps sheep only as a small portion of the ranching enterprise, as depicted by the land ratios. Incomes from this cohort come from the sales of springbuck meat, as well as wool and mutton. This section reports and discusses the results of the KOVs for the various alternatives.

5.3.3.1 Net Cash Income

The estimated yearly net cash incomes for the cohort three scenarios are as shown in Figure 5.18. The graph shows how each scenario performs in thousands of rands, throughout the 15-year planning horizon. In the Appendix, Table B9 presents the mean, standard deviation, CV, minimum, and maximum values for the net cash income. In general, all the scenarios returned an income above R100 thousand throughout the planning horizon. In 2011, the SLW NI SR scenario returned the highest net income, followed by the SW NI SR and SL NI SR scenarios, respectively. The reason for this were the low production costs incurred in the SLW NI SR scenario, whereas for the SL NI SR scenario, it was because of high winter-feeding costs in the wool sheep enterprise. The SLW NI SR scenario returned a net cash of R155 thousand in 2011. This figure grew to R362 thousand, in 2025. Unlike in the cohort one scenarios, the net cash income for the SL NI SR scenario were generally decreasing owing to high costs of winter feeding in the sheep enterprise which reduced the net cash income earned to R39 thousand in 2025. For the SW NI SR and SL NI SR scenarios, the estimated yearly net cash income was R144 thousand and R117 thousand in 2011, respectively. It grew to R179 thousand in 2019 for SW NI SR, whereas for SL NI SR it decreased to R88 thousand, in the same year.

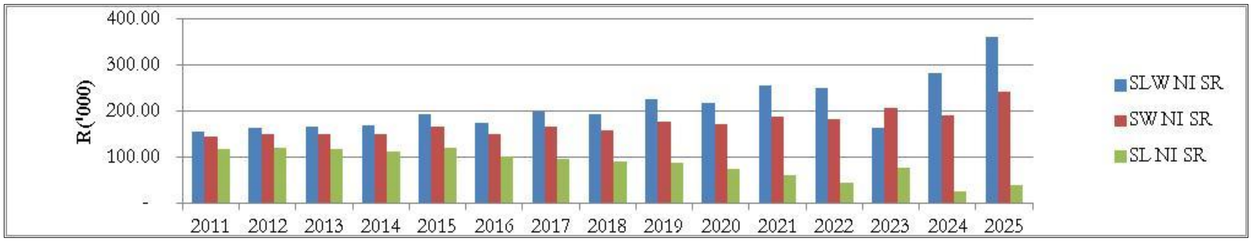

Figure 5.18: Estimated yearly net cash income for a 5 000ha Farm producing venison as a premier ecological-economic activity without incentives.
See Table 5.2 for a detailed explanation of acronyms.

In 2025, the SL NI SR scenario had the lowest net cash income amongst the three scenarios. This suggests that a 70% springbuck ranching enterprise might not blend well with a 30% wool sheep enterprise because of the high costs of feeding. Based on the net cash income, decision makers may earn higher net income returns if they combine 70% springbuck ranching for meat production with 20% mutton production and 10% wool on a 5 000ha farm.

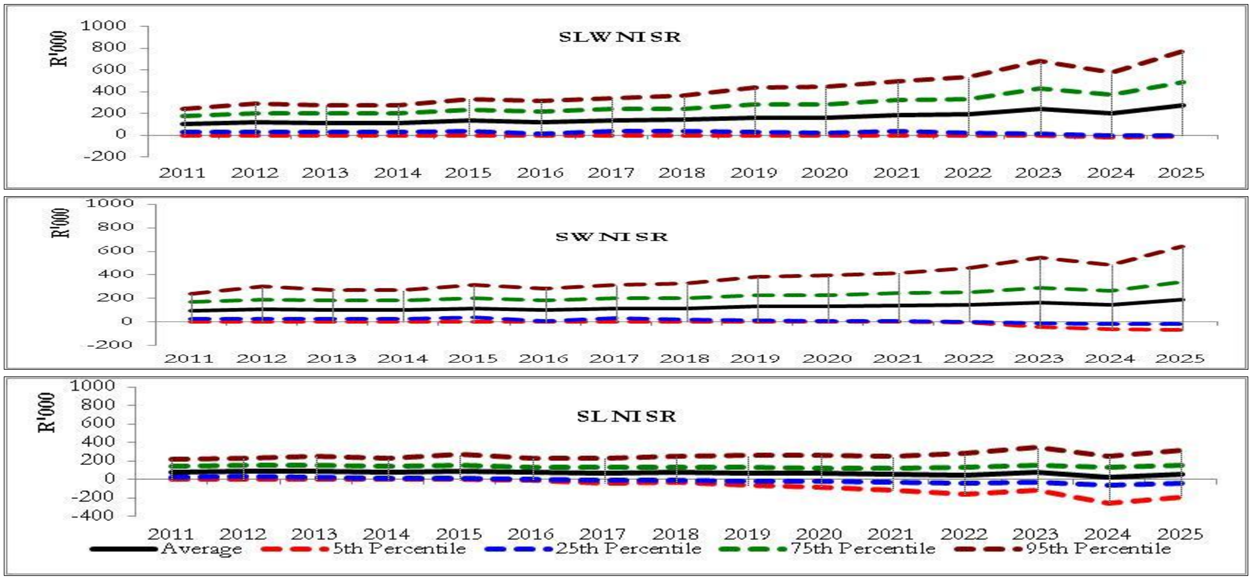

Figure 5.19: Estimated yearly net cash income risk for a 5 000ha Farm producing venison as a premier ecological-economic activity without incentives.
See Table 5.2 for a detailed explanation of acronyms.

The results of the range and risk of the simulated estimated yearly net cash income, as shown by the fan graph in Figure 5.19 expound the cohort three net incomes further. For scenario one (SLW NI SR), the range and risk is largest in 2011 through to 2025. The coefficient of variability also shows that the simulated probable yearly net cash incomes for this scenario grows from 23.57 percent in 2011 to 40.01 percent, in 2025. The probability of returning a negative net income is zero in the first 13 years of the planning horizon and there is a 0.4 percent chance that the returns will be negative in the last 2 years. For SW NI SR, a 3 percent chance that the net cash income will be negative in 2024 and 2025 exists, whereas the likelihood that the simulated yearly net income would be negative in the SL NI SR scenario grows from 2 percent in 2016 to 37 percent in 2025. The negative net cash income was because of growing supplementary feeding costs for the wool sheep and mutton enterprises, but also because of the falling springbuck meat/venison and mutton prices, as captured by the mutton and venison wedge, which compromised the net income from the springbuck enterprise.

In 2011, 90 percent of the simulated estimated yearly net cash income for SLW NI SR, SW NI SR, and SL NI SR were between R23 thousand and R292 thousand, R23 thousand and R 299 thousand and R29 thousand and R214 thousand, respectively. The SL NI SR had the thinnest range amongst the three scenarios in 2011. The SLW NI SR scenario had the largest range in 2025, followed by the SW NI SR and SL NI SR scenarios, respectively. Ninety percent of the simulated yearly net cash income was between (R8) thousand and R775 thousand, (R69) thousand and R640 thousand and (R189) thousand and R316 thousand for the SLW NI SR, SW NI SR, and SL NI SR scenarios in 2025, respectively. The SLW NI SR and SW NI SR scenarios had a 50% chance that their net cash income would be greater than R100 thousand throughout the entire planning horizon, whereas the SL NI SR scenario had a 50% chance that it would yield a net cash income between R50 thousand and R80 thousand throughout the entire planning horizon. The probability that the SLW NI SR, SW NI SR and SL NI SR would be negative in 2025 was 0.2%, 2.4% and 36.7%, respectively. The high probability of yielding a negative net cash income in scenario three suggest that the combination of 30% wool sheep farming and 70% springbuck ranching might not necessarily be a profitable and wise enterprise mix.

5.3.3.2 Ending Cash Balance

Figure 5.20 presents the simulated estimated ending cash balances for the cohort three scenarios, whilst Table B10 in appendix B, presents the mean, standard deviation, CV, minimum and maximum values for the ending cash balance. The graph shows that the ending cash balance is positive and increases every year of the planning horizon, albeit with varying magnitude. The estimated ending cash balances for all the cohort three scenarios started low in 2011, with SL NI SR having the smallest ECB amongst the three. In 2011, for example, the SL NI SR scenario had an ECB of R262 thousand, followed by the SW NI SR scenario with an ECB of R276 thousand. The SLW YI SR had the largest ECB of R279 thousand, in the same year. Except for SL NI SR – owing to high supplementary feeding costs in the wool sheep enterprise – the SLW NI SR and SW NI SR scenarios yielded ECBs which were increasing throughout the planning horizon to R3.223 million and R2.27 million, respectively in 2025.

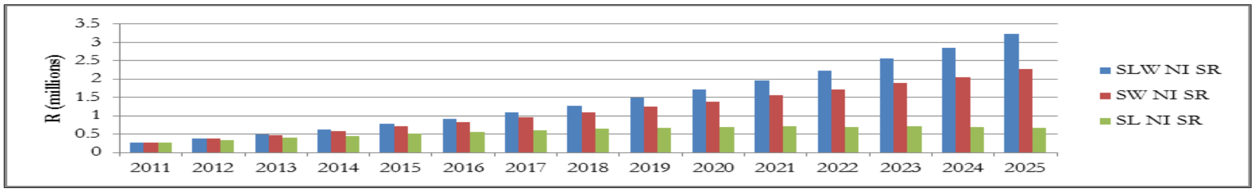

Figure 5.20: Estimated yearly ending cash balance for a 5 000ha Farm in producing venison as a premier ecological-economic activity without incentives.
See Table 5.2 for a detailed explanation of acronyms.

A direct comparison of the cohort three ECBs with the cohort one and two ECBs reveal that the cohort three scenarios returned higher ECBs from 2012 of the planning horizon, to the end. Unlike the cohort one ending cash balances, for example, the ECB of the cohort three scenarios were increasing throughout the planning horizon. This is despite that in this cohort (cohort three) the scenarios showed a higher chance of returning negative net cash incomes. Similarly, cohort three scenarios received no incentives, whilst in cohort two they are present. This is somewhat an unexpected result given that the price of venison is not as attractive as that of mutton or wool throughout the planning horizon. However, if one considers the cost of production between the two cohorts, it becomes apparent that because of the low variable costs in springbuck ranching more money is left at the bank to accumulate interest; hence, the higher ending cash balances.

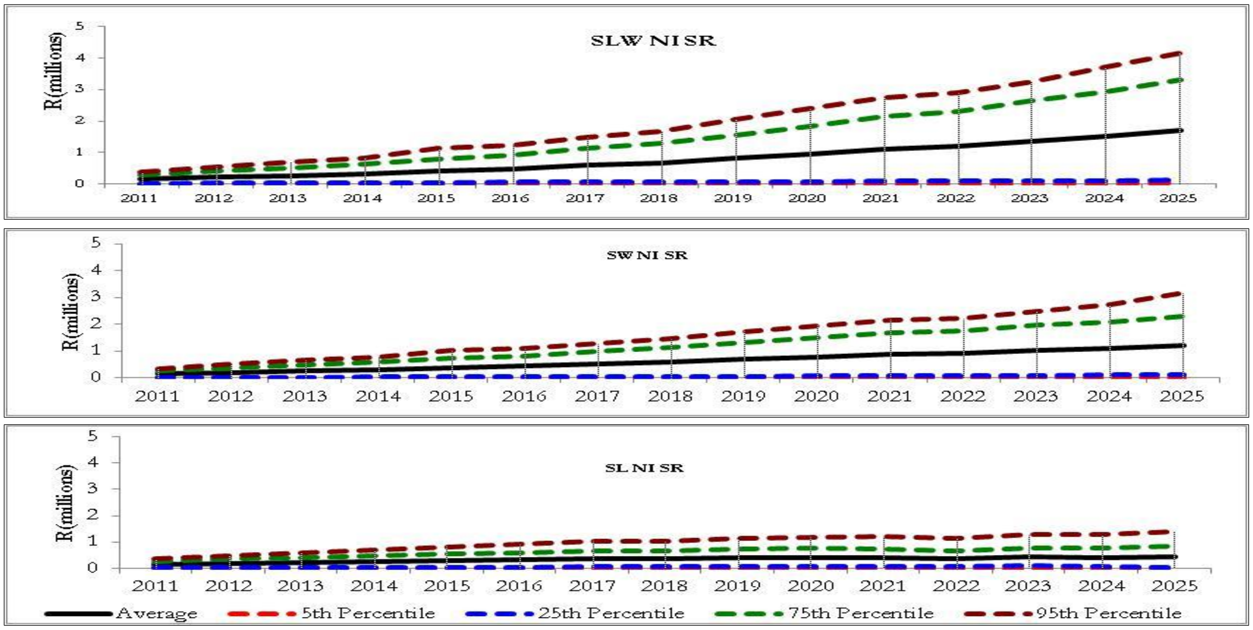

Figure 5.21: Estimated yearly ending cash balance risk for a 5 000ha Farm producing venison as a premier ecological-economic activity without incentives.
See Table 5.2 for a detailed explanation of acronyms.

Figure 5.21 concludes the analysis of the ECBs. This figure presents synopsis of the range and risk of the estimated yearly net ending cash balances for the three alternative scenarios, in cohort three. All the scenarios have a zero probability of returning a negative ECB at any point of the planning horizon. Of the simulated estimated yearly ending cash balances, 90 percent of them were between R27 thousand and R4.168 million, R28 thousand and R3.156 million and R800 and R1.405 million for SLW NI SR, SW NI SR and SL NI SR, respectively, in 2025. The SL NI SR scenario had the lowest estimated yearly ECBs, an anticipated result given the high amount of variable feed costs, in the sheep enterprise. The ECBs shows increasing variability towards the end of the planning horizon, suggesting an increase in risk level because of compounding of risk from net cash income in each year.

5.3.3.3 Real Net Worth

The real net worth for the cohort three scenarios is presented on Figure 5. 22, whilst the mean, standard deviation, coefficient of variation, minimum and maximum values for the real net worth are presented in Table B11 of appendix B. Figure 5.21 shows that the estimated average real net worth decreases from 2011 to 2025, with SW NI SR and SL NI SR having the lowest real net worth in 2025, respectively. The real net worth decreases due to the deflating factor and the costs of borrowing, which decreases the income as the year progresses. In 2011, SLW NI SR, SW NI SR and SL NI SR had a real net worth of R1.010 million, R1.043 million and R1.073 million, respectively. For the SLW NI SR scenario, the real net worth was R721 thousand, in 2025.

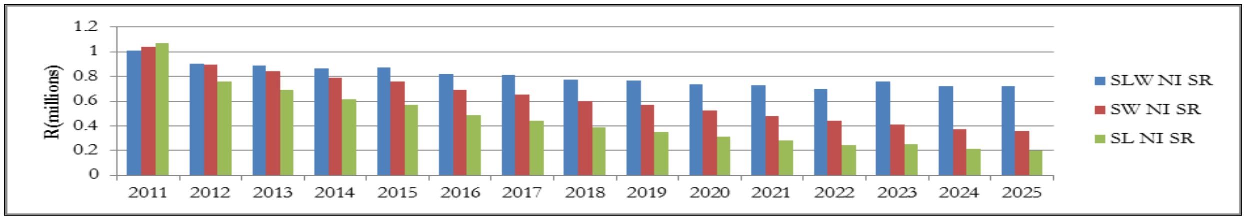

Figure 5.22: Estimated yearly real net worth for a 5 000ha Farm producing venison as a premier ecological-economic activity without incentives.
See Table 5.2 for a detailed explanation of acronyms.

The SW NI SR and SL NI SR scenarios returned a real net worth of R 360 thousand and R198 thousand, respectively, in 2025. Clearly, the real net worth was smallest in the SL NI SR scenario. The fan graph for the real net worth as presented in Figure 5.23 illustrates that the range and risk of the simulated average real net worth was increasing for the SLW NI SR scenario whilst for SW NI SR and SL NI SR scenarios it was more or less constant throughout the planning horizon. Ninety percent of the simulated average real net worth was between R 13 thousand and R 1.280 million for the SLW NI SR scenario, in 2011. The SW NI SR and SL NI SR scenario had 90 percent of the simulated real net worth falling between R8 thousand and R1.310 million and R11 thousand and R1.412 million, respectively in 2011. The SL NI SR scenario had the thinnest range in 2025, followed by the SW NI SR scenario. In the same year, the SLW NI SR scenario had the largest range and risk of simulated real net worth. In 2025, 90 percent of the simulated real net worth was between R60 thousand and R3.825 million, R29 thousand and R2.035 million, and R22 thousand and R1.532 million for SLW NI SR, SW NI SR and SL NI SR, respectively.

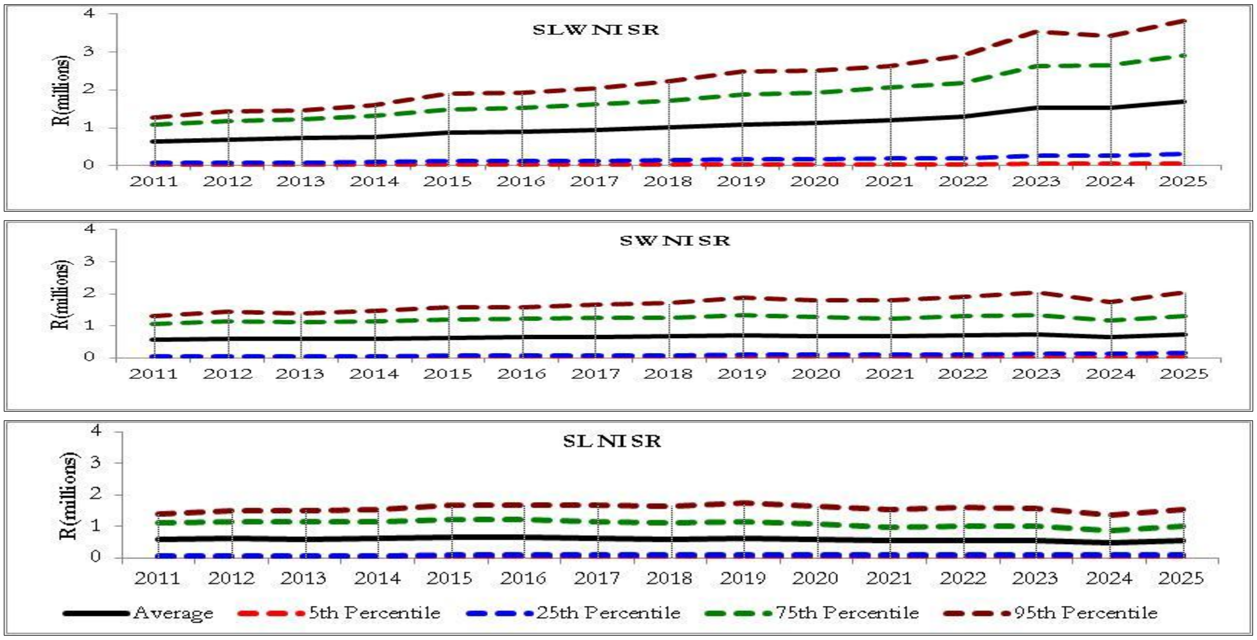

Figure 5.23: Estimated yearly real net worth risk for a 5 000ha Farm producing venison as a premier ecological-economic activity without incentives.
See Table 5.2 for a detailed explanation of acronyms

5.3.3.4 Net Present Value

The CDF graphs for the NPVs of the 5000 ha farm producing springbuck; mutton and wool with springbuck as the premier ecological-economic system, without incentives are as presented in Figure 5.24. In appendix B, Table B12 contains all the summary statistics for the mean, standard deviation, coefficient of variation, and minimum and maximum values for the NPV. From the CDF graph, it is clear that the SL NI SR scenario has a 0.3 percent chance of returning a negative NPV, whilst SLW NI SR and SW NI SR have a zero percent chance of returning a negative NPV throughout the planning horizon. The NPV for the SLW NI SR scenario is R505 thousand, whilst that of the SW NI SR and SL NI SR scenarios is R489 thousand and R436 thousand, respectively. The CDF graphs further show that the NPV for SLW NI SR - shown by a black solid line - is greater than that of SW NI SR (dashed red line) and SL NI SR (dotted blue line), respectively. The NPVs for the cohort three scenarios are actually greater than the NPVs of their cohort one and two counterparts. This is expected as the cohort three scenarios have lower production costs relative to the cohort one and two scenarios, leaving the rancher with more money that accumulated interest in the bank.

