A system dynamics approach to understanding the ostrich industry of South Africa

by

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Date: March 2016

Abstract

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Although the livestock production sector is recognised as an essential contributor to the green economy in South Africa, there is a lack of simulation tool development for the green economy transition of livestock production. The ostrich production industry, mainly exporting leather and meat, is a significant part of livestock production of South Africa. In terms of the global ostrich product market, the ostrich industry of South Africa accounts for approximately 70% of the total supply. Ostrich leather is positioned as an exclusive luxury item, while meat is positioned as an every-day alternative to red meat in their respective markets. A strong relationship exists between previous market supply of ostrich leather and current income from leather, while the ostrich meat income is considered to be largely unaffected by market supply of ostrich meat. The meat market has the potential to absorb more than tenfold the current market supply of meat. This study contributed the only systems thinking analysis of the ostrich production industry in South Africa, known to the author. The analysis in the form of a system dynamics model, proposed a causal loop diagram, as well as a stock and flow diagram that represented the structure of the ostrich production industry of South Africa. The livestock model proposed was set within a different socio-economic environment, as well as a different type of commodity market, to that of the well-known hog cycle proposed by Meadows (1970).

The model, known as the Ostrich Industry Model of South Africa (OIMSA), assumed that ostrich producers base their decision in terms of future production amounts on the gross profit margin per ostrich, mainly influenced by income from leather, income from meat, as well as the production cost. The model forecasted future production size and income received from each commodity, in addition to replicating historical behaviour. Results from an extensive scenario and policy analysis indicated that the only influence that can cause a sustainable increase in the ostrich industry size is the market size of ostrich leather. Scenarios including disturbances is exchange rates, changes in market demands, changes in product values, food safety concerns, fluctuations in production cost as well as changes in economic climate are also investigated.

Recommendations regarding the green economy transition of the South African ostrich industry include fixing the long term industry focus on ostrich leather, as well as the development of additional ostrich leather demand. Additionally, new entrant black farmers should be included into the industry at a rate corresponding to the growth in leather demand. The highly contentious subject of a mandatory transition to a small camp breeding system is shown to be sustainable, yet highly unpopular. The two potential policies, carbon tax per ostrich produced, and water tax on irrigated crops used for ostrich feed, will have the exact same effect of ostrich production, and is therefore not recommended to implement the two types of taxes simultaneously.

Uittreksel

'n Stelsel dinamiese benadering tot die begrip van die Suid-Afrikaanse volstruis bedryf

("A system dynamics approach to understanding the ostrich industry of South Africa")

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Hoewel die vee produksie sektor erken word as 'n noodsaaklike bydrae tot die groen ekonomie in Suid-Afrika, is daar 'n gebrek aan simulasie hulpmiddel ontwikkeling om die groen ekonomie oorgang, in terme van vee produksie, te bestudeer. Die volstruis bedryf, hoofsaaklik uitgemaak deur die uitvoer van leer en vleis, is 'n belangrike deel van vee produksie in Suid-Afrika. Die volstruis bedryf van Suid-Afrika is verantwoordelik vir ongeveer 70% van die wêreldwye volstruis produk aanbod. Volstruis leer is geposisioneer as 'n eksklusiewe en luukse item, terwyl volstruis vleis geposisioneer is as 'n daaglikse verbruiker alternatief tot rooivleis in hul onderskeie internasionale markte. 'n Sterk verhouding bestaan tussen vorige mark aanbod van leer en die huidige inkomste uit leer, terwyl vleis inkomste grootliks onaangeraak is deur mark aanbod van vleis. Die vleis mark het die potensiaal om meer as tien keer die huidige aanbod te absorbeer. Hierdie studie stel die enigste stelsels dink ontleding van die volstruis bedryf, wat bekend is aan die skrywer, voor. Die ontleding, in die vorm van 'n stelsel dinamiese model, stel 'n oorsaaklike lus diagram, sowel as 'n voorraad en vloei diagram voor om die struktuur van die volstruis bedryf in Suid-Afrika te verteenwoordig. Die vee model wat voorgestel word, word bevind in 'n ander sosio-ekonomiese omgewing, sowel as 'n ander tipe kommoditeit mark, as die wat deur Meadows (1970) se bekende vark siklus voorgestel word.

Die model, genoem die *Ostrich Industry Model of South Africa* (OIMSA), veronderstel dat volstruis produsente hulle besluit oor toekomstige produksie baseer op die bruto winsmarge per volstruis. Die bruto winsmarge word hoofsaaklik beïnvloed deur inkomste uit leer, inkomste uit vleis, asook die produksiekoste. Die model herhaal historiese gedrag in van die volstruis bedryf en voorspel toekomstige produksie grootte en inkomste ontvang uit elke kommoditeit. Die model, in 'n toestand van ewewig, ondergaan ook uitgebreide scenario en beleid analise. Resultate van 'n uitgebreide scenario en beleid analise dui aan dat die enigste invloed wat 'n volhoubare toename in die volstruis bedryf grootte kan veroorsaak word, is die mark aanvraag grootte van volstruis leer. Scenario's insluitend versteurings in wisselkoerse, veranderinge in die mark aanvraag, veranderinge in die produk waardes, voedselveiligheid kommer, veranderinge in produksiekoste sowel as 'n verandering in ekonomiese klimaat was ook ondersoek.

Aanbevelings ten opsigte van die groen ekonomie oorgang van die Suid-Afrikaanse volstruis bedryf sluit die vasstelling van die langtermyn industrie fokus op volstruis leer, sowel as die ontwikkeling van bykomende volstruis leer aanvraag in. Daarbenewens moet nuwe toetreder swart boere by die bedryf ingesluit word teen 'n koers wat ooreenstem met die groei in leer aanvraag. Die hoogs omstrede onderwerp van 'n verpligte oorgang na 'n klein kamp stelsel is bewys as volhoubaar, tog baie ongewild. Dit word nie aanbeveel om die twee potensiële beleide, koolstof belasting per volstruis geproduseer, en water belasting op besproeide gewasse gebruik word vir volstruis voer, gelyktydig te implementeer nie, aangesien die twee tipes belastings presies dieselfde uitwerking op die volstruis bedryf sal hê.

Dedications

This thesis is dedicated to Julie Duminy

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Nomenclature

Acronyms

BSE Bovine Spongiform Encephalopathy
CLD Causal Loop Diagram
DEA Department of Environmental Affairs
EU European Union
FMD Foot and Mouth Disease
OIMSA Ostrich Industry Model of South Africa
SAGEM South African Green Economy Model
SDF Stock and Flow Diagram
UNEP United Nations Environment Program
USA United States of America

Model sectors

Primary Production Ostrich production sector of OIMSA
Leather Income Leather income sector of OIMSA
Meat Income Meat income sector of OIMSA
Producer Cost Production cost sector of OIMSA

Stocks

$\mathrm{BMP}(t)$	Baseline Producer Meat