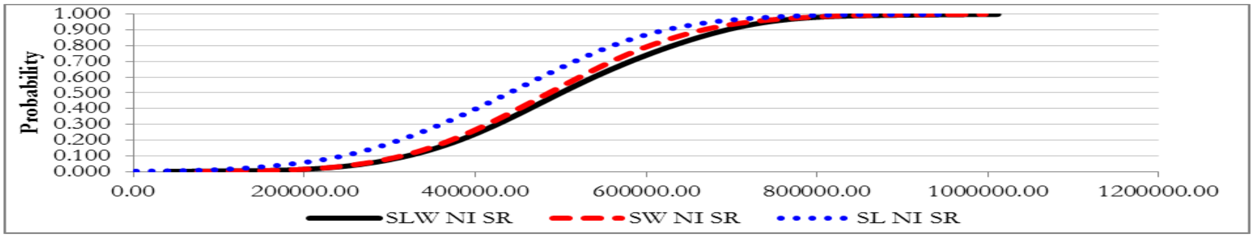

Figure 5.24: Cumulative density functions graph of net present value for a 5 000ha farm producing venison as the premier product of focus without incentives.
See Table 5.2 for a detailed explanation of acronyms.

It is, however, difficult to tell for sure which of the cohort three scenarios is most preferred by decision makers since the CDF graphs for the NPVs cross each other in the tails, giving the impression that decision makers would be indifferent amongst the three.

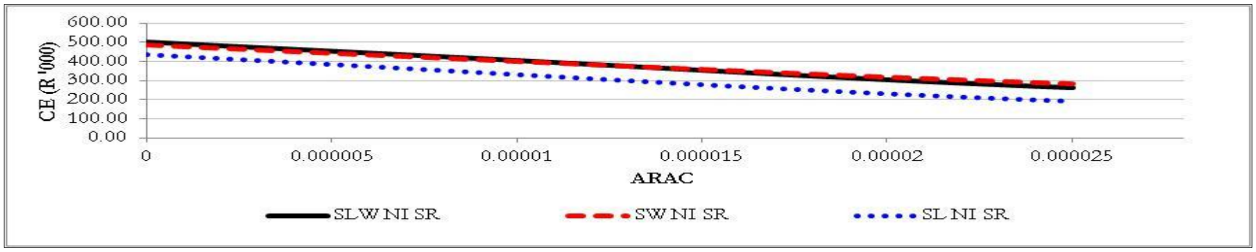

Figure 5.25: Stochastic Efficiency with Respect to a Function graph of net present value for a 5 000ha farm producing venison as the premier product of focus without incentives.
See Table 5.2 for a detailed explanation of acronyms.

To resolve this, a SERF analysis of the cohort three NPVs was performed as shown on Figure 5.25. The SERF graph shows that decision makers prefer different scenarios between SLW NI SR (solid black line) and SW NI SR (dashed red line) across a range of absolute risk aversion factors, whilst SW NI SR is the least preferred scenario amongst the three. The CE lines for the SLW NI SR and SL NI SR scenarios, which cross once, demonstrate this. For risk neutral decision makers (ARAC of 0.0), the SL NI SR scenario is preferred whereas moderately risk averse (ARAC of 0.0000125) decision makers are somewhat indifferent between the two scenarios. Risk averse decision makers (ARAC of 0.000025) prefer the SW NI SR scenario.

Table 5.5 shows the risk premiums for a 5 000ha Farm in Graaff-Reinet, producing SLW, SW, and SL with springbuck ranching as a premier ecological-economic activity without incentives, using the SLW NI SR scenario as the base. Not surprisingly, the risk premiums for SW NI SR are almost close to zero for moderately risk averse decision makers, whilst for risk averse decision makers they are positive and greater than one. This confirms the finding that for risk averse decision makers, SW NI SR is preferred as illustrated by the positive risk premium. Moreover, in general, the results on Table 5.5 also confirm that the SLW NI SR scenario is preferred over the other two scenarios except for risk averse decision makers who prefer scenario SW NI SR.

Table 5.5: Risk Premiums for a 5 000ha Farm producing venison as a premier ecological-economic activity without incentives.

	Risk Neutral	Moderately Risk Averse	Risk Averse
		R	
SLW NI SR	-	-	-
SW NI SR	(15,466.90)	-	22,373.38
SL NI SR	(68,063.20)	(76,528.70)	(73,191.90)

See Table 5.2 for a detailed explanation of acronyms.

For risk neutral decision makers the risk premiums are lower at R15 466.90 and R68 063.20 for SW NI SR and SL NI SR, respectively. An interesting observation is that risk averse decision makers would have to lose or forego R22 373.38 to be indifferent between the preferred SLW NI SR scenario and the SW NI SR, whereas they would have to be paid R73 191.90 to be indifferent between the SLW NI SR scenario and the SL NI SR scenario. The reason for this is that for decision makers who are risk neutral, the SLW NI SR scenario is mostly preferred, whereas on for risk averse decision makers the SW NI SR scenario is preferred. Generally, these results suggest that decision makers are more-or-less indifferent between the SLW NI SR and the SW NI SR scenario, given that the risk premiums between the two are low.

5.3.4 Simulation Results for Cohort Four Scenarios

The objective of this scenario was to explore the effect of tax abatements and a restoration subsidy on the profitability of the cohort 3 scenarios. The incentives changed the net cash income, ending cash balance, real net worth and NPV of the cohort three scenarios. As in the cohort three scenarios, an assumption that the rancher invests substantially on boundary fences, is made. This section reports the results of the KOVs.

5.3.4.1 Net Cash Income

The net cash incomes are as shown in Figure 5.26, whereas Table B13 of Appendix B presents a detailed presentation of the mean, standard deviation, coefficient of variation, minimum and maximum net cash income values. The results show that the net income in the various scenarios pretty much follow the same trend as those in cohort three, but with varying magnitudes. In 2011, the net cash income was R200 thousand, R177 thousand and R163 thousand, for the SLW-, SW-, and SL YI SR scenarios, respectively. The net income for the SL NI SR scenario was decreasing throughout the entire planning horizon.

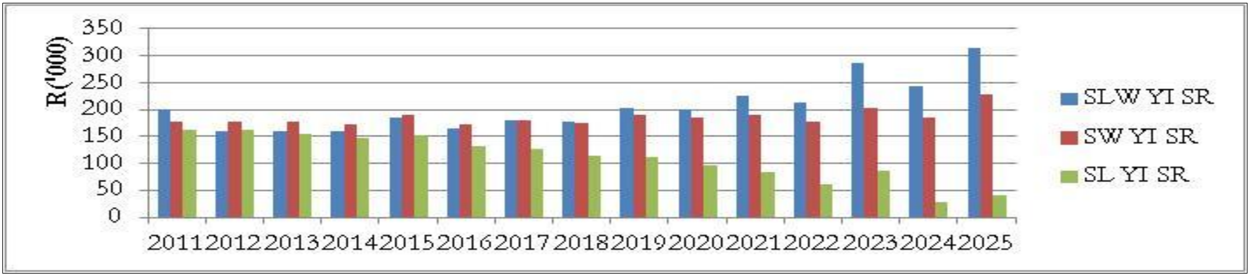

Figure 5.26: Estimated yearly net cash income for a 5 000ha Farm, producing venison as a premier ecological-economic activity with incentives.
See Table 5.2 for a detailed explanation of acronyms.

In 2025, the SLW YI SR scenario had the highest net cash income, followed the SW- and SL YI SR scenarios, respectively. The net cash income was R315 thousand, R227 thousand and R39 thousand in the three scenarios, respectively, in 2025. The reason for the drop in net cash income for the SL YI SR was expected. This was because the incentives induced more farmers to convert to springbuck ranching, which subsequently decreased the price of venison thus influencing the net cash income negatively. Also important is that there was no income coming from the mutton enterprise, because of the realistic assumption that the farmer focused on wool production and springbuck ranching only. Likewise, high winter-feeding costs in the sheep enterprise in this scenario were responsible for the drop in net cash income in the same period. A comparison of the cohort four scenarios and the cohort one reveal that the cohort four scenarios returned a relatively higher net cash income than their cohort one counterparts, except for the SL YI SR scenario which failed to return attractive incomes beyond 2020.

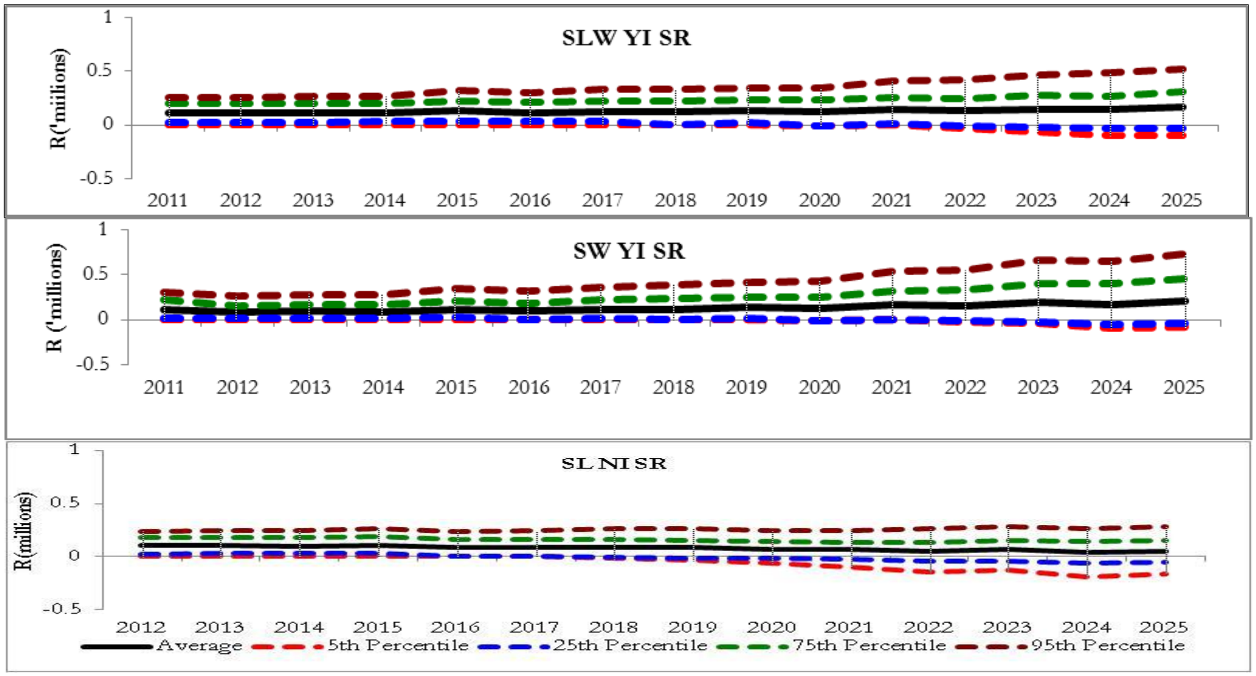

Figure 5.27: Estimated yearly net cash income risk for 5 000ha Farm producing venison as a premier ecological-economic activity with incentives.
See Table 5.2 for a detailed explanation of acronyms.

The range and risk of the simulated estimated yearly net cash income is shown in Figure 5.27 and is largest in the SW NI SR scenario, whilst the SL NI SR scenario produced the thinnest range and risk, amongst the three scenarios in cohort four. In 2011, 90 % of the simulated estimated average net income for the SLW-, SW-, and SL YI SR scenarios was between R7 hundred and R 310 thousand, R 5 thousand and R251 thousand and R5 thousand and R240 thousand, respectively. The probability that the net income will be negative occurs after the first 10 years of the simulation period. In 2011, the SLW YI SR scenario had a 0.8% chance of returning a negative net income and this probability increases gradually to 2.2% in 2024. For the SW- and SL YI SR scenarios, the probability that the estimated net cash income will be negative is 1% and 1.8% in 2019 and 2.6% and 38.4 % and 2025, respectively.

5.3.4.2 Ending Cash Balance

The ending cash balances for the cohort four scenarios are as shown in Figure 5.28. Scenario SLW YI SR returned the highest ending cash balances throughout the planning horizon. In all the scenarios, the ending cash balances are increasing, an expected result given the influence of interest earned on cash on the total ending cash balances.

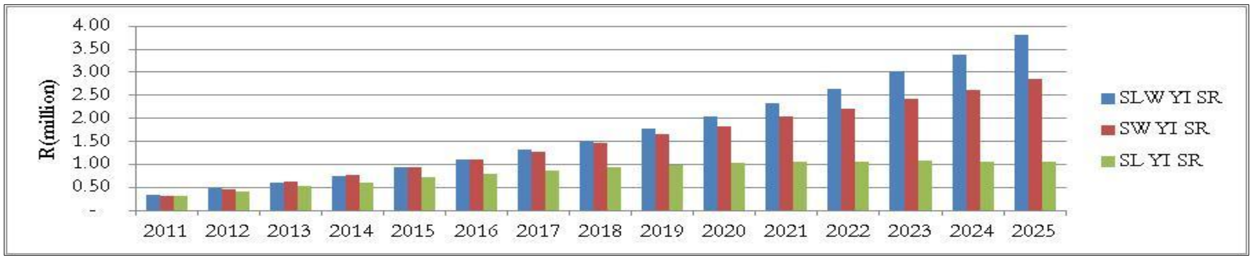

Figure 5.28: Estimated yearly ending cash balance for a 5 000ha Farm producing venison as a premier ecological-economic activity with incentives.
See Table 5.2 for a detailed explanation of acronyms.

In the appendix, Table B14 provides the mean, standard deviation, coefficient of variation, minimum and maximum values for the estimated yearly ending cash balances. The estimated ending cash balances were R3.811 million, R2.848 and R1.045 million for the SLW-, SW-, SL YI SR scenarios, respectively in 2025. The SLW YI SR scenario's ending cash balance was highest amongst the three scenarios illustrating the financial proficiency of springbuck ranching when incentives enter the equation. The difference between the ending cash balances for the SLW- and SL YI SR was above R2 million, a result that can be attributed to the effect of both incentives and interest on cash as being responsible for this wide margin. In scenario one the influence of mutton enterprise on the ranch is quite significant, whereas in scenario three money earned from the springbuck enterprise is further used to settle the costs of the wool sheep enterprise.

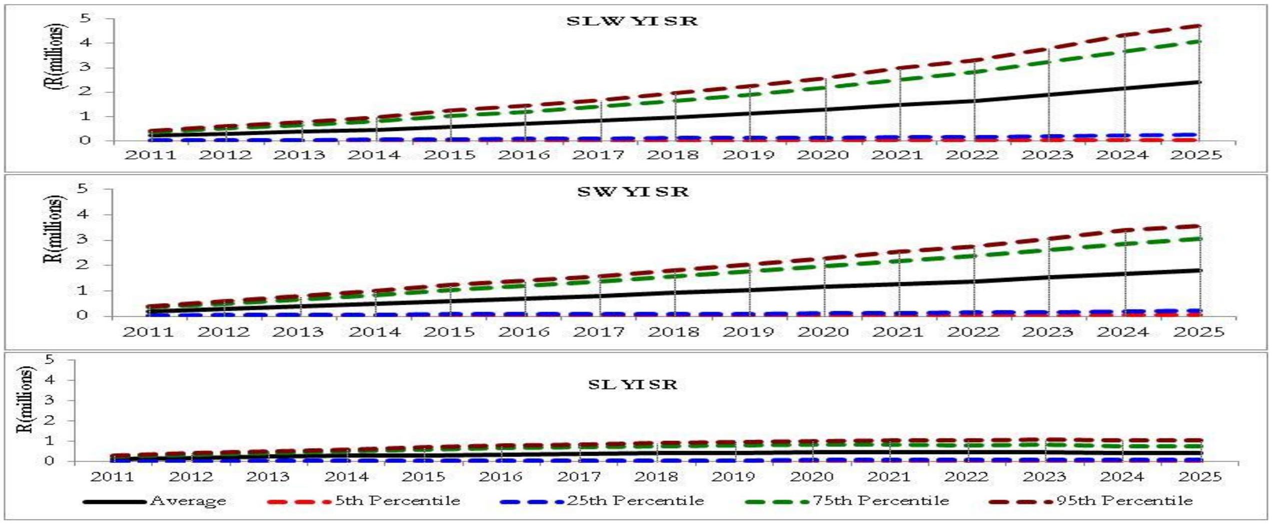

Figure 5.29: Estimated yearly ending cash balance risk for a 5 000ha Farm producing venison as a premier ecological-economic activity with incentives.
See Table 5.2 for a detailed explanation of acronyms.

Figure 5.29 reports the fan graphs of the range and risk of the ending cash balances for the cohort four scenarios. The results show that there is a zero probability that any of the scenarios in cohort four would return a negative estimated ending cash balance at any time in the planning horizon. As expected, the SLW YI SR scenario had the largest ending cash balance range, whilst the SL YI SR scenario had the smallest. Of the simulated estimated ending cash balances, 90% were between R 5 thousand and R443 thousand, R5 thousand and R397 thousand and R7 hundred and R 307 thousand in SLW-, SW-, and SL YI SR scenarios in 2011, respectively. In 2025, however, 90% of the simulated estimated ending cash balances were between R55 thousand and R4.710 million, R43 thousand and R3.571 million and R4.5 thousand and R1.033 million, for the three scenarios respectively.

5.3.4.3 Real Net Worth

The estimated real net worth is shown in Figure 5.30, whilst the mean, standard deviation, coefficient of variation, minimum and maximum real worth values are shown in Table B15 of Appendix B. Throughout the planning horizon, the real net worth for all the three scenarios was increasing and above the one million mark. In 2011, the real net worth for the SLW YI SR scenario was the smallest at R1.079 million, whilst the SL YI SR had the highest real net worth with an average of R1.153 million, in the same year. This is an interesting result since a further analysis of the real net worth reveals that the real net worth for scenario three becomes less superior in 2015.

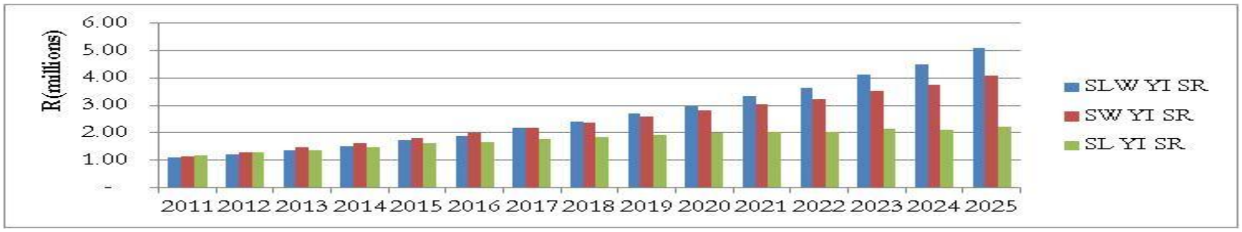

Figure 5.30: Estimated yearly real net worth for a 5 000ha Farm producing venison as a premier ecological-economic activity with incentives.
See Table 5.2 for a detailed explanation of acronyms.

The real net worth rises from R1.075 million in 2010 to R5.107 million in 2025 for the SLW YI SR scenario. In the SW- and SL YI SR scenarios, the real net worth increases from R1.125 million and R1.153 million in 2011 to R4.091 million and R2.224 million, in 2025 respectively. The average real net worth for the SW YI SR scenarios rises from R1.125 million in 2011 to R4.091 million in 2025, whereas the average real net worth for the SLW YI SR scenario was R5.107 million, in the same year.

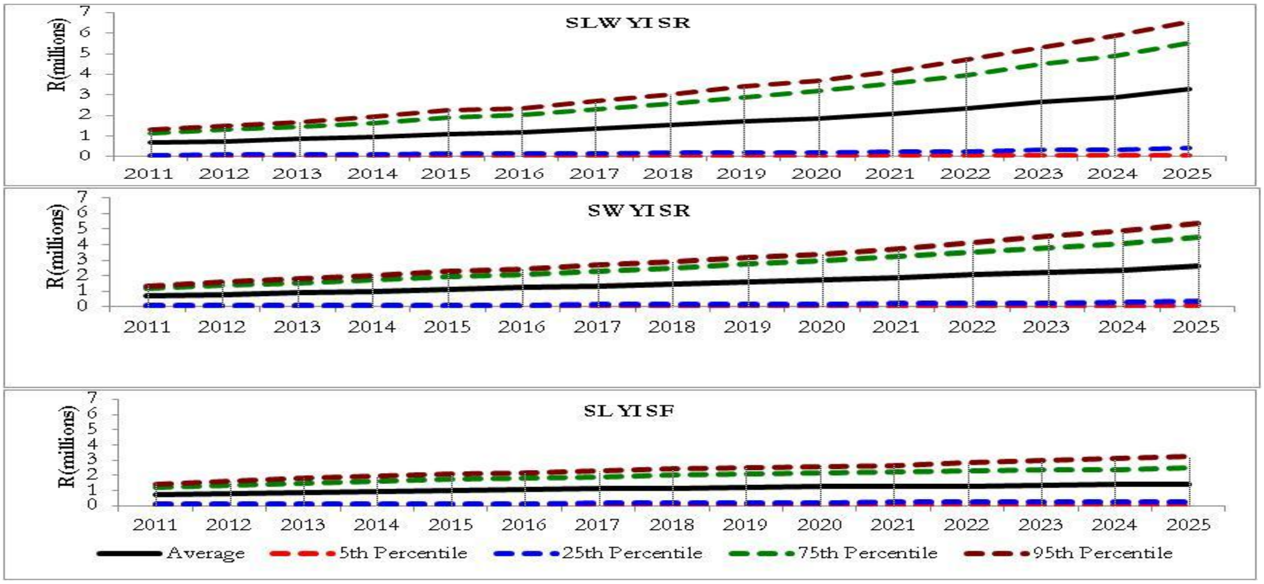

Figure 5.31: Estimated yearly real net worth risk for a 5 000ha Farm producing venison as a premier ecological-economic activity with incentives.
See Table 5.2 for a detailed explanation of acronyms.

The range and risk of the simulated real net worth for all the cohort four scenarios are presented on Figure 5.31. The real net worth is estimated to be positive throughout the planning horizon. There is a zero percent likelihood that the real net worth would become negative at any point in the planning horizon, whilst the real net worth's range and risk increases for all the scenarios from 2011 to 2025. For the SLW-, SW-, and SL YI SR scenarios, 90% of the simulated real net worth are between R81 thousand and R6.554 million, R69 thousand and R5.398 million and R57 thousand and R3.217 million, respectively in 2025.

5.3.4.4 Net Present Value

In Figure 5.32, the CDF graphs for the net present value for all the scenarios in cohort four, are presented. Table B16 of Appendix B shows the mean, standard deviation, coefficient of variation, minimum and maximum NPVs values for the cohort four scenarios. Unlike the NPVs for the cohort one and two scenarios, all the NPVs of the cohort two scenarios are positive and greater than R200 thousand. The SLW YI SR scenario shown by a black solid line, returned the greatest NPV amongst the three scenarios, in cohort four. The black solid line being located furthest from the other two CDF lines for the NPVs shows this. There is a clear distinction between the SL YI SR scenario marked by a blue dotted line and the SLW- and SW YI SR scenarios, verifying that it yielded the smallest NPV amongst the three.

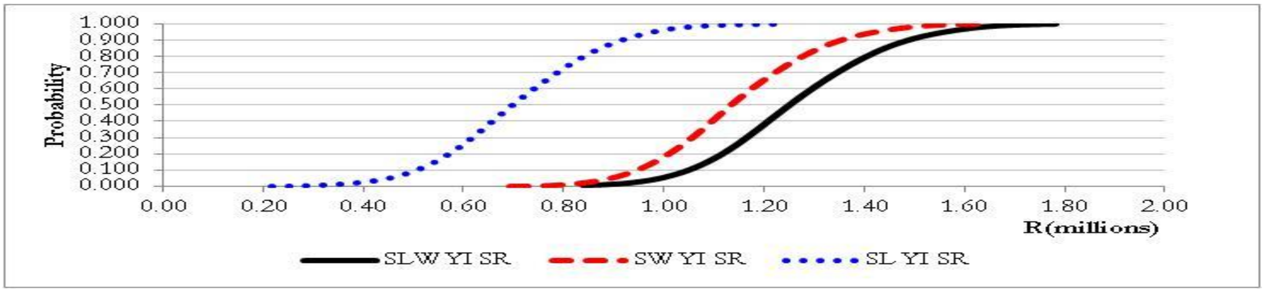

Figure 5.32: Cumulative density functions graph of net present value for a 5 000ha farm producing venison as a premier ecological-economic activity with incentives.
See Table 5.2 for a detailed explanation of acronyms.

The probability that any of the cohort four scenarios will return a negative NPV at any point in the planning horizon is zero. The average NPVs are R1.262 million, R1.143 million and R706 thousand, for the SLW-, SW-, and SL YI SR scenarios, respectively. These NPVs are bigger than those of any of the other scenarios in the three cohorts – suggesting that the inclusion of incentives in springbuck ranching for meat production makes it to be more profitable than when the rangeland is used for sheep farming or under springbuck ranching without incentives. Furthermore, the CDF graphs illustrate that the SL YI SR scenario yielded the smallest NPV amongst the three. However, since the CDF lines for the NPVs for the SL- and SW YI SR scenarios cross each other at the tails, it is quite difficult to distinguish the most profitable scenario amongst the two.

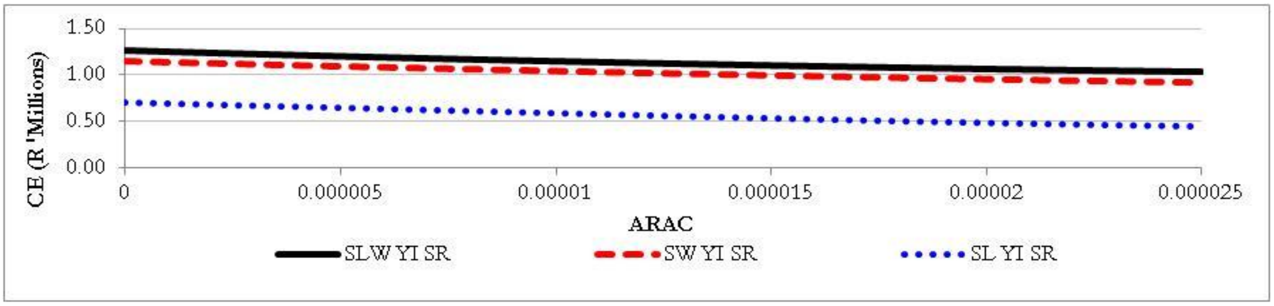

Figure 5.33: Stochastic Efficiency with Respect to a Function graph of net present value for a 5 000ha farm producing venison as a premier ecological-economic activity with incentives.

See Table 5.2 for a detailed explanation of acronyms.

Nevertheless, using the SERF analysis of the net present value for the cohort four scenarios as shown in Figure 5.33, the alternatives that are preferred can be mapped out as per the risk aversion coefficients (RACs) of decision makers - which were calculated using equation 5.1 as documented in McCarl and Bessler (1989). For this cohort, risk neutral decision makers had a lower limit ARAC of 0.0 whilst risk averse decision makers had an upper limit ARAC of 0.000025. The WLS YI SR scenario is the most preferred alternative across all the ARACs levels. Furthermore, since the CE lines do not cross, it is clear that the SLW YI SR scenario is followed by the SW YI SR scenario. Risk neutral decision makers would settle for a CE of R1.143 million whilst risk averse decision makers would settle for a lower CE of R1.036 million.

Table 5.6: Risk Premiums for a 5000 ha Farm in Graaff-Reinet, producing venison with springbuck as a premier ecological-economic activity with incentives.

	Risk Neutral	Moderately Risk Averse	Risk Averse
		R	
SLW YI SF	-	-	-
SW YI SF	-118,874.93	-111,085.86	-120,824.58
SL YI SF	-556,639.76	-566,568.40	-595,139.75

See Table 5.2 for a detailed explanation of acronyms.

Table 5.6 shows the risk premiums for all the alternative scenarios for risk neutral- (zero), moderately risk averse- (0.0000125) and risk averse- (0.000025) decision makers. For risk neutral decision makers to be equally well-off between the preferred SLW YI SR scenario and the SW YI SR and SL YI SR scenarios, they would have to be paid R118 874.93 and R556 639.76, respectively. This is in contrast to R111 085.86 and R566 568.02 which would be required by moderately risk averse decision makers to be, respectively, equally well-off between the preferred SLW YI SR scenario and the SW YI SR and SL YI SR scenarios. The risk premium that would have to be paid to risk averse decision makers to be indifferent between the SLW YI SR scenario and the SW YI SR scenario is R120 824.58, whereas that for the SL YI SR scenario it is R595 139.75. These risk premiums are significantly high, confirming that the SLW YI SR scenario is the mostly preferred scenario, but also illustrating that the ranking was equally robust.

5.4 Economic Sustainability

To analyse the economic sustainability of the three-rangeland use combinations of the three alternative scenarios, in the four cohorts, the study simulated the relative frequency of surviving realisations as outlined in equation 4.24 of section 4.3.1.6. A Bernoulli distribution was used to simulate whether the variable costs would be greater than the maximum threshold (in sheep farming 58.1% or 29.45% in springbuck ranching (see Table A1 of Appendix A)) of variable costs relative to total farm income obtained from the respective scenarios, at time, t. The models were linked to the financial statements, and were specifically programmed to give one (1) if the variable costs are less than the maximum threshold and zero (0) if otherwise.

The notion behind this economic sustainability measure was adapted following a realisation that in Graaff-Reinet – like in most semi-arid rangelands (Quaas *et al.*, 2007) - grazing systems are tightly coupled. Given that at the end of the planning horizon failure is irreversible, this study assumed that failure could be averted through early detection of financial stress. This could be achieved by conducting an analysis of the variable costs of the family farm relative to total farm income. The reasoning is that, an increase in variable costs would induce an increase in financial strain on the family farm, thereby acting as a directive on the viability of the farm relative to total income[35], and *vice versa*. Similarly, and in the spirit of Hein and Weikard (2008) and Quaas *et al.* (2007), an increase in variable costs implicitly suggests that the rangeland is not producing enough biomass to sustain the animals within its carrying capacity. Thus increasing the need to provide supplementary feeding or in the case of springbuck ranching leads to a decrease in output, which reduces total farm income. As a result, whilst this criterion focuses on the economic aspects of each scenario, it implicitly models ecological sustainability by quantifying the amount of money spent on variable costs relative to total income to inform decision makers on how the enterprise is performing in relation to green forage biomass productivity on the farm and subsequently its health[36]. In sheep farming, costs of supplementary (winter) feeding contribute the largest share of variable costs, whereas in springbuck ranching, this study assumed there would be no variable costs of feeding as the animals feed exclusively on the rangeland. This means that the amount of income obtained from the sales of springbuck output reveals, in a way, the productivity of the rangeland. For example, decreasing total output and subsequently sales could act as an indicator that the rangeland is no longer producing enough green forage biomass thus is compromising total output, which would invariably lead to a decrease in total income. The costs of winter-feeding for the sheep enterprises in the springbuck dominated scenarios are offset by sheep output sales, such that if variable costs

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[35] This study chooses to identify failure when the variable costs relative to income increase beyond the 58.1% and 29.45% maximum threshold of variable costs to total income in sheep farming and springbuck ranching, respectively. This is opposed to using debt-to-equity ratio (by Hansen and Jones, 1996) or negative owner's equity (by Lien *et al.*, 2007a) because, in this case, the chosen sustainability measure presents a reasonable approximation of the probable response of lenders if the family farm were to face financial problems. This is especially because this study did not consider land – which could be equally obliterated by continued degradation- thus leaving lenders worse off.

[36] The weakness of this measure is that it focuses on the financial aspect of sustainability and could overestimate failure, thus limiting its applicability. However, in this study it does give a directive with regard to rangeland health if it is assumed, as is the case, that most of the variable costs go towards feeding or in the case of springbuck ranching, that there are no costs of feeding.

increase relative to total income, it is assumed that the rangeland is unable to support the animals and thus the enterprise is approaching failure.

Hence, if the variable costs are greater than the maximum threshold of variable costs to total income, this study assumes that the rangeland faces two sets of problems. The first is a growing ecological strain on the farm, which could potentially lead to degradation and ultimately failure of the enterprise, whilst the second relates to economic failure, which signifies a growing cost-price squeeze that could equally lead to failure. Likewise, this might mean that the costs of feed relative to the price of output are repeatedly eroding the enterprise's profitability. Alternatively, in the case of springbuck, it could also signal the failure of the rangeland to produce enough green forage biomass, which may possibly decrease total output thus compromising the farmer's income returns. However, because different farming families have different tolerance thresholds for difficult situations, this measure should be understood within the tolerance thresholds of variable costs as a percentage of enterprise income, as assumed in this study[37].

Using Simetar®, the economic sustainability model in each cohort was simulated for 500 iterations. The results are as presented in Figures 5.34 to 5.36 and explained below.

a. Cohort 1

The results reveal that none of the cohort one scenarios (graph not shown, since it was almost 100% not economically sustainable) was economically sustainable throughout the planning horizon, based on the economic sustainability measure used in this study. This means that for the cohort one scenarios, none of them yielded variable costs, which were below the average maximum threshold of variable costs to total income of 58.1%. This was partly because of high costs of winter-feeding in the sheep enterprise, which increased the variable costs making the scenarios not sustainable in the planning horizon. It could also be because of declining biomass production in the farm, which meant the farmer had to spend more on feeding than usual. Thus, whilst all the scenarios, in cohort one, returned positive net cash

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[37] Skinner *et al.* (1986) reported a maximum threshold level of 51.1% in sheep farming and 31% in springbuck ranching.

income returns from 2011 through to 2025, much of this income was used to settle the variable costs of the family farm. In the long-run, this could mean that the family farm might fail to produce positive net cash income due to high feeding costs. While the net income obtained from springbuck ranching was theoretically expected to improve the sustainability of the alternative scenarios, it did very little as the farmer used them to finance the other various aspects of the sheep enterprise. This illustrates the various survival mechanisms (on-farm strategies) that farmers employ to sustain their livestock enterprises in the Karoo.

This result suggests that all the cohort one scenarios were unsuccessful owing to a higher need for supplementary feeding which meant that the rangeland was not producing enough forage biomass to sustain the animals in the summer months, or that the farmer tended to keep many animals in winter, which consequently increased the winter feeding costs. Another reason could be increasing variable costs of feeding throughout the years, which equally led to an outcome of more simulated failures due to higher variable costs. This is likely to be true given that sheep do not promote biological diversity, which is acclaimed for its benefits to above ground productivity and rangelands health. This further highlights the major effects of sheep farming on the environment, which could lead to the total degradation of the rangelands if it continues unabated, but which could similarly lead to the failure of farming enterprises in the Karoo.

b. Cohort 2

Figure 5.34 presents the economic sustainability results for the cohort two scenarios. The graphs demonstrate the relationship between time and economic sustainability of the cohort two scenarios. Unlike the cohort one scenario, which had a zero probability of being economically sustainable, in cohort two the results are different. The probability of financial survival for the WLS YI SF scenario is 41.8% in 2011, increases to 56.6% in 2019 before reaching 35.8% in 2025. This is in contrast to a probability of survival of 63% and 100% for the WS-and WL YI SF scenarios, in 2011 and 94.2% and 96% in 2025, respectively. These results suggest that the introduction of incentives in springbuck ranching can improve the sustainability of the cohort one scenarios. Furthermore, these results show that with an introduction of incentives in springbuck ranching, the farmer is able to improve his total income, which decreases the number of simulated failures. From an income point of view, it suggests that because of the income returns from springbuck ranching, the farmer may have been able to keep the variable costs closer to the maximum threshold of 58.1% of total farm income.

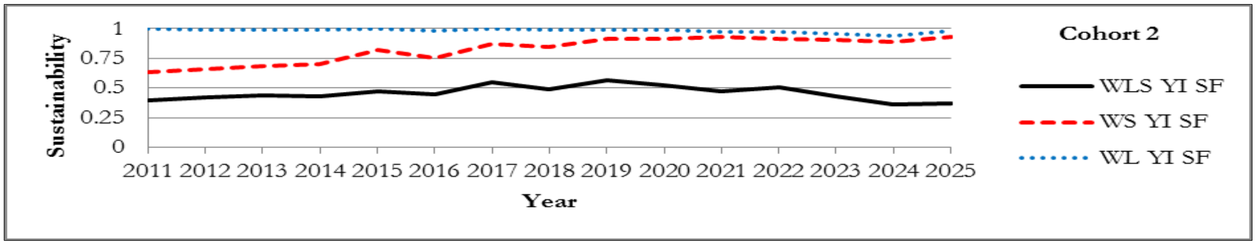

Figure 5.34: Relationship between time and economic sustainability of the WLS-, WS-, and WL YI SF scenarios with incentives.
See Table 5.2 for a detailed explanation of acronyms.

This finding is quite insightful in that it demonstrates the influence of incentives on the sustainability of the alternative scenarios and the applicability of the economic sustainability analysis in further isolating the most sustainable utilisation system. For example, the WL YI SF scenario received the greatest proportion of incentives amongst the three alternatives, because of the assumption that springbuck ranching utilised up to 30% of the 5 000ha rangeland. The economic sustainability analysis has shown that the WL YI SF scenario has an ability to survive financially into the future.

However, there are a few problems with this outcome. First, the South African Revenue Services (SARS) is very strict with permitting rangelands owners' tax breaks for ecological-economic systems that improve biological diversity if the farmer cannot prove that it does (Price Waterhouse Coopers, 2009). Keeping a given quantity of springbuck on the rangeland might be seen as beneficial on the rangeland, only to discover that it is in actual fact not. In such an instance, SARS may require such landowners to pay back (with interest) all monies not deducted as tax for the whole period that such tax breaks were allowed, thus further driving the family farm into serious financial problems.

c. Cohort 3

Figure 5.35 illustrates the relationship between time and economic sustainability of the cohort 3 scenarios. The graph shows that the SLW- and SL NI SR scenarios had a 100%

probability of being economically sustainable in the first eight years of the planning horizon, whilst the SW NI SR scenario had a 100% probability of being economically sustainable only in the first two years of the planning horizon. Moreover, the probability of survival of the SW NI SR scenario gradually decreases such that by 2025, it was at 32.1%. This is a notable result because it reveals that since in calculating economic sustainability feeding costs in springbuck ranching are ignored, the variable costs relative to total income were increasing, highlighting the influence of sheep production on total income on the springbuck ranching enterprise. Even though feeding costs are ignored in this scenario (SW NI SR), the results further reveal that, since the income from sheep farming, in this cohort, is theoretically expected to improve the net income – it is also expected to offset any feeding costs, not unless they grow so high that they infringe on the springbuck ranching enterprise. In which case, the variable cost relative to net income would grow beyond the minimum threshold of 29.45% of net income. This would, in spite of the assumption that there are no feeding costs, imply that the enterprise is now facing an environmental strain – which is upsetting the out of springbuck or that it is facing a financial strain which is equally threatening the financial survival of the family farm, as shown by the results of the SW NI SR scenario. Because sheep were utilising up to 50% of the rangeland, this result does suggest that a combination of 50% springbuck and 50% wool sheep might not be economically sustainable based on the assumptions of this study.

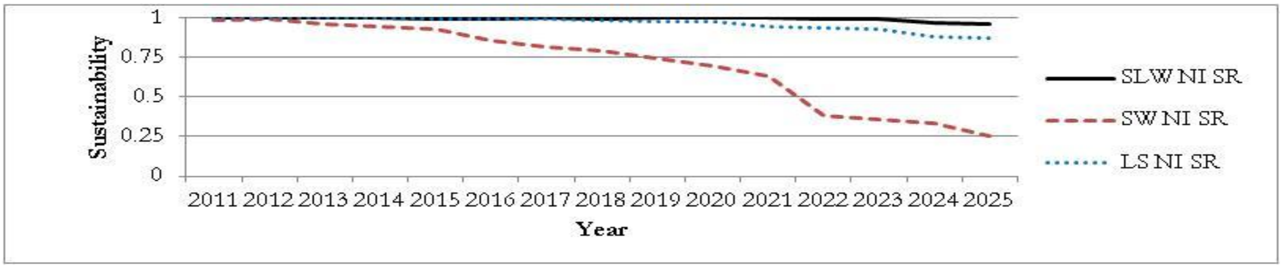

Figure 5.35: Relationship between time and economic sustainability of the SLW-, SW-, and SL NI SR scenario without incentives.
See Table 5.2 for a detailed explanation of acronyms.

Moreover, for the SLW NI SR and SL NI SR scenarios, the probability of survival stays more-or-less constant, such that it was found to be 90.2% and 99%, respectively in 2025. The sustainability results further illustrate that the SLW NI SR scenario had a higher chance of surviving throughout the planning horizon followed by the SL NI SR scenario. This is despite the results of the SERF analysis, which revealed that decision makers who are more risk averse would prefer the SW NI SR scenario. Based on the sustainability criteria, the most economically sustainable alternative amongst the cohort three scenarios would be the SLW NI SR scenario. It should be qualified though that both scenarios SLW NI SR and SL NI SR are comparatively more economically sustainable than the SW NI SR scenario, because of the lower production costs as exemplified by the amount of land set aside for springbuck ranching. Further, the reader is reminded that the sustainability measure does not quantify the extent to which the variable costs in one scenario surpass those in another; rather they explore the probability at which an alternative scenario will have variable costs that are greater than the maximum threshold of 29.45% of net income throughout the planning horizon. This should, therefore, cast some light on the finding that the SW NI SR scenario is, based on the sustainability measure, least sustainable. Even though the SW NI SR scenario may have had a superior NPV than the SL NI SR scenario, it returned a higher number of zero (0) iterations in the total 500 iterations than the other two scenarios, throughout the planning horizon.

d. Cohort 4

The economic sustainability results of the cohort four scenarios are shown by the graphs in Figure 5.36. The introduction of a restoration subsidy and tax reductions for these scenarios improved the sustainability of especially the SW YI SR scenario. For example, compared to the sustainability scenarios of the cohort three scenarios - where the farmer does not receive incentives - it is clear that the scenario has a higher chance of financial survival, especially in the first five years of the planning horizon, after which it decreased to 50% compared to the 32.1% in cohort three. However, for the SLW- and SL YI SR scenarios, the results further exemplify that the introduction of incentives in springbuck ranching impacts the price of venison negatively which marginally affect the total income of these scenarios. For example, in cohort three where there are no incentives, these two scenarios had a 100 percent chance of being sustainable in the first 8 years of the planning horizon. Moreover, with the introduction of incentives, the 100% sustainability falls to the first five years, explaining the effects of incentives on the conversion rates and venison prices.

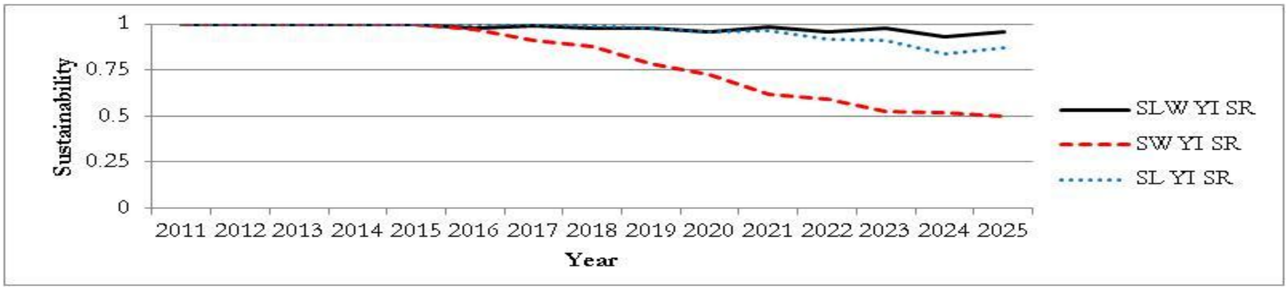

Figure 5.36: Relationship between time and economic sustainability of the SLW-, SW-, and SL YI SR with incentives (Cohort 4).
See Table 5.2 for a detailed explanation of acronyms.

For the SLW- and SL YI SR scenarios, instead of improving, the sustainability respectively dropped to about 96.7% and 84% in 2025, compared to 99% and 90.2% respectively, in cohort three. As the incentives are introduced, more farmers are drawn into springbuck ranching, which increases the output quantity. The increase in output causes the price to decrease, which in turn reduces the total income of the enterprises. However, the scenarios yielded a comparatively higher economic sustainability versus time results than in the sheep farming scenarios, suggesting that springbuck ranching could be potentially more economically sustainable than sheep farming in a 5 000ha farm in Graaff-Reinet.

5.5 Sensitivity Analysis

The profitability of the alternatives is dependent upon the influence of certain variables on the NPV. By conducting sensitivity analyses, the effect of very small changes of some key variables on the NPV of the alternative scenarios, can be explored. In this study, sensitivity tests were conducted to investigate and rank the variables that affect the NPVs in the three alternative scenarios of the two rangeland utilisation ecological-economic systems. Sensitivity analyses are imperative in mapping out the key variables, which affect the financial viability of the alternative scenarios. From a profitability perspective, sensitivity analyses can help pin point the key variables that influence the viability of the various scenarios. To investigate the effect of the various variables on the NPV, sensitivity elasticities are used. Elasticity in its generic sense describes the relationship between a proportional change in a dependent variable in response to a proportional change in the independent variable. It is a unit less measure and can be either negative or positive, and is used in cases where there is a relationship between two variables.

The calculated elasticities for the three alternative scenarios with respect to wool yield and price, lamb yield and price, venison yield and price and variable costs in a 5000 ha farm-producing sheep as a premier ecological-economic activity are shown on Figure 5.37. The graphs show that the variable costs had the greatest negative effect on the NPV in all the three scenarios, whereas yield or output and prices had a positive effect.

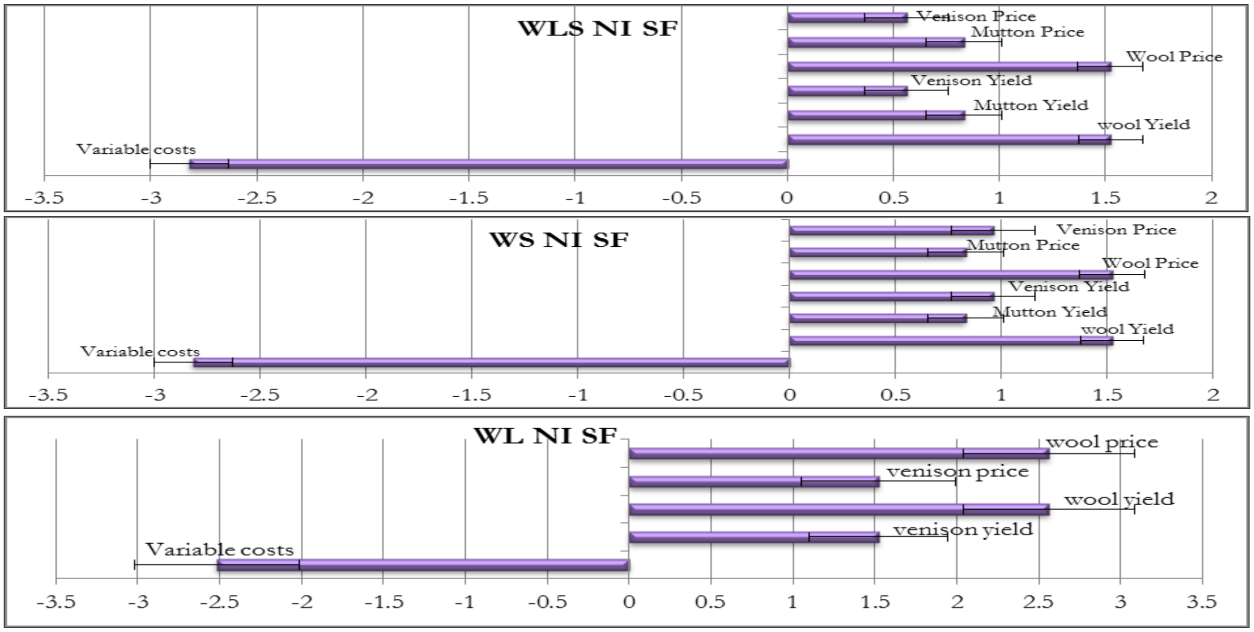

Figure 5.37: Sensitivity analyses of three alternative scenarios with respect to wool yield and price, mutton yield and price, venison yield and price and variable costs in a 5000 ha farm producing wool as a premier ecological-economic activity.
See Table 5.2 for a detailed explanation of acronyms.

This was expected as variable costs represent the costs of doing business and winter-feeding costs in the dry season for the sheep enterprise. In scenario one, about 65% of the income came from wool sales, whilst 20% came from the sales of culled sheep or mutton. Venison contributed about 15% of the total farm income. Therefore, the finding that both the prices and yields of wool, mutton and venison had the greatest effect on the NPV or profitability is not surprising.

The elasticities for the WLS NI SF and WS NI SF scenarios were somewhat similar, whereas the WL NI SR scenario had slightly different elasticities. This is an expected result given the assumptions of the WL NI SR scenario. For scenario one, the results illustrate that a 1% yearly increase in variable costs would decrease the NPV by about 3%, in each scenario. This result could also be interpreted to mean that a 1% decrease per year in variable costs could induce a 3% increase in the NPV, in each alternative. However, wool yield and price had the greatest positive effect on the NPV in this scenario, followed by mutton yield and price and venison yield and price. A 1% increase in wool output and price, would lead to an increase in NPV of about 1.7% in both scenarios WLS NI SF and WS NI SF, whereas it would lead to an increase of about 3% in the WL NI SF scenario. Moreover, for the WL NI SF scenario, a 1% increase in venison output and price would lead to an increase of about 2% in NPV.

Figure 5.38 shows the calculated elasticities for the three alternative scenarios with respect to wool yield and price, lamb yield and price, venison yield and price and variable costs in a 5 000ha farm producing springbuck as a premier ecological-economic activity. The results show that variables costs exert the greatest effect on the NPV in all the three scenarios even in the springbuck dominated scenarios. However, unlike in the sheep farming scenarios, the variable costs have a comparatively smaller effect on the NPV. In the sheep farming scenarios, the variable costs had an elasticity of about -3, whereas in the springbuck ranching enterprises the elasticities are about -1. A 1% increase in variable costs would lead to a 0.9%, 1.1% and 1.2% decrease in the NPV in the three scenarios, respectively. Venison yield and output had the greatest effect on the NPV in all the three scenarios. A 1% increase in venison output and price, would lead to a 2.4% increase in the NPV in the SLW NI SR scenario, whereas in the SW NI SR and SL NI SR scenarios, it would respectively lead to a 3% and 3.5% increase in the NPV. Interestingly is that the venison price seem to exert the greatest influence on the NPV especially on the SW NI SR, than the venison yield.

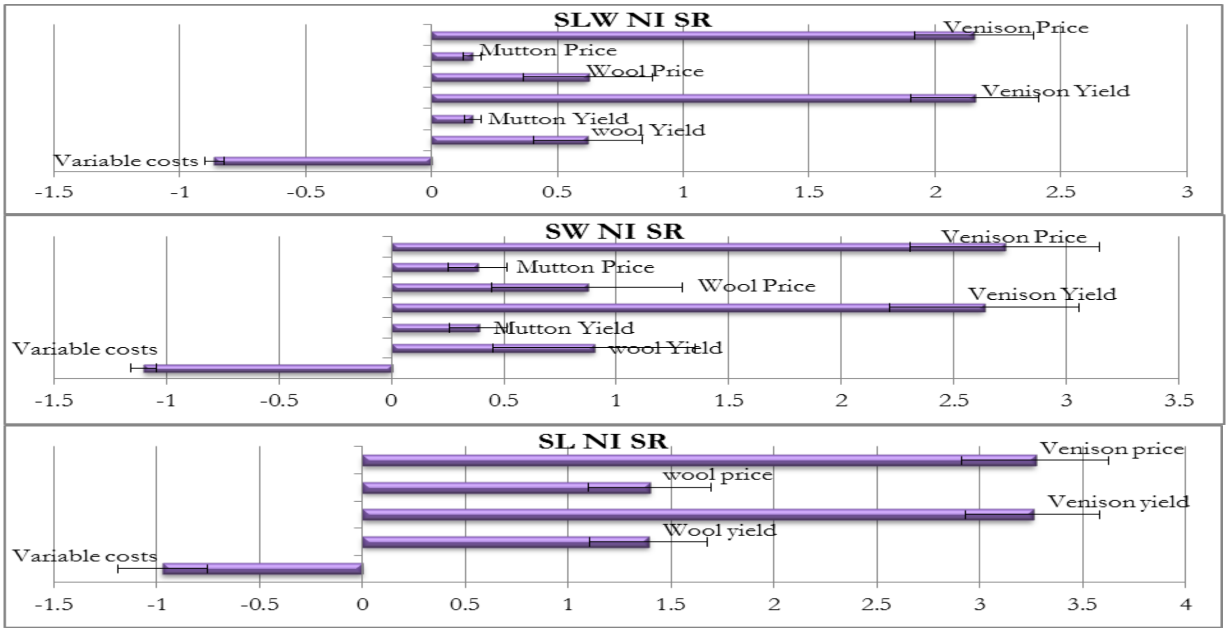

Figure 5.38: Sensitivity analyses three alternative scenarios with respect to wool yield and price, mutton yield and price, venison yield and price and variable costs in a 5000 ha farm producing venison as a premier ecological-economic activity.
See Table 5.2 for a detailed explanation of acronyms.

This is mainly because the farmer is not maximizing on springbuck production, as 50 percent of the land on this scenario was used for springbuck ranching. What this means is that when the farmer uses 50% of his rangeland for springbuck ranching and the remainder for sheep farming, the price of venison influences the profitability of the springbuck ranching enterprise, whereas for the wool enterprise, the wool yield seem to be the major deciding factor. Not surprising, the variable costs had the highest negative influence on this scenario than in the other two scenarios. This further illustrates the importance of other factors on the profitability of the springbuck ranching industry. If the rangelands are converted *en masse* to springbuck ranching, the price of venison would go down, but similarly the variable costs would also decrease significantly, which would make springbuck ranching for meat production more profitable in the long-run.

5.6 Summary of Results

This chapter presented the empirical results of the simulation procedures used to explore the profitability of converting a sheep farm into a springbuck ranch in the Eastern Cape Karoo.

The NPV and the SERF analysis were used to explore the question of whether it is economically profitable to convert a 5 000ha sheep farm into a springbuck ranch, given risk. An economic sustainability measure was linked to the Monte Carlo financial statements to examine the financial sustainability of the various scenarios. Using sensitivity analysis, the effects of the different key variables on the NPV were explored.

Several key findings are worth mentioning. Firstly, in cohort one, the SERF analysis was able to illustrate that the WS NI SF scenario is the most profitable and hence preferred scenario amongst the three scenarios. This scenario yielded the highest NPV despite having an 18.7% chance of being negative. The results further illustrated that based on both the NPV and SERF analysis; the current rangeland utilisation system being employed by the principal decision maker returned the worst NPV with a 62% chance of being negative and were the least preferred. It produced negative certainty equivalents stream across all the absolute risk aversion coefficients assumed to be the plausible risk aversion ranges in this study, suggesting that the farmer is better off discontinuing with such a combination. Secondly, the introduction of incentives for the springbuck enterprises in cohort two did not significantly change the NPVs of the various scenarios. The WS YI SF scenario was still the most preferred amongst the three. This was despite the WL YI SF scenario receiving the largest amount of subsidies. The results further demonstrate that if the farmer were to be paid incentives for springbuck ranching, the probability of yielding a positive NPV would increase, albeit marginally for the preferred WS YI SF scenario.

Moreover, an assessment of the third and fourth cohorts' results, respectively, a different picture emerges. The results reveal that if the farmer were to convert the farm into a springbuck ranch with 70% of the land used for springbuck ranching, the farmer would not only return attractive net cash inflows but that the farmer would earn an NPV which is significantly higher than that of all the scenarios in cohort one. This suggests that when the income streams are discounted, the springbuck ranching enterprises appear to be more profitable than sheep farming in the area. The results further show that the introduction of incentives into springbuck ranching causes it to out-perform the wool sheep dominated enterprises, by a significant margin. Based on the assumptions of this study, one can conclude that springbuck ranching for meat production is a profitable ecological-economic system in Graaff-Reinet when comparing the

NPVs of the sheep farming scenarios and the springbuck ranching for meat production scenarios.

The results of the economic sustainability analysis further confirmed that springbuck ranching does not only yield greater NPVs than sheep farming, they also evinced that it is also more economically sustainable than sheep farming in Graaff-Reinet. Such a finding is imperative because it economically legitimises springbuck ranching as an ecological-economic activity that may well be adopted by farmers in Graaff-Reinet. It also suggests that decision makers who are risk averse and non-satiated in income but are interested in conserving their rangelands and halting degradation can adopt springbuck ranching. The main goal of this study was to investigate the profitability of converting a sheep farm into a springbuck ranch. The conclusion is made that decision makers in Graaff-Reinet could potentially make more money if they were to convert their sheep farms into springbuck ranches for meat production. However, as the results of this study show, a combination of 70% springbuck, 20% mutton and 10% wool could potentially be the most profitable enterprise mix of springbuck ranching and sheep farming in Graaff-Reinet.

Chapter 6.

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

Halting continued rangelands degradation and achieving sustainable agricultural production has featured strongly in government policymaking in South Africa (Scogings *et al.*, 1998). The development of policies geared towards the sustainable use of natural ecosystems as envisaged in the constitution has brought awareness to domestic livestock farmers on the sustainable use of natural ecosystems (Lindsey *et al.*, 2009). In Graaff-Reinet, however, such policies have yielded hardly any benefits in terms of reversing actual degradation on the rangelands. Instead, fears of continuing degradation and a realisation that the rangelands are fast losing their biological productivity have seen livestock farmers reducing the number of domestic livestock on their farms (Nel and Hill, 2008). This decrease in livestock numbers has been, in most cases, accompanied by an equivalent increase in the number of farms that have incorporated game ranching (Nel and Hill, 2008), essentially springbuck ranching for meat production in the Karoo (Neethling, *personal communication*), to their livestock enterprises. However, there is no empirical evidence on which alternative between sheep farming and springbuck ranching for meat production is an economically more profitable rangelands utilisation ecological-economic system, let alone whether it is profitable to convert a sheep farm into a springbuck ranch.

Thus, this study investigated the profitability of converting a 5 000ha wool sheep dominated farm into a springbuck ranch in Graaff-Reinet in the Eastern Cape Karoo. The study was motivated by the endemic nature of the springbuck in Graaff-Reinet (Roche, 2008; Roche, 2004; Beinart, 2003) and its rangelands reclamation potential given that it has co-evolved with the Karoo ecosystem (Roche, 2008). Rangeland owners are in search of profitable rangeland utilisation ecological-economic systems to boost their revenue and ensure that their enterprises remain profitable. Springbuck ranching can be a productive and environmentally benign rangelands utilisation option in the Eastern Cape Karoo. It has the potential to reconcile the often incompatible goals of economic profitability and sustainable agricultural production. Springbuck meat (venison) also known in overseas markets as antelope is on high demand especially among European Union consumers (Neethling, *personal communication*) who are continually demanding lean meat produced by natural means (Wiklun and Hoffman, 2005). However, for springbuck ranching for meat production to be adopted by rangeland owners, it must transcend the "huge economic deterrent" (Hodgson *et al.*, 2005: 243) and pay higher returns than existing conventional ecological-economic systems on the rangelands.

Risk analysis in a whole-farm budgeting context (Lien, 2003) was chosen to conduct the analysis. This procedure was selected specifically because all businesses face risky decisions, which make risk an important attribute of agricultural production (Lien *et al.*, 2009; Hardaker *et al.*, 2004a; Hardaker *et al.*, 2004b; Lien, 2003). Secondly, converting from one enterprise mix to another involves many uncertainties that can be best understood when studied in a system context (Richardson *et al.* 2006). Specifically, whole-farm stochastic simulation (Lien, 2003) was used to incorporate the stochastic components of the production relationships between wool sheep, mutton yield and springbuck yield with their respective prices, in a bid to capture the uncertainty in the real system under study.

The central premise of this study was that the springbuck when reintroduced appropriately could promote the resumption of crucial ecological processes that are essential for healthy and biologically productive rangelands (Skinner *et al.*, 1986). Thus, because of the biodiversity restoration potential of springbuck ranching, this study also explored the effect of incentive packages on the profitability of converting a sheep farm into a springbuck ranch, in Graaff-Reinet. The inclusion of risk in a profitability analysis allowed for the examination of economic sustainability (Lien *et al.*, 2007a). It also necessitates the comparison of those variables, which directly affect the profitability of the various enterprise mixes through sensitivity analysis (Sartwelle *et al.*, 2006). This yields valuable information to decision makers regarding the economics of springbuck ranching for meat production before committing large sums of money and land to an utilisation system that could potentially be unprofitable and economically unsustainable, despite its ecological benefits.

6.2 Study Scenarios

The analysis was for an average sized (5 000ha) sheep farm in Graaff-Reinet and included three different utilisation scenarios, grouped into four cohorts. In the first two cohorts, the first scenario comprised of 70% of the rangeland used for wool sheep farming (W), 20% for mutton production (L) and the remaining 10% was used for springbuck ranching (S) for meat production. The second scenario was similar to the first only that the land use ratios were changed to 50% (W), 30% (L) and 20% (S). In the third scenario of cohort one and cohort two, 70% of the rangeland was used for wool sheep farming and 30% for springbuck ranching for meat production. Cohort 3 and 4 were based on the cohort one and two scenarios, respectively, with the exception that the premier ecological-economic system was assumed springbuck ranching. Thus, in cohort three and four, scenario one assumed that 70% of the rangeland was used for springbuck ranching for meat production (S), 20% for mutton (L) and 10% for wool sheep farming (W). The enterprise mix in scenario two of cohort three and four consisted of 50% of the land being used for springbuck ranching (S), 30% mutton (L) and 20% for wool sheep farming; whereas scenario three had 70% of the rangeland used for springbuck ranching for meat production and 30 percent for wool sheep farming. Cohort one and three necessitated the comparison of the key indicators when the premier ecological-economic system on the rangeland is sheep farming and springbuck ranching, respectively, whereas cohorts two and four were used to explore the effect of tax incentives and the introduction of a fixed annual biodiversity restoration subsidy on the springbuck ranching enterprises.

6.3 Summary of Findings

The results suggest that springbuck ranching for meat production is more profitable than sheep farming in Graaff-Reinet, as shown by the projected NPVs. In other words, converting a 5 000ha sheep farm to a springbuck ranch in Graaff-Reinet could potentially yield a relatively higher income return and maximise expected utility than incorporating springbuck ranching into an already existing sheep enterprise or continuing with sheep farming. This finding confirms that springbuck ranching for meat production is potentially a more economically desirable ecological-economic system than sheep farming in Graaff-Reinet, over the 15 year planning horizon, based on the assumptions made on this study.

6.3.1 Key Output Variables

For all the wool sheep dominated scenarios (cohort one and two), the projected profitability results show that the net cash incomes were decreasing throughout the planning horizon, whereas for the springbuck dominated scenarios (cohort three and four) on the other hand, the net cash incomes were increasing. For cohort one and two, the net cash incomes were decreasing because of the assumption that the production costs in the wool sheep enterprises were expected to increase throughout the entire planning horizon, whereas for cohort three and four it was mainly because of the reduced costs of production, in springbuck ranching. The magnitudes of net cash income were likewise different between the sheep farming scenarios and the springbuck ranching scenarios. For the sheep farming scenarios (Cohort one and two), a higher net cash income was obtained at the beginning of the planning horizon. However, such net cash income was affected by the high costs of borrowing in sheep farming, such that they were smallest at the end of the planning period. When a fixed R13/ha restoration subsidy together with a 15 year tax break for springbuck ranching enterprises was introduced, the net cash income for springbuck ranching enterprises improved significantly signalling the effect that incentives might have on the profitability of springbuck ranching for meat production. Moreover, with the introduction of the restoration subsidy more farmers were presumably drawn to springbuck ranching, which inversely caused the price of venison to decrease. Consequently, the low price of venison led to compromised net returns and subsequently the net cash income structure of the cohort four scenarios.

A direct comparison of the cohort one and cohort three scenarios revealed that the cohort three scenarios had higher net cash income returns than their cohort one counterparts. Similarly, cohort four scenarios yielded higher net cash income than those in cohort two, suggesting that converting from wool sheep dominated farming enterprise to a springbuck dominated enterprise is potentially more profitable than incorporating springbuck ranching into an existing wool sheep farm. Moreover, regrettably the probability of returning negative net cash incomes was higher in cohort three and four, than in cohort one and two. This could be attributed to lower venison prices and especially output per animal towards the end of planning horizon due to the assumption that as the farmer gradually increases output from springbuck ranching; the venison output per animal would subsequently decrease. It is notable that even though the cohort three and four scenarios returned higher probabilities of being negative relative to the cohort one and two scenarios, they were more likely to be economically sustainable than the cohort one and two scenarios. This suggests that as more farmers convert to springbuck ranching, their net cash incomes are likely to decrease because of a decrease in the farm gate price of venison; however, such a decrease will not lead to financial ruins.

The results for the ending cash balances for the entire cohort one and two scenarios, except WL YI SF (in cohort two) were, like the net cash income, highest in the first year and decreasing throughout the entire planning horizon. In contrast, all the ending cash balances were positive in cohort three and four, respectively. Cohort one and two scenarios had higher expenses and financial obligations than the cohort three and four scenarios, which compromised the money available to accumulate, interest at bank, greatly. The SLW YI SR scenario in cohort four returned the highest ending cash balances, further illustrating the effects of incentives on the profitability of the respective rangeland use ecological-economic systems. The real net worth had a zero probability of being negative in all the scenarios. Moreover, because of the deflation factor and especially in cohort one, two and three respectively, the real net worth was decreasing, whereas in cohort four it was increasing and flattened towards end of planning horizon.

6.3.2 Stochastic Efficiency with Respect to a Function

Using stochastic efficiency with respect to a function (SERF) analysis, the study ranked the alternative scenarios across a range of absolute risk aversion coefficients (ARACs). The SERF procedure provides the decision maker with a vigorous and robust method of assigning the alternatives into different certainty equivalents (CE) values across a range of absolute risk aversion coefficients. It also necessitates the exploration of the future consequences of the various alternatives on the profitability of the 5 000ha farm, based on the risk preferences as shown by the ARACs. For the wool sheep dominated enterprises, the WS NI SF and WS YI SF scenarios were the most preferred scenarios in cohort one and two respectively, whereas in the springbuck dominated enterprises, the SLW NI SR scenario was only preferred by risk neutral decision makers (ARAC 0). Risk moderate (ARAC 0.0000125) decision makers were indifferent between the SLW NI SR and the SW NI SR scenarios whereas risk averse (ARAC 0.000025) decision makers, on the other hand, preferred the SW NI SR scenario. In cohort four, however, all decision makers preferred the SLW YI SR scenario across the range of ARACs. To quantify the monetary value that risk neutral, risk moderate and risk averse decision makers would respectively require to convert from the preferred alternative to the next and still be equally well-off, this study calculated their risk premiums. Essentially, a risk premium is the amount of money that would leave decision makers equally well-off between the preferred scenario and another alternative. Like the CE values, the risk premiums vary across a range of risk aversion coefficients (risk preferences). Moreover, their true and conspicuous benefit is in mapping out the impact of various enterprise mixes on the profitability of the ranch and can further be used as a tool to confirm the robustness of the rankings. In this study, the risk premiums were high and reasonably consistent, especially for risk averse decision makers, thus confirming the robustness of the rankings.

6.3.3 Economic Sustainability

The economic sustainability of converting alternative wool sheep-farming scenarios into alternative springbuck ranching scenarios was also explored. The sheep farming alternatives returned a higher probability of being economically unsustainable, whereas, all the springbuck ranching scenarios were most likely to be economically sustainable, in the planning horizon. Using the economic sustainability measure, this study demonstrated that the scenario that is preferred mostly by decision makers might also be the most economically sustainable one. None of the sheep farming scenarios throughout the planning horizon returned net incomes, which were below the maximum threshold of variable costs relative to total income. This was not surprising as most of the income in sheep farming is used to finance costs of winter-feeding and in cases where rains are not good enough to warrant adequate forage biomass production - making the cost of producing sheep on a 5 000ha to be comparatively higher than in springbuck ranching. Consequently, the sheep farming scenarios showed a 100 percent potential of being economically unsustainable. The introduction of incentives for the springbuck enterprises in the wool sheep dominated scenarios, were inadequate to improve their sustainability, except for the WL YI SF scenario, which showed a sustainability of greater than 80%. However, it is worth noting that, whilst the introduction of incentives may have improved the probability of financial survival into the future of this scenario, all this was possible because of the extra income from springbuck ranching – justifying fears of a cost-price squeeze in sheep farming, in the area.

On the contrary, the springbuck enterprises were sustainable throughout the planning horizon. There was, however, a higher probability that in cohort 3, the SW NI SR scenario would be unable to meet its financial obligations during the planning horizon, suggesting that perhaps an enterprise mix of 70% springbuck and 30% wool sheep might not be a judicious combination. This was because of the rising need to provide supplementary feeding for the wool sheep enterprise considering that the farmer was assumed not to cull for mutton production. Nonetheless, with the introduction of incentives in cohort four, the economic sustainability of this scenario improved, albeit only marginally. The differences in economic sustainability between a sheep dominated farm and a springbuck dominated ranch are significant, implying that farmers are likely better off in springbuck ranching dominated enterprises than in sheep farming. The results further illustrate the extent to which different combinations of utilisation processes could improve the economic sustainability of the 5 000ha farm.

6.3.4 Sensitivity Analysis

Sensitivity analysis results confirmed that variable costs have the greatest effect on profitability. The results illustrated that a 1% annual increase in variable costs would decrease the profitability by about 3%, in all the sheep farming scenarios, respectively. This was because, for the sheep farming enterprises, the variable costs were largely made up of winter-feeding costs, which took up a substantial share of the total variable costs. Moreover, wool, mutton and venison price together with their respective yield contributed significantly to the profitability of these enterprises, as anticipated. A 1% increase in wool and wool price was found to lead to a 1.5% increase in profitability in all the cohort one scenarios. Likewise, the sensitivity results illustrated that a 1% yearly increase in variable costs would lead to a decrease in profitability of about 1% in the springbuck dominated scenarios and *vice versa*, suggesting that even in springbuck ranching, a need to contain costs exists if the profitability of springbuck ranching is to be sustained.

6.4 Conclusions and Recommendations

This thesis has studied the profitability of converting a 5 000ha wool sheep dominated farm into a springbuck dominated ranch in Graaff-Reinet, in the Eastern Cape Province of South Africa, in a bid to motivate a new approach and paradigm towards the utilisation of the rangelands. This approach, when adopted by rangeland owners, is hypothesised as going to positively impact the ecological diversity and integrity of these rangelands, and lead to their reclamation (Skinner *et al.*, 1986). Furthermore, based on an extensive literature analysis, the opinion that once springbuck ranching for meat production is adopted by rangelands owners, the idea of sustainable agricultural production could be achieved in the area is made. This will not only mean a continuation of the area's leading source of livelihoods – settling fears of downplaying some of the progress made in human development in South Africa - but also of the natural ecosystems, thus saving them for generations yet to come. In other words, the conclusion is made that, with the production of the springbuck (which is natural capital in the area) an ecological and economic trajectory that will benefit both the immediate users of the rangelands and their surrounding communities is potentially possible. Natural capital, as argued in the preceding chapters, promotes biodiversity restoration, which promotes the sustained productivity of these systems.

The results of this study have some implications for rangelands management and especially for farmers who are interested in those ecological-economic systems that have a potential to arrest on-going biodiversity loss and rangelands degradation in the Karoo. First, the results show that under the assumptions of this study, it is profitable to convert a 5 000ha 70% wool sheep, 20% mutton and 10% springbuck, sheep farm into a 70% springbuck ranch and 30% (sheep farm 20% mutton and 10% wool sheep) in Graaff-Reinet. This is particularly so given that in Graaff-Reinet there is a well-developed facility for processing springbuck meat that has access to international markets. Even though this study assumed that consumption would stay approximately the same throughout the planning horizon, the results suggest that springbuck ranching is potentially a practicable land use option in the area. The results further illustrate that farmers who are reluctant on converting their farms into full springbuck enterprises, following the findings of Dlamini, Fraser and Grové (2012), can actually choose from a set of other feasible springbuck and sheep farming enterprise combinations.

Secondly, the findings of this study suggest that converting a 5 000ha sheep farm into a springbuck ranch is not only profitable but economically sustainable as well. Springbuck ranching for meat production involves low expenses and variable costs compared to sheep farming (Skinner *et al.*, 1986). Moreover, the benefits of game ranching in the light of looming degradation catastrophes in the Karoo make springbuck meat production a more realistic and judicious rangelands utilisation option to sheep farming. Farmers who are concerned about the cost-price squeeze in commercial wool sheep farming in Graaff-Reinet have an achievable option: convert to springbuck ranching, which will minimise variable costs and management requirements, whilst simultaneously stimulating biodiversity restoration and thus aid in improving ecological potency. Given these findings together with those of Dlamini *et al.* (2012) that it is financially feasible to convert a 5 000ha farm into a full springbuck ranch, the impression that rangeland owners in Graaff-Reinet are perhaps misusing their rangelands through sheep farming could easily be made.

Particularly, this is so given that sheep do not promote biological diversity in these rangelands following that they are not part of the natural capital in the Karoo. This is notwithstanding that sheep farming is somewhat perceived as a monumental and historically important industry, having shaped and established much of the economy of the Karoo (Beinart, 2003). Indeed, the disappearance of some keystone species intertwined with overgrazing by domestic livestock and their failure to promote biological diversity that has led to the great deal of degradation evident in most parts of the Karoo. Thus, the study also suggests that the reintroduction of springbuck ranching on a bigger scale might improve the buffering capacity of the rangelands thus halting degradation in the long-run. The existence of a lucrative springbuck meat market in the European Union (Neethling, *personal communication*) presents further proof that perhaps now more than ever is the right time to convert the rangelands into a more environmentally benign utilisation economic system. The growing acceptance of venison by the modern consumer (Hoffman and Wiklund, 2005), for instance, should further be taken as evidence that meat production from wild animals is a viable land use option.

The main findings of this study also present opportunities to policy makers to create policies and mechanisms that will promote the uptake of springbuck ranching as a means towards halting degradation and reversing the effects of 200 years of domestic livestock farming in the Karoo. One possible mechanism to address the current degradation challenges of these rangelands is to encourage the adoption of those ecological-economic systems that are benevolent toward the environment. Such ecological-economic systems should involve the use of wild animals that have the potential to promote biodiversity restoration. This is because biodiversity can act as a source of ecological insurance and could in the long-run promote an ecological trajectory that is conducive to ecological integrity and ultimately resilience. This study has shown that the government can provide incentives to springbuck ranching enterprises to improve their profitability, and their subsequent uptake by landowners. Such incentives could potentially include:

- A biodiversity restoration subsidy to those farmers who are utilising their rangelands for the production of keystone species that have been scientifically proven to aid in biodiversity restoration.
- Paying farmers subsidies for merging their farms in a bid to undo the effects of 200 years of domestic livestock farming, especially the removal of fences to allow the free movement of wild animals; and
- Enforcing the newly (late 2009) introduced tax incentives to those farmers who are utilising their lands for biodiversity restoring projects.

Whilst it might be contended – rightly - that such a policy initiative may not be a judicious use of government funds, the thrust of this policy advice is mainly informed by the need to prevent the unavoidable and avoiding the unpreventable. Surely, the next stage would be to conduct a careful evaluation of this policy. However, it should be noted that the future costs of resettling the many farmers and residents of Graaff-Reinet in the event that desertification were to be fast-tracked as a result of a changing climate or a crash of the ecosystem due to continued monotonous domestic livestock farming might be higher than prevention.

The government may also explore the possibility of introducing conservation easements and management and preservation agreements, which are particularly appealing when a desire to conserve and preserve natural ecosystems is sought. These agreements are usually entered into between the relevant government agencies and individual rangeland owners. They entail individual farmers being compensated for putting aside land for those ecological-economic systems that are benevolent toward the environment (Abebayehu *et al.*, 2003). Springbuck ranching for meat production might blend well with such policies by promoting biodiversity whilst producing food.

However, as can be seen, the success of these policies will depend on the government's ability to implement them appropriately without disrupting the livelihoods of the farmers and the Graaff-Reinet community at large. It will also depend on how much rangeland owners are willing to sacrifice their current consumptive use of the rangelands for future generations. It should be noted, however, that the aforementioned policies will not in themselves result in springbuck ranching realising supernormal profits, but that they will aid in driving the cost of production in springbuck ranching down and further cushion farmers against any production risks that may arise in springbuck ranching. The foundational result that this study has provided is that springbuck ranching can be used as an ecological-economic system in the Eastern Cape Karoo. However, equally true is that for landowners fully to reap the ecological advantages of springbuck ranching, some compromises would have to be made. Firstly, farmers would have to provide an enabling environment for springbuck production to thrive through a substantial reduction of fences in the area. As Archer (2000) recollects, the introduction of such modern farming practices has brought about some of the environmental hardships in the area. In the progression, these farming practices have led to the displacement of much of the natural capital and have robbed these rangelands of their ecological integrity (Roche, 2004). Secondly, farmers would have to be willing to manage their farms jointly to realise the rewards of free movement of the springbuck on the rangelands. Thirdly, even though springbuck ranching is in absolute terms profitable, farmers would have to be prepared to settle for lesser income returns, if the continued sustainability of these rangelands is to be realised. Indeed, the successful implementation of such actions could, in the long-run, lead to the development of other forms of managing the resultant biodiversity of the area and could potentially yield other income earning projects.

Finally, the finding that springbuck ranching could potentially be more profitable than sheep farming beckons a need for careful consideration of other programmes that will enforce the management of these rangelands through springbuck ranching and related keynote species. An example could be the promotion of other spill over industries that could directly benefit rangeland owners through the joint management of these rangelands and the resultant industries. Such could include ecotourism projects that are progressive and geared towards the holistic management of biodiversity (both flora and fauna) with a potential of creating employment that could absorb some of the jobs that would have been lost because of the transition from sheep farming to game ranching. These programmes should include all landowners, resident and non-resident, to enable a holistic development of biodiversity inspired projects for the benefit of all the people of Graaff-Reinet and South Africa as a whole and more importantly for future generations as well.

6.5 Concluding Remarks

Thoughtfulness should be exercised when interpreting these results. Besides the unavoidable limitations on data and modelling, the results of this study also have some weaknesses, which need to be taken into consideration. The analysis did not include other forms of domestic livestock, which the decision maker kept during the historical period that could otherwise make livestock farming more profitable than springbuck ranching. Livestock farmers in Graaff-Reinet keep a variety of other domestic stock including cattle, goats, domestic fowl and horses. Similarly, this study made an ambitious assumption regarding the gradual re-introduction of springbuck into the farm. In practice, this might not materialise. Rangeland owners are reluctant to change from conventional farming systems they know to something that is new and practically unknown. Thus, the viability of springbuck ranching will depend very much on how individual landowners view the potential benefits of biological diversity on rangelands health. In particular, those farmers who are forward looking and appreciate the influence of keystone species on biodiversity restoration and its prospective ability to contribute towards the rangeland's ecological insurance would place more value on springbuck ranching and *vice versa*. Similarly, the conversion rates and especially output numbers in springbuck ranching might vary considerably; affecting the probable profitability of springbuck meat production enterprises.

Therefore, whilst there is a springbuck ranching processing facility in Graaff-Reinet, this analysis assumed that the business model would stay the same throughout the planning period. In the same way, the costs of harvesting the springbuck were deliberately left out of the analysis given that the current agreement between the meat processor and individual springbuck ranchers is such that the meat processor pays all costs related to the harvesting of the springbuck on the farm. It was, consequently, hard to ascertain the cost of springbuck harvesting per farm. The study was also unable to establish whether the per kilogram price of venison excluded the cost of harvesting i.e. if the Meat Processor had a way of recovering the costs of harvesting from the ranchers. Clearly, as this study has shown, a slight increase in the variable costs of production in springbuck ranching could affect the probable profitability of springbuck meat production. More than likely, the meat processor might in the long-run push the cost of harvesting (helicopter and labour costs) to the individual ranchers, which could increase the variable costs of production significantly.

Another critical limitation of this study was the assumption that the annual mean prices in the planning horizon will grow linearly as per the changes in consumer inflation, which might not be the case. In this study, the changes in inflation rates were near estimates that could be used to forecast future prices. Actually, recent studies (Chen *et al*., 2008) have shown that wool prices are explained more by exchange rates variation than by other factors. Similarly, the price of venison might also be affected by changes in exchange rates as venison is mainly sold in overseas markets. The assumption that wool production per ewe will be fixed throughout the planning horizon is also a weakness of this study. Indeed, it might seem that farmers are more capable to improve wool productivity per ewe than improving the productivity of the rangelands. However, as shown in chapter two, this study was more interested in settling the degradation impasse of the rangelands in the Karoo.

An additional limitation of this study was the assumption that farmers might be drawn to springbuck meat production because of its profitability. Whilst there is some theoretical and empirical basis to this, a major challenge is convincing farmers that the limited local venison market will in the future pick up and be a force to reckon with like the wool industry in the area.

However, as discussed with Camdeboo Meat Processors, it does appear that they are in a drive to sensitise the local consumer market on the health benefits of venison. However, as it might seem, farmers are less likely to convert their farms to something new - that still has a lot of market uncertainties. It is precisely because of this challenge that this study decided to use incentives – to boost incomes and confidence whilst the local market is being nurtured.

Despite these limitations, the study was able to show that under its assumptions, springbuck ranching could return a higher NPV and net worth for a 5 000ha farm producing springbuck on 70% of the farm, mutton on 20% and wool on 10%. Decision makers who are interested in converting their sheep farms could use these results as a foundation in coming up with the appropriate enterprise mixes for their rangelands. Policymakers, on the other hand, could use them as a springboard to evaluate further the type of policy initiatives and state programmes that could perhaps lead to the uptake of not only springbuck ranching but also other ecological-economic systems. This could promote biodiversity restoration and the eventual reclamation and protection of these natural ecosystems for the benefit of future generations as stipulated in the constitution of the Republic of South Africa.

6.6 Recommendations for Further Study

This study analysed the profitability of converting a 5 000ha sheep farm into a springbuck ranch for meat production. It is recommended that the study be extended to include other forms of domestic livestock in the Karoo together with other spill over businesses from springbuck ranching, including trophy hunting, ecotourism, and the economic benefits of floristic diversity on the profitability of converting livestock farms into springbuck ranches. In addition, this study did not explicitly consider the ecological insurance value of springbuck ranching, which could increase the value of farms in Graaff-Reinet significantly. This study did not use actual wool output from the farm due to lack of data. Future studies might expand this study by incorporating actual wool output data as opposed to wool from a representative ewe or yearling. This will give a more realistic picture of the net returns from wool sheep farming.

Secondly, economic profitability of springbuck ranching might benefit from scale, which was not considered in the present study. Farms in Graaff-Reinet are also bigger than 5 000ha. Future studies could potentially extend the present study by analysing the profitability of converting a much bigger sheep farm into a springbuck ranch. Merely replacing sheep farming with springbuck ranching, without quantifying - if any - benefits that accrue to the local people in terms of jobs and food security may prove to be a big mistake. This point may seem somewhat obvious, but it is clearly important from a local economic development perspective and on whether the government endorses and supports springbuck ranching as a solution towards halting environmental health concerns. Similarly, further analysis on the economic impact of converting from sheep farming to springbuck ranching on the Graaff-Reinet economy should be conducted with data set that has been obtained from the farmers, community members and other concerned stakeholders, to get better insights into the economics of springbuck based rangelands utilisation in Graaff-Reinet. There is also opportunity to expand this study through the identification of strategies and programmes that can be used to expand the limited domestic market for venison in South Africa. This might turn out to be an important component of this research going forward if the recommendations of this study do yield a significant uptake in springbuck ranching in Graaff-Reinet.

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APPENDICES

APPENDIX A 1

Table A. 1. Costs Analysis

	Percent of total income from Sheep enterprise	Percent of total income from Springbuck enterprise
Supplementary feeding costs	20	0
Marketing and related costs	7	0
Manager's salary	10	12
Labour	5	7
Stock purchases	2	1
Production (veterinary, husbandry etc.)	5	1
Maintenance		
Grounds/veld	0.5	0
Vehicles and tractor	2	1
Buildings	1	0.2
Fences	1.1	0.15
Fuel		
Diesel	2	5
Petrol	1	1
Office costs	0.1	0.1
Miscellaneous	1	1
Total costs	58.1	29.45

The cost structure for a sheep farming enterprise *versus* a springbuck ranching enterprise in Graaff-Reinet. The figures are representative of the costs faced by the principal decision maker in the case study farm. Note the high percentage of feed costs in sheep farming *versus* nil in springbuck ranching. Also note that labour costs in springbuck ranching appear to be higher than in sheep farming because the farmer pays more wages in ranching than in sheep farming.

Source: Author's own calculations.

Table A2. Inflation, Interest and Exchange Rates for Deterministic and Stochastic Variables.

Year	%change in CPI	% change in PPI	Fixed costs	Interest rates	Exchange rates
2011	0.080	0.051	0.089	0.090	0.073
2012	0.057	0.060	0.084	0.090	0.072
2013	0.054	0.056	0.081	0.099	0.077
2014	0.052	0.055	0.078	0.109	0.076
2015	0.058	0.057	0.067	0.110	0.080
2016	0.057	0.057	0.067	0.110	0.084
2017	0.055	0.055	0.067	0.114	0.088
2018	0.055	0.052	0.067	0.112	0.091
2019	0.055	0.052	0.067	0.109	0.093
2020	0.055	0.051	0.067	0.109	0.097
2021	0.053	0.051	0.067	0.107	0.100
2022	0.053	0.050	0.067	0.107	0.104
2023	0.053	0.049	0.067	0.105	0.108
2024	0.053	0.049	0.067	0.105	0.112
2025	0.053	0.049	0.067	0.104	0.115

Source: BER, 2011

Table A.3. Summary Statistics for the Simulation of Wool Sheep, Lamb, Springbuck, Wool Price, Mutton Price, Venison Price, Rainfall and Biomass

Wool sheep	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Mean	1188.34	1174.06	1153.55	1112.45	1060.61	1061.41	951.08	955.53	827.37	831.06	704.23	706.46	585.32	586.11	469.23
StDev	233.07	221.80	217.80	218.23	203.77	196.79	182.96	183.24	160.82	161.28	135.04	131.36	108.55	112.59	88.31
CV	19.61	18.89	18.88	19.62	19.21	18.54	19.24	19.18	19.44	19.41	19.18	18.59	18.55	19.21	18.82
Min	791.53	782.92	767.41	745.29	707.22	708.88	636.27	636.94	558.80	553.99	471.03	471.32	390.69	390.84	312.97
Max	1576.72	1563.86	1531.72	1486.54	1412.94	1413.33	1272.01	1269.13	1105.20	1104.60	940.01	940.25	779.67	778.61	624.31

Lamb Yield	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Mean	340.82	343.76	358.35	363.25	380.33	374.10	410.24	414.58	439.54	445.32	487.53	487.38	513.42	513.03	555.94
StDev	139.38	140.35	142.72	148.03	146.68	145.55	147.47	146.82	146.68	146.16	153.78	147.39	141.10	141.88	121.72
CV	40.90	40.83	39.83	40.75	38.57	38.91	35.95	35.41	33.37	32.82	31.54	30.24	27.48	27.66	21.89
Min	156.04	156.11	162.46	171.71	178.91	180.41	198.77	200.64	233.57	233.77	268.04	269.99	300.37	298.94	358.73
Max	708.17	719.60	746.59	772.25	773.65	759.18	802.62	817.78	856.57	844.31	918.20	908.76	939.31	957.04	977.73

Venison Yield	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Mean	577.24	584.54	595.63	624.66	668.95	670.34	735.19	737.23	831.97	832.97	956.69	955.94	1119.08	1119.14	1338.81
StDev	114.10	113.47	114.65	123.63	126.63	130.57	142.96	143.45	158.11	159.29	184.95	184.33	213.13	221.22	259.67
CV	19.77	19.41	19.25	19.79	18.93	19.48	19.44	19.46	19.00	19.12	19.33	19.28	19.04	19.77	19.40
Min	385.59	391.41	397.15	417.70	447.53	446.93	491.22	491.10	554.65	555.93	639.71	638.90	747.53	746.86	896.48
Max	770.24	778.04	794.11	833.66	892.17	892.04	981.38	979.22	1108.60	1106.94	1274.89	1274.24	1491.92	1487.78	1790.62

Wool Price	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Mean	33.67	35.23	36.87	38.55	40.28	42.51	44.93	47.36	50.24	52.97	55.86	59.13	62.24	65.79	69.49
StDev	6.44	6.93	7.11	7.45	7.66	8.12	8.42	9.22	9.66	10.13	10.93	11.56	12.05	12.90	13.39
CV	19.13	19.68	19.28	19.32	19.01	19.10	18.75	19.46	19.23	19.13	19.57	19.55	19.35	19.61	19.27
Min	22.42	23.46	24.55	25.64	26.88	28.41	30.02	31.68	33.40	35.29	37.28	39.36	41.55	43.83	46.26
Max	44.79	46.71	48.95	51.24	53.64	56.60	59.84	63.22	66.56	70.51	74.44	78.62	82.97	87.61	92.37

Table A.3. Continued

Mutton Price	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Mean	34.18	35.82	36.16	37.10	38.30	39.69	40.94	42.77	44.78	46.06	48.36	51.35	52.95	55.74	58.62
StDev	6.56	6.87	6.96	7.58	8.07	8.41	8.92	9.13	10.44	11.07	11.66	11.76	12.75	12.99	13.56
CV	19.19	19.17	18.24	18.91	19.07	18.81	19.00	18.35	19.78	20.10	19.98	18.86	19.63	18.90	18.67
Min	22.72	24.07	27.43	30.35	32.38	35.41	37.54	40.84	48.14	47.14	50.35	53.89	56.71	52.60	55.56
Max	45.38	47.93	52.52	55.91	60.50	66.14	68.70	78.00	78.99	84.12	89.10	94.10	100.13	98.52	104.05

Venison Price	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Mean	21.37	22.42	23.53	24.63	28.12	26.70	27.61	28.64	29.79	30.63	31.36	32.15	32.92	33.65	34.57
StDev	4.13	4.38	4.56	4.60	5.30	5.07	5.21	5.43	5.71	5.93	6.14	6.31	6.09	6.48	6.57
CV	19.34	19.53	19.39	18.69	18.84	18.98	18.88	18.94	19.18	19.36	19.59	19.63	18.48	19.25	18.99
Min	14.24	15.06	15.69	16.47	18.79	17.87	18.44	19.09	19.79	20.47	20.97	21.48	21.98	22.54	22.96
Max	28.42	29.93	31.31	32.77	37.37	35.60	36.87	38.16	39.44	40.89	41.90	42.89	43.84	44.89	45.64

Rainfall/Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Mean	346.74	299.57	291.15	346.24	438.62	294.13	287.31	331.13	418.67	294.73	281.05	316.06	392.82	277.78	306.31
StDev	90.60	58.94	57.56	66.45	98.51	58.39	58.82	65.99	100.98	60.74	58.74	66.91	100.30	59.29	56.40
CV	25.96	19.04	18.80	19.19	19.18	18.89	19.14	19.06	19.66	19.61	19.19	19.33	19.56	19.26	18.41
Min	243.82	205.60	204.28	231.37	343.20	205.78	204.52	231.49	342.23	205.60	204.59	231.17	344.16	206.25	204.34
Max	349.66	393.55	378.03	461.12	534.03	382.47	370.10	430.78	495.11	383.87	357.51	400.96	441.48	349.31	408.28

Biomass /Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Mean	3152.57	1892.98	1879.94	2130.49	3152.56	2523.10	3011.75	3410.39	5047.92	3032.97	3009.85	2802.62	2753.09	1654.31	1642.71
StDev	606.57	364.68	360.80	410.23	607.11	487.28	578.91	653.59	967.37	585.67	582.90	539.28	528.30	320.62	318.24
CV	19.24	19.26	19.19	19.26	19.26	19.31	19.22	19.16	19.16	19.31	19.37	19.24	19.19	19.38	19.37
Min	2104.94	1263.01	1256.11	1422.19	2103.67	1684.76	2009.65	2274.50	3372.71	2026.15	2009.80	1872.12	1836.02	1104.68	1096.53
Max	4203.49	2525.02	2505.37	2837.55	4202.04	3364.00	4014.88	4543.63	6724.58	4040.87	4012.91	3739.39	3666.29	2205.39	2190.02

Appendix B

SIMULATION SUMMARY STATISTICS OF KEY OUTPUT VARIABLES FOR A 5 000ha SHEEP FARM IN GRAAFF-REINET PRODUCING WOOL AS A PREMIER ECOLOGICAL-ECONOMIC SYSTEM WITHOUT INCENTIVES.

Table B.1. Simulation Summary Statistics for Ending Cash Balance for a 5 000ha producing WLS, WS, and WL with sheep as a premier economic activity without incentives.

WLS NI SF	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Mean	159 717.66	106 495.00	80 626.98	80 626.98	77 160.65	66 822.05	62 050.01	45 861.88	44 249.93	32 682.13	38 367.89	21 709.50	17 376.12	12 672.81	-1 870.59
StDev	79 215.31	50 117.99	31 365.17	31 365.17	28 594.25	24 471.13	22 465.33	16 050.28	14 745.31	10 171.06	10 928.09	5 861.63	4 616.31	3 316.86	489.35
CV	49.60	47.06	38.90	38.90	37.06	36.62	36.21	35.00	33.32	31.12	28.48	27.00	26.57	26.17	-26.16
Min	17 435.03	-8 432.44	-17 577.83	-17 577.83	-18 436.78	-16 100.38	-21 001.48	-19 366.23	-24 047.83	-27 929.13	-28 872.40	-32 367.38	-44 961.18	-42 139.61	-53 866.17
Max	355 411.75	241 883.43	210 083.50	210 083.50	205 929.39	190 167.29	147 234.06	126 848.13	147 594.64	123 202.45	126 090.70	97 995.99	86 828.83	82 867.39	68 370.79
P(NCI<0)	0	3	4	3	3	1	2	2	2	1	1	2	2	7	9

WS NI SF	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Mean	183 541.44	136 666.85	95 482.43	95 482.43	89 174.17	71 379.29	62 644.32	39 702.72	37 393.47	17 368.19	20 752.56	2 879.08	834.21	-6 282.56	-24 275.61
StDev	90 204.55	64 860.30	45 007.84	43 827.84	40 039.28	31 027.50	26 771.30	15 987.27	14 100.83	6 203.76	6 837.21	944.22	231.23	1 003.67	3 304.90
CV	49.15	47.46	47.14	45.90	44.90	43.47	42.74	40.27	37.71	35.72	32.95	32.80	27.72	-15.98	-13.61
Min	-2 079.99	6 127.66	-8 870.61	-8 870.61	-14 177.94	-24 504.23	-21 162.14	-27 438.31	-30 684.55	-50 101.75	-32 761.73	-64 238.72	-58 662.82	-59 439.11	-76 717.75
Max	420 544.06	312 440.89	235 377.44	235 377.44	217 287.33	186 529.99	149 385.13	102 118.32	132 846.50	93 532.89	102 509.29	69 076.20	56 592.87	52 713.93	38 276.81
P(NCI<0)	1	0	1	1	1	1	1	2	2	2	4	10	10	12	13

WL NI SF	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Mean	100 335.92	90 944.82	91 730.69	91 730.69	90 294.49	98 445.03	93 217.95	85 745.92	86 173.88	72 169.67	74 922.34	64 378.34	69 543.00	64 771.72	7 529.26
StDev	57 005.36	49 779.43	43 259.04	43 259.04	44 119.17	45 309.38	38 220.32	31 306.90	38 057.78	33 178.48	32 217.21	27 643.81	30 345.99	26 365.54	2 659.73
CV	56.81	54.74	47.16	47.16	48.86	46.03	41.00	36.51	44.16	45.97	43.00	42.94	43.64	40.71	35.33
Min	-10 158.42	-583.40	10 034.21	10 034.21	4 351.70	5 070.26	22 030.34	17 428.76	18 136.06	5 818.93	14 690.88	-6 659.48	5 217.14	9 894.98	-81 343.08
Max	244 100.05	232 627.53	226 879.19	226 879.19	183 581.41	216 299.55	182 138.01	169 254.27	169 883.05	175 067.06	181 548.89	132 308.79	145 679.35	137 950.59	27 566.16
P(NCI<0)	1.00	1.00	-	-	-	-	-	-	-	-	-	-	-	-	15.00

See Table 5.2 for a detailed explanation of acronyms.

Table B.2. Simulation Summary Statistics for Ending Cash Balance for a 5 000ha producing wool as a premier economic activity without incentives.

WLS NI SF	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Mean	213,379.59	224,729.01	219,487.66	205,712.80	185,827.49	158,642.33	136,029.75	115,462.63	103,555.29	91,232.54	87,185.71	79,902.70	79,902.70	66,221.18	65,929.72
StDev	32,619.32	48,358.92	53,578.99	52,633.31	47,658.55	42,253.12	39,959.54	32,566.25	28,795.56	30,492.07	31,779.14	31,215.48	31,215.48	24,252.96	16,013.62
CV	15.29	21.52	24.41	25.59	25.65	26.63	29.38	28.21	27.81	33.42	36.45	39.07	39.07	36.62	24.29
Min	118,136.19	61,362.55	55,515.23	37,172.61	18,512.28	34,938.11	28,437.48	17,442.74	31,721.05	5,249.23	1,490.35	3,487.87	3,487.87	9,899.06	29,398.25
Max	309,100.46	336,466.88	348,902.23	341,168.22	318,977.96	290,777.67	245,414.30	192,554.85	176,526.11	175,483.09	170,085.73	158,780.86	158,780.86	129,426.87	112,309.19
P(ECB<0)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

WS NI SF	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Mean	242,047.39	213,891.59	181,406.20	153,913.09	135,685.50	113,208.38	100,788.18	89,669.42	89,323.33	84,699.08	89,133.38	85,167.69	75,196.05	80,455.87	87,670.42
StDev	23,570.92	33,842.55	38,650.86	40,271.89	38,830.23	33,759.83	33,118.24	29,631.74	29,352.57	29,201.84	30,218.36	28,924.33	29,869.70	24,994.04	22,215.07
CV	9.74	15.82	21.31	26.17	28.62	29.82	32.86	33.05	32.86	34.48	33.90	33.96	39.72	31.07	25.34
Min	183,156.97	124,864.32	70,474.62	53,226.31	40,774.89	15,868.30	6,404.15	11,345.77	17,603.13	16,580.07	23,810.85	19,172.44	3,270.85	19,731.05	29,484.05
Max	314,190.71	314,561.54	303,618.14	268,750.57	254,472.95	232,243.98	219,045.96	185,620.05	193,398.96	190,603.19	168,030.83	170,325.61	151,975.38	137,447.79	146,709.53
P(ECB<0)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

WL NI SF	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Mean	261,670.33	232,448.79	200,289.51	175,192.61	162,940.33	141,166.09	130,430.60	119,077.02	118,171.30	111,397.96	114,119.61	108,835.79	108,835.79	83,417.01	109,183.98
StDev	33,603.21	45,752.31	49,147.84	49,085.45	47,326.27	42,040.36	40,185.14	34,475.86	32,526.99	32,614.96	32,441.76	31,251.28	31,251.28	27,695.84	29,092.77
CV	12.84	19.68	24.54	28.02	29.05	29.78	30.81	28.95	27.53	29.28	28.43	28.71	28.71	33.20	26.65
Min	178,807.44	128,895.03	84,636.29	55,063.56	42,048.93	34,630.56	27,538.33	27,110.10	39,326.71	25,291.58	32,706.98	33,815.24	33,815.24	12,829.14	42,491.31
Max	355,415.92	359,875.46	362,943.55	321,811.67	312,314.04	298,091.47	283,732.60	228,004.41	206,993.27	215,219.44	213,573.40	203,232.76	203,232.76	155,399.34	194,031.46
P(ECB<0)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

See Table 5.2 for a detailed explanation of acronyms.

Table B.3. Simulation Summary Statistics for Real Net Worth for a 5 000ha Farm in Graaff-Reinet, producing WLS, WS, and WL with sheep as a premier economic activity without incentives.

WLS NI SF	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Mean	65,929.72	66,221.18	79,902.70	79,902.70	87,185.71	91,232.54	103,555.29	115,462.63	136,029.75	158,642.33	185,827.49	205,712.80	219,487.66	224,729.01	213,379.59
StDev	16,013.62	24,252.96	31,215.48	31,215.48	31,779.14	30,492.07	28,795.56	32,566.25	39,959.54	42,253.12	47,658.55	52,633.31	53,578.99	48,358.92	32,619.32
CV	24.29	36.62	39.07	39.07	36.45	33.42	27.81	28.21	29.38	26.63	25.65	25.59	24.41	21.52	15.29
Min	29,398.25	9,899.06	3,487.87	3,487.87	1,490.35	5,249.23	31,721.05	17,442.74	28,437.48	34,938.11	18,512.28	37,172.61	55,515.23	61,362.55	118,136.19
Max	112,309.19	129,426.87	158,780.86	158,780.86	170,085.73	175,483.09	176,526.11	192,554.85	245,414.30	290,777.67	318,977.96	341,168.22	348,902.23	336,466.88	309,100.46
P(RNW<0)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

WS NI SF	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Mean	87,670.42	80,455.87	75,196.05	85,167.69	89,133.38	84,699.08	89,323.33	89,669.42	100,788.18	113,208.38	135,685.50	153,913.09	181,406.20	213,891.59	242,047.39
StDev	22,215.07	24,994.04	29,869.70	28,924.33	30,218.36	29,201.84	29,352.57	29,631.74	33,118.24	33,759.83	38,830.23	40,271.89	38,650.86	33,842.55	23,570.92
CV	25.34	31.07	39.72	33.96	33.90	34.48	32.86	33.05	32.86	29.82	28.62	26.17	21.31	15.82	9.74
Min	29,484.05	19,731.05	3,270.85	19,172.44	23,810.85	16,580.07	17,603.13	11,345.77	6,404.15	15,868.30	40,774.89	53,226.31	70,474.62	124,864.32	183,156.97
Max	146,709.53	137,447.79	151,975.38	170,325.61	168,030.83	190,603.19	193,398.96	185,620.05	219,045.96	232,243.98	254,472.95	268,750.57	303,618.14	314,561.54	314,190.71
P(RNW<0)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

WL NI SF	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Mean	109,183.98	83,417.01	108,835.79	108,835.79	114,119.61	111,397.96	118,171.30	119,077.02	130,430.60	141,166.09	162,940.33	175,192.61	200,289.51	232,448.79	261,670.33
StDev	29,092.77	27,695.84	31,251.28	31,251.28	32,441.76	32,614.96	32,526.99	34,475.86	40,185.14	42,040.36	47,326.27	49,085.45	49,147.84	45,752.31	33,603.21
CV	26.65	33.20	28.71	28.71	28.43	29.28	27.53	28.95	30.81	29.78	29.05	28.02	24.54	19.68	12.84
Min	42,491.31	12,829.14	33,815.24	33,815.24	32,706.98	25,291.58	39,326.71	27,110.10	27,538.33	34,630.56	42,048.93	55,063.56	84,636.29	128,895.03	178,807.44
Max	194,031.46	155,399.34	203,232.76	203,232.76	213,573.40	215,219.44	206,993.27	228,004.41	283,732.60	298,091.47	312,314.04	321,811.67	362,943.55	359,875.46	355,415.92
P(RNW<0)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

See Table 5.2 for a detailed explanation of acronyms.

Table B.4. Simulation Summary Statistics for Net Present Value for a 5 000ha producing WLS, WS, and WL with sheep as a premier economic activity without incentives.

Variable	WLS NI SF	WS NI SF	WL NI SF
Mean	-83,033.6	-23,700.7	137,193.4
StDev	36,015.3	10,754.5	45,093.1
CV	-43.4	-45.4	32.9
Min	-663,185.9	-587,230.6	-293,615.9
Max	341,867.3	411,163.5	518,301.7
P(NPV<0)	64.7%	51.0%	18.7%

See Table 5.2 for a detailed explanation of acronyms.

SIMULATION SUMMARY STATISTICS OF KEY OUTPUT VARIABLES FOR A 5 000ha SHEEP FARM PRODUCING WOOL AS A PREMIER ECOLOGICAL-ECONOMIC SYSTEM WITH INCENTIVES.

Table B.5. Simulation Summary Statistics for Net Cash Income for a 5 000ha Farm producing WLS, WS, and WL with sheep as a premier economic activity with incentives.

WLS YI SF	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Mean	156,342.55	134,536.28	129,650.57	56,964.32	55,629.48	63,701.08	64,450.38	59,731.06	61,775.07	55,082.61	55,758.72	50,318.13	53,572.78	52,221.56	52,053.23
StDev	58,821.50	44,579.43	42,371.50	20,371.50	18,047.69	21,837.17	22,645.42	20,889.77	19,278.07	18,299.69	18,299.69	14,569.19	12,923.74	10,706.53	10,585.56
CV	37.62	33.14	32.68	35.76	32.44	34.28	35.14	34.97	31.21	33.22	32.82	28.95	24.12	20.50	20.34
Min	82,266.87	101,463.78	52,928.76	52,928.76	46,689.54	38,257.72	28,220.82	17,854.19	21,915.58	17,656.30	17,656.30	21,759.14	17,281.03	10,332.29	10,981.23
Max	179,622.86	181,540.80	194,787.14	194,787.14	178,939.95	233,825.01	190,477.26	186,795.00	177,065.45	179,018.81	179,018.81	160,501.20	149,737.60	186,793.30	128,600.15
P(NCI<0)	0.4	0.1	1.2	1.6	2.4	2.8	3.2	1	1	1	1	1	2.6	8.4	12

WS YI SF	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Mean	214,461.52	173,239.85	150,963.05	156,080.41	152,347.65	135,916.41	133,690.22	114,855.61	113,121.88	98,883.17	102,167.86	87,188.94	84,121.34	81,686.81	72,419.89
StDev	90,669.02	70,492.22	61,490.33	55,770.30	51,526.08	44,055.21	43,247.11	36,067.38	33,908.00	31,834.05	32,098.32	26,710.56	26,142.90	24,445.53	22,294.43
CV	42.28	40.69	40.73	35.73	33.82	32.41	32.35	31.40	29.97	32.19	31.42	30.64	31.08	29.93	30.78
Min	25,314.72	9,539.93	13,221.81	41,352.92	39,046.51	23,630.76	36,393.62	33,186.86	35,461.37	17,828.46	28,099.85	12,633.78	18,700.23	23,433.26	19,862.80
Max	460,021.95	350,312.30	332,575.09	313,012.90	299,438.87	266,160.87	270,886.35	222,844.51	209,920.56	189,993.48	193,830.88	169,513.65	158,825.59	190,854.71	137,481.43
P(NCI<0)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

WL YI SF	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Mean	213,986.30	167,018.53	72,776.44	158,408.84	158,198.91	152,943.33	153,015.35	140,631.68	139,189.58	129,609.35	136,678.19	121,003.23	119,692.76	116,820.28	106,803.39
StDev	71,299.49	58,525.31	54,619.39	53,139.91	49,568.02	43,505.86	44,181.90	36,267.15	36,971.11	32,841.22	33,570.06	28,768.75	28,129.15	26,313.94	25,643.88
CV	33.32	35.04	75.05	33.55	31.33	28.45	28.87	25.79	26.56	25.34	24.56	23.78	23.50	22.53	24.01
Min	64,645.89	12,251.38	95,312.73	34,509.21	33,703.00	64,183.61	60,176.13	55,278.47	56,023.27	53,867.25	63,056.34	50,448.79	61,200.22	57,109.59	56,272.46
Max	405,723.89	311,966.03	221,352.44	304,637.35	293,693.25	262,710.31	289,952.04	246,158.15	234,798.05	223,745.59	248,544.77	213,762.64	198,500.76	194,178.66	182,726.48
P(NCI<0)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

See Table 5.2 for a detailed explanation of acronyms.

Table B.6. Simulation Summary Statistics for Ending Cash Balance for a 5 000ha Farm producing wool sheep as a premier economic activity with incentives.

WLS YI SF	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Mean	220,335.92	180,987.18	164,370.27	151,730.69	120,294.49	98,445.03	93,217.95	85,745.92	86,173.88	72,169.67	74,922.34	64,378.34	69,543.00	64,836.43	50,745.74
StDev	57,005.36	49,806.98	43,259.04	43,259.04	44,119.17	40,309.38	38,220.32	36,306.90	37,057.78	32,178.48	32,217.21	27,643.81	30,345.99	26,393.35	23,659.73
CV	25.87	27.52	26.32	28.51	36.68	40.95	41.00	42.34	43.00	44.59	43.00	42.94	43.64	40.71	46.62
Min	10,158.42	583.40	10,034.21	10,034.21	4,351.70	5,070.26	22,030.34	17,428.76	18,136.06	5,818.93	14,690.88	6,659.48	5,217.14	9,894.98	5,068.08
Max	244,100.05	232,627.53	226,879.19	226,879.19	183,581.41	216,299.55	182,138.01	169,254.27	169,883.05	175,067.06	181,548.89	132,308.79	145,679.35	137,950.59	103,841.16
P(ECB<0)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

WS YI SF	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Mean	264,756.62	219,639.95	179,304.71	181,431.03	176,447.50	159,867.98	152,248.01	130,329.34	128,958.56	109,794.26	113,968.53	96,819.72	93,771.27	88,997.57	71,499.39
StDev	90,204.55	73,898.87	56,670.20	55,007.84	51,839.28	45,027.50	39,771.30	29,987.27	37,159.83	30,203.76	31,837.21	27,444.22	26,831.23	24,649.75	23,304.90
CV	34.07	33.65	31.61	30.32	29.38	28.17	26.12	23.01	28.82	27.51	27.94	28.35	28.61	27.70	32.59
Min	79,135.18	89,058.40	69,534.82	77,077.99	73,095.39	63,984.46	68,441.55	63,188.31	60,880.54	42,324.33	60,454.24	29,701.92	35,942.66	35,776.31	19,057.25
Max	501,759.24	395,371.63	312,460.90	321,326.05	304,560.67	275,018.68	238,988.81	192,744.93	224,411.59	185,958.97	195,725.26	163,016.84	151,198.34	148,350.61	134,051.81
P(ECB<0)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

WL YI SF	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Mean	253,932.84	202,468.10	179,575.59	179,575.59	177,433.99	168,310.73	164,653.69	149,488.50	148,815.02	138,108.21	144,583.85	128,650.14	124,981.60	120,952.94	106,904.41
StDev	72,675.31	60,147.85	51,365.17	51,365.17	48,594.25	43,471.13	39,465.33	34,050.28	39,745.31	31,171.06	34,928.09	28,361.63	28,616.31	27,767.68	27,222.75
CV	28.62	29.71	28.60	28.60	27.39	25.83	23.97	22.78	26.71	22.57	24.16	22.05	22.90	22.96	25.46
Min	111,650.21	87,498.30	81,370.77	81,370.77	81,836.55	85,388.30	81,602.20	84,260.39	80,517.26	77,496.95	77,343.56	74,573.26	62,644.29	66,075.81	54,908.83
Max	449,626.93	337,814.17	309,032.10	309,032.10	306,202.73	291,655.98	249,837.74	230,474.75	252,159.73	228,628.53	232,306.67	204,936.63	194,434.31	191,504.08	177,145.79
P(ECB<0)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

See Table 5.2 for a detailed explanation of acronyms.

Table B.7. Simulation Summary Statistics for Real Net Worth for a 5 000ha Farm producing WLS, WS, and WL with sheep as a premier economic activity with incentives.

WLS YI SF	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Mean	1,122,194.64	936,363.10	931,290.31	909,114.21	914,641.74	917,178.97	888,025.14	888,300.61	841,953.74	856,632.13	704,211.18	675,033.60	649,294.60	570,783.40	482,029.32
StDev	142,704.66	152,128.25	164,089.82	146,431.39	187,916.28	181,017.39	192,025.40	163,343.38	196,556.93	196,399.65	244,746.47	265,018.79	239,044.93	241,238.27	224,026.65
CV	12.72	16.25	17.62	16.11	20.55	19.74	21.62	18.39	23.35	22.93	34.75	39.26	36.82	42.26	46.48
Min	785,956.09	668,393.24	576,074.41	491,788.93	573,923.59	499,197.78	479,086.79	548,684.23	400,410.22	394,224.19	193,199.77	151,969.30	173,392.91	71,011.09	6,304.60
Max	1,486,427.35	1,381,846.04	1,370,104.44	1,253,074.75	1,359,662.21	1,391,660.55	1,454,288.70	1,347,652.66	1,375,731.80	1,291,485.75	1,299,876.11	1,354,552.77	1,313,828.08	1,102,828.21	1,043,811.88
P(RNW<0)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

WS YI SF	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Mean	1,096,752.48	1,011,609.14	956,532.94	950,155.03	995,187.52	995,076.51	1,033,577.03	1,045,892.04	1,091,767.16	1,149,204.49	1,169,383.31	1,250,097.47	1,220,370.72	1,393,690.15	1,560,478.96
StDev	96,393.03	105,229.54	109,447.87	107,423.49	135,840.00	130,497.45	148,960.36	135,218.59	173,777.90	206,046.85	257,165.11	284,366.48	250,522.72	348,662.21	352,199.78
CV	8.79	10.40	11.44	11.31	13.65	13.11	14.41	12.93	15.92	17.93	21.99	22.75	20.53	25.02	22.57
Min	884,958.50	822,066.92	741,194.91	649,481.46	771,237.18	723,566.38	765,723.13	782,543.06	741,870.19	733,046.92	696,998.17	737,094.75	662,470.53	719,890.03	725,607.98
Max	1,324,935.13	1,249,004.18	1,224,426.20	1,187,049.00	1,352,476.43	1,306,095.25	1,416,302.10	1,454,077.55	1,530,080.38	1,716,795.23	1,917,917.06	2,055,992.62	1,883,186.42	2,244,223.16	2,527,984.50
P(RNW<0)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

WL YI SF	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Mean	1,122,194.64	936,363.10	931,290.31	909,114.21	914,641.74	917,178.97	888,025.14	888,300.61	841,953.74	856,632.13	704,211.18	675,033.60	649,294.60	570,783.40	482,029.32
StDev	142,704.66	152,128.25	164,089.82	146,431.39	187,916.28	181,017.39	192,025.40	163,343.38	196,556.93	196,399.65	244,746.47	265,018.79	239,044.93	241,238.27	224,026.65
CV	12.72	16.25	17.62	16.11	20.55	19.74	21.62	18.39	23.35	22.93	34.75	39.26	36.82	42.26	46.48
Min	785,956.09	668,393.24	576,074.41	491,788.93	573,923.59	499,197.78	479,086.79	548,684.23	400,410.22	394,224.19	193,199.77	151,969.30	173,392.91	71,011.09	-6,304.60
Max	1,486,427.35	1,381,846.04	1,370,104.44	1,253,074.75	1,359,662.21	1,391,660.55	1,454,288.70	1,347,652.66	1,375,731.80	1,291,485.75	1,299,876.11	1,354,552.77	1,313,828.08	1,102,828.21	1,043,811.88
P(RNW<0)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

See Table 5.2 for a detailed explanation of acronyms.

Table B.8. Simulation Summary Statistics for Net Present Value for a 5 000ha Farm producing WLS, WS, and WL with sheep as a premier economic activity with incentives.

Variable	WLS YISF	WS YI SF	WL YI SF
Mean	-101,615.28	63,312.81	136,965.68
StDev	39,244.59	23,155.02	37,249.24
CV	-38.62	36.57	27.20
Min	-609,072.23	-508,725.25	-295,855.62
Max	414, 056.62	527, 227.87	635, 025.03
P(NPV<0)	70%	31.9%	17.5%

See Table 5.2 for a detailed explanation of acronyms.

SIMULATION SUMMARY STATISTICS OF KEY OUTPUT VARIABLES FOR A 5 000ha FARM PRODUCING VENISON AS A PREMIER ECOLOGICAL-ECONOMIC SYSTEM WITHOUT INCENTIVES.

Table B.9. Simulation Summary Statistics for Net Cash Income for a 5 000ha Farm producing SLW, SW, and SL with springbuck ranching as a premier economic activity without incentives.

SLW NI SR	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Mean	154876.13	163064.41	165474.73	168607.74	194861.47	175030.91	198334.06	192932.44	225034.63	218264.86	256517.32	250781.50	325354.28	284349.76	361959.98
StDev	36501.96	39737.18	43101.68	45654.78	56004.44	55006.80	61923.15	66668.49	82188.73	82565.78	94525.51	103944.64	131425.66	133633.28	171589.81
CV	23.57	24.37	26.05	27.08	28.74	31.43	31.22	34.56	36.52	37.83	36.85	41.45	40.39	41.00	40.01
Min	77016.15	74837.03	68886.51	41319.76	67802.32	16746.87	52253.88	53407.12	38440.36	24749.63	47218.96	32456.23	19428.55	(20829.60)	(7967.42)
Max	258307.51	315642.14	295467.91	294390.04	360913.74	341346.73	366944.25	394440.33	473329.28	491127.15	536261.86	583255.52	744642.16	624570.88	848454.09
P(NCI<0)	0	0	0	0	0	0	0	0	0	0	0	0	0	0.04	0.02

SW NI SR	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Mean	144125.27	151021.22	151245.37	150587.90	166765.78	151254.08	165266.88	158944.01	178456.16	170808.76	189222.66	181814.54	206914.40	192027.56	241805.62
StDev	32302.57	35434.93	38177.72	39341.69	47731.81	48010.10	51929.97	56430.11	67855.63	69536.57	79240.13	87017.93	105981.83	112965.09	142927.92
CV	22.41	23.46	25.24	26.13	28.62	31.74	31.42	32.50	32.02	32.71	32.88	33.86	34.22	34.83	35.11
Min	74689.92	66530.49	58612.40	37622.08	53674.42	6837.54	40881.18	29317.97	20105.09	11720.25	9581.88	(3071.48)	(4422.78)	(64925.35)	(69063.06)
Max	238181.17	299018.30	271964.64	267542.19	311683.25	284797.23	314061.30	328496.11	381973.55	395350.53	417171.17	460497.75	547528.27	487266.01	638642.81
P(NCI<0)	0	0	0	0	0	0	0	0	0	0	0	0.01	0.02	3	2.4

SL NI SR	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Mean	117226.54	121326.96	116633.38	111715.34	119236.39	100570.27	97142.99	89898.36	87778.98	74744.24	61931.25	44652.14	76360.64	24176.17	39092.39
StDev	35004.28	36921.31	39181.65	39944.32	46429.68	47160.17	53691.91	53909.87	64232.74	64808.41	73352.61	80187.45	87726.57	89620.03	97405.73
CV	29.86	30.43	33.59	35.76	38.94	36.89	35.27	35.97	35.18	36.71	36.44	37.58	37.88	37.70	29.17
Min	40557.44	44789.80	36681.10	14618.16	17258.45	(6805.44)	(42261.24)	(34764.52)	(66083.92)	(82757.02)	(114450.31)	(165510.67)	(123046.05)	(256984.93)	(189438.81)
Max	214404.77	229655.47	251328.97	226670.42	266115.51	232725.55	229056.47	248592.38	256667.19	259259.83	248912.37	280227.93	345843.19	251846.64	315677.54
P(NCI<0)	0	0	0	0	0	0.6	2	3.4	7	12.4	20.6	32.6	20.4	40.7	36.7

See Table 5.2 for a detailed explanation of acronyms.

Table B.10. Simulation Summary Statistics for Ending Cash Balance for a 5 000ha Farm in Graaff-Reinet, producing SLW, SW, and SL with springbuck ranching as a premier economic activity without incentives.

SLW NI SR	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Mean	279168.42	383380.69	497128.39	621312.38	776730.41	923531.52	1099236.53	1278316.58	1489749.01	1707240.79	1962333.02	2224159.94	2553032.19	2858723.52	3223434.61
StDev	33338.89	54282.54	69461.68	85454.60	104469.10	115040.59	128353.35	142193.80	156793.80	168464.94	178456.20	196176.03	217730.32	236197.40	267915.53
CV	11.94	14.16	13.97	13.75	13.45	12.46	11.68	11.12	10.52	9.87	9.09	8.82	8.53	8.26	8.31
Min	207788.78	255441.40	316000.66	401759.85	476267.20	575296.72	769224.99	872635.27	1030673.62	1276433.21	1492403.48	1701379.56	1996159.02	2142564.63	2400580.25
Max	373194.21	550113.72	713647.98	843601.86	1141995.72	1263916.99	1498202.98	1697175.40	2074915.00	2416664.37	2773220.26	2923396.96	3279503.00	3748240.29	4203995.42
P(ECB<0)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

SW NI SR	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Mean	275678.46	374311.70	477987.98	585285.15	711390.93	828046.30	961760.19	1092052.94	1243508.42	1389961.37	1555646.12	1714454.03	1892451.05	2059944.53	2271223.30
StDev	29950.03	48949.89	62122.20	75725.09	90003.75	97629.77	108272.46	119701.99	135147.79	143674.33	154122.16	174071.77	200764.46	230396.20	281465.13
CV	10.86	13.08	13.00	12.94	12.65	11.79	11.26	10.96	10.87	10.34	9.91	10.15	10.61	11.18	12.39
Min	209748.55	248101.87	321765.90	388564.91	432485.72	553084.89	707001.82	783546.34	864538.17	1028757.70	1164635.75	1261941.86	1423651.11	1432395.89	1440420.47
Max	361873.63	517822.36	664133.50	790939.41	1028836.52	1108221.76	1296522.12	1469898.16	1750869.61	1972458.47	2191694.24	2243264.74	2508888.58	2746162.88	3190534.28
P(ECB<0)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

SL NI SR	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Mean	262631.45	329749.36	392490.87	450558.50	516313.76	563486.81	607228.35	643626.76	677706.44	698443.85	705944.61	695617.75	716316.47	684002.97	665621.72
StDev	35004.28	54572.79	69334.57	82714.26	95039.26	100152.38	113214.77	125780.34	139382.10	151016.38	159352.64	176403.53	192864.66	211703.73	234010.46
CV	13.33	16.55	17.67	18.36	18.41	17.77	18.64	19.54	20.57	21.62	22.57	25.36	26.92	30.95	31.16
Min	185962.36	208610.66	227353.76	236412.43	267186.14	281893.02	304328.06	288809.36	312244.89	326344.98	244445.43	148879.50	243289.91	125785.07	39457.05
Max	359809.69	499378.48	607278.77	701694.78	828497.36	921470.33	1049588.42	1025092.71	1154218.11	1203530.33	1216068.32	1160906.59	1304802.75	1291322.93	1429292.70
P(ECB<0)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

See Table 5.2 for a detailed explanation of acronyms.

Table B.11. Simulation Summary Statistics for Real Net Worth for a 5 000ha Farm producing SLW, SW, and SL with springbuck ranching as a premier economic activity without incentives.

SLW NI SR	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Mean	1010077.68	1078047.09	1154358.21	1224960.30	1344410.23	1379686.57	1483556.78	1543624.73	1666322.43	1734795.10	1864768.98	1949665.76	2319891.42	2391554.66	2597771.66
StDev	88727.75	104150.78	114116.11	127620.40	156683.23	157056.28	177375.87	191277.86	222060.21	226705.28	250831.57	269274.78	355926.56	338259.60	400016.56
CV	8.78	9.66	9.89	10.42	11.65	11.38	11.96	12.39	13.33	13.07	13.45	13.81	15.34	14.14	15.40
Min	819514.67	843969.33	886461.58	833959.82	897019.33	973014.74	1032074.48	1114878.13	1013640.03	1161075.55	1279097.13	1360699.43	1431148.09	1510682.11	1657753.42
Max	1280098.87	1433432.64	1447195.26	1605273.08	1904375.64	1934279.52	2033352.60	2219936.23	2485252.23	2517141.52	2634564.72	2898552.70	3543508.16	3419730.74	3824864.16
P(RNW<0)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

SW NI SR	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Mean	1043433.82	1072478.88	1102050.98	1120807.13	1169145.21	1154989.64	1177961.51	1165876.16	1189407.21	1171413.63	1166265.59	1146462.08	1164966.18	1131004.50	1209788.71
StDev	85687.87	99155.44	107448.59	114810.51	135274.65	138738.96	156587.02	165974.22	192627.07	199061.68	224302.53	233867.67	256676.46	247762.73	293453.10
CV	8.21	9.25	9.75	10.24	11.57	12.01	13.29	14.24	16.20	16.99	19.23	20.40	22.03	21.91	24.26
Min	825471.13	855879.77	822179.28	785806.88	808688.44	814559.55	809174.27	787290.13	742164.74	702537.92	628243.96	646191.00	566554.73	573226.15	530414.54
Max	1320069.83	1450855.33	1400143.01	1473300.87	1598912.55	1607497.11	1683775.42	1730062.40	1908097.29	1831106.43	1832665.74	1947369.89	2089080.32	1775966.47	2066148.37
P(RNW<0)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

SL NI SR	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Mean	1073617.42	1095542.96	1111464.33	1114928.12	1146217.62	1105891.72	1082840.93	1053583.99	1027083.26	989187.39	921519.51	886007.95	896849.55	859015.66	929198.32
StDev	110237.02	123588.04	134873.42	142388.58	161022.48	164814.70	189027.78	191239.12	212101.53	210724.52	225616.47	227733.73	226122.76	211372.69	227261.30
CV	10.27	11.28	12.13	12.77	14.05	14.90	17.46	18.15	20.65	21.30	24.48	25.70	25.21	24.61	24.46
Min	834520.18	829218.98	746323.69	796304.58	753027.86	714396.31	560521.08	540123.82	548854.63	484724.34	401613.30	399726.70	407837.20	323922.66	434054.05
Max	1424282.68	1500066.37	1530869.44	1539987.37	1679085.95	1699743.99	1717294.65	1678101.35	1754909.62	1657514.43	1552657.10	1620514.69	1593898.42	1391880.87	1554547.56
P(RNW<0)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

See Table 5.2 for a detailed explanation of acronyms.

Table B.12. Simulation Summary Statistics for Net Present Value for a 5 000ha Farm producing SLW, SW, and SL with springbuck ranching as a premier economic activity without incentives.

Variable	SLW NI SR	WS NI SR	SL NI SR
Mean	504521.3618	489096.867	436439.7483
StDev	140193.5641	133984.5959	142834.1228
CV	27.78743869	27.39428626	32.72711144
Min	38933.8142	75490.24329	-33957.1889
Max	1011218.359	996407.5416	945813.8975
P(NPV<0)	0%	0%	3%

See Table 5.2 for a detailed explanation of acronyms.

SIMULATION SUMMARY STATISTICS OF KEY OUTPUT VARIABLES FOR A 5 000ha FARM PRODUCING VENISON AS A PREMIER ECOLOGICAL-ECONOMIC SYSTEM WITH INCENTIVES.

Table B.13. Simulation Summary Statistics for Net cash Income for a 5 000ha Farm producing SLW, SW, and SL with springbuck ranching as a premier economic activity with incentives.

SLW YI SR	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Mean	200662.19	158767.30	159554.88	159142.34	185162.51	164371.92	180957.70	176618.67	203676.19	199958.87	225856.33	213504.00	287220.82	243818.84	315076.22
StDev	37994.49	39079.57	44556.59	48854.01	56938.24	55785.18	63254.75	66713.79	80017.13	81437.06	100878.94	102751.59	138335.39	137697.81	165153.76
CV	18.93	24.61	27.93	30.70	30.75	33.94	34.96	37.77	39.29	40.73	44.67	48.13	48.16	56.48	52.42
Min	122776.55	41729.39	57697.77	29389.51	70501.64	22812.82	31863.26	5154.97	32990.42	-7666.86	11310.83	-18956.59	-33717.40	-93285.18	-82353.16
Max	312737.94	265896.69	281819.23	284295.65	349372.77	321359.28	373852.37	396056.15	429565.17	435018.24	543217.25	555564.33	677747.53	659672.44	740252.84
P(NCI<0)	0	0	0	0	0	0	0	0	0	0.2	0	1	0.6	2.4	1.2

SW YI SR	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Mean	176884.69	178814.78	177712.00	173543.78	189308.93	172984.55	180237.73	175214.66	189606.33	184842.21	191100.87	177677.02	201725.40	184059.04	227361.76
StDev	33388.75	34422.36	39864.72	42983.21	47542.48	48618.82	53556.08	56509.07	67783.47	69121.16	84506.84	86618.03	112449.50	117206.01	138990.89
CV	18.88	19.25	22.43	24.77	25.11	28.11	29.71	32.25	35.75	37.39	44.22	48.75	55.74	63.68	61.13
Min	100350.52	67042.04	84613.94	50994.39	93282.10	45254.28	53077.69	9116.88	40073.14	-9782.46	13690.25	-31315.50	-72793.33	-112164.30	-108706.14
Max	264399.90	276258.82	288204.87	287945.70	344430.75	317168.77	354304.94	363494.94	378099.46	376836.44	450986.58	462995.62	510478.77	537737.62	577688.80
P(NCI<0)	0	0	0	0	0	0	0	0	0	0	0.1	1.2	2.6	5	2.8

SL YI SR	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Mean	163136.76	162896.20	155455.40	147493.91	153429.92	132684.07	126675.91	114614.28	110891.72	96344.12	82618.21	60529.73	86483.07	28883.53	39926.18
StDev	35657.51	36198.57	37632.01	41081.66	46503.02	46336.15	52434.94	55287.41	64513.74	68448.12	77836.45	77649.96	94340.95	97032.81	97897.04
CV	21.86	22.22	24.21	27.85	30.31	34.92	41.39	48.24	58.18	71.05	94.21	128.28	109.09	335.95	245.20
Min	93991.79	80294.17	73803.38	54105.57	59535.76	3143.15	6528.66	-17601.88	-39409.87	-70893.76	-111195.50	-173583.62	-151051.47	-227157.86	-191493.31
Max	260648.12	252607.60	267303.25	264880.21	288551.20	259916.16	262695.74	288191.37	293257.78	267914.16	278337.75	294942.25	319839.52	297428.97	313173.89
P(NCI<0)	0	0	0	0	0	0	0	0.6	1.8	8.4	16	22.6	17.8	39	35.8

See Table 5.2 for a detailed explanation of acronyms.

Table B.14. Simulation Summary Statistics for Ending Cash Balance for a 5 000ha Farm producing SLW, SW, and SL with springbuck ranching as a premier economic activity with incentives.

SLW YI SR	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Mean	279168.42	383380.69	497128.39	621312.38	776730.41	923531.52	1099236.53	1278316.58	1489749.01	1707240.79	1962333.02	2224159.94	2553032.19	2858723.52	3223434.61
StDev	33338.89	54282.54	69461.68	85454.60	104469.10	115040.59	128353.35	142193.80	156793.80	168464.94	178456.20	196176.03	217730.32	236197.40	267915.53
CV	11.94	14.16	13.97	13.75	13.45	12.46	11.68	11.12	10.52	9.87	9.09	8.82	8.53	8.26	8.31
Min	207788.78	255441.40	316000.66	401759.85	476267.20	575296.72	769224.99	872635.27	1030673.62	1276433.21	1492403.48	1701379.56	1996159.02	2142564.63	2400580.25
Max	373194.21	550113.72	713647.98	843601.86	1141995.72	1263916.99	1498202.98	1697175.40	2074915.00	2416664.37	2773220.26	2923396.96	3279503.00	3748240.29	4203995.42
P(ECB<0)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

SW YI SR	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Mean	275678.46	374311.70	477987.98	585285.15	711390.93	828046.30	961760.19	1092052.94	1243508.42	1389961.37	1555646.12	1714454.03	1892451.05	2059944.53	2271223.30
StDev	29950.03	48949.89	62122.20	75725.09	90003.75	97629.77	108272.46	119701.99	135147.79	143674.33	154122.16	174071.77	200764.46	230396.20	281465.13
CV	10.86	13.08	13.00	12.94	12.65	11.79	11.26	10.96	10.87	10.34	9.91	10.15	10.61	11.18	12.39
Min	209748.55	248101.87	321765.90	388564.91	432485.72	553084.89	707001.82	783546.34	864538.17	1028757.70	1164635.75	1261941.86	1423651.11	1432395.89	1440420.47
Max	361873.63	517822.36	664133.50	790939.41	1028836.52	1108221.76	1296522.12	1469898.16	1750869.61	1972458.47	2191694.24	2243264.74	2508888.58	2746162.88	3190534.28
P(ECB<0)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

SL YI SR	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Mean	262631.45	329749.36	392490.87	450558.50	516313.76	563486.81	607228.35	643626.76	677706.44	698443.85	705944.61	695617.75	716316.47	684002.97	665621.72
StDev	35004.28	54572.79	69334.57	82714.26	95039.26	100152.38	113214.77	125780.34	139382.10	151016.38	159352.64	176403.53	192864.66	211703.73	234010.46
CV	13.33	16.55	17.67	18.36	18.41	17.77	18.64	19.54	20.57	21.62	22.57	25.36	26.92	30.95	31.16
Min	185962.36	208610.66	227353.76	236412.43	267186.14	281893.02	304328.06	288809.36	312244.89	326344.98	244445.43	148879.50	243289.91	125785.07	39457.05
Max	359809.69	499378.48	607278.77	701694.78	828497.36	921470.33	1049588.42	1025092.71	1154218.11	1203530.33	1216068.32	1160906.59	1304802.75	1291322.93	1429292.70
P(ECB<0)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

See Table 5.2 for a detailed explanation of acronyms.

Table B.15. Simulation Summary Statistics for Real Net Worth for a 5 000ha Farm in Graaff-Reinet, producing SLW, SW, and SL with springbuck ranching as a premier economic activity with incentives.

SLW YI SR	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Mean	1010077.68	1078047.09	1154358.21	1224960.30	1344410.23	1379686.57	1483556.78	1543624.73	1666322.43	1734795.10	1864768.98	1949665.76	2319891.42	2391554.66	2597771.66
StDev	88727.75	104150.78	114116.11	127620.40	156683.23	157056.28	177375.87	191277.86	222060.21	226705.28	250831.57	269274.78	355926.56	338259.60	400016.56
CV	8.78	9.66	9.89	10.42	11.65	11.38	11.96	12.39	13.33	13.07	13.45	13.81	15.34	14.14	15.40
Min	819514.67	843969.33	886461.58	833959.82	897019.33	973014.74	1032074.48	1114878.13	1013640.03	1161075.55	1279097.13	1360699.43	1431148.09	1510682.11	1657753.42
Max	1280098.87	1433432.64	1447195.26	1605273.08	1904375.64	1934279.52	2033352.60	2219936.23	2485252.23	2517141.52	2634564.72	2898552.70	3543508.16	3419730.74	3824864.16
P(RNW<0)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

SW YI SR	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Mean	1043433.82	1072478.88	1102050.98	1120807.13	1169145.21	1154989.64	1177961.51	1165876.16	1189407.21	1171413.63	1166265.59	1146462.08	1164966.18	1131004.50	1209788.71
StDev	85687.87	99155.44	107448.59	114810.51	135274.65	138738.96	156587.02	165974.22	192627.07	199061.68	224302.53	233867.67	256676.46	247762.73	293453.10
CV	8.21	9.25	9.75	10.24	11.57	12.01	13.29	14.24	16.20	16.99	19.23	20.40	22.03	21.91	24.26
Min	825471.13	855879.77	822179.28	785806.88	808688.44	814559.55	809174.27	787290.13	742164.74	702537.92	628243.96	646191.00	566554.73	573226.15	530414.54
Max	1320069.83	1450855.33	1400143.01	1473300.87	1598912.55	1607497.11	1683775.42	1730062.40	1908097.29	1831106.43	1832665.74	1947369.89	2089080.32	1775966.47	2066148.37
P(RNW<0)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

SL YI SR	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Mean	1073617.42	1095542.96	1111464.33	1114928.12	1146217.62	1105891.72	1082840.93	1053583.99	1027083.26	989187.39	921519.51	886007.95	896849.55	859015.66	929198.32
StDev	110237.02	123588.04	134873.42	142388.58	161022.48	164814.70	189027.78	191239.12	212101.53	210724.52	225616.47	227733.73	226122.76	211372.69	227261.30
CV	10.27	11.28	12.13	12.77	14.05	14.90	17.46	18.15	20.65	21.30	24.48	25.70	25.21	24.61	24.46
Min	834520.18	829218.98	746323.69	796304.58	753027.86	714396.31	560521.08	540123.82	548854.63	484724.34	401613.30	399726.70	407837.20	323922.66	434054.05
Max	1424282.68	1500066.37	1530869.44	1539987.37	1679085.95	1699743.99	1717294.65	1678101.35	1754909.62	1657514.43	1552657.10	1620514.69	1593898.42	1391880.87	1554547.56
P(RNW<0)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

See Table 5.2 for a detailed explanation of acronyms.

Table B.16. Simulation Summary Statistics for Net Present Value for a 5 000ha Farm producing SLW, SW, and SL with springbuck ranching as a premier economic activity with incentives.

Variable	SLW YI SR	WS YI SR	SL YI SR
Mean	1262367.487	1143492.556	705729.6968
StDev	163771.6341	153784.4082	155469.0901
CV	12.97	13.45	22.03
Min	839157.8752	694705.3512	219447.3002
Max	1781526.083	1650788.741	1245475.762
P(NPV<0)	0	0	0

See Table 5.2 for a detailed explanation of acronyms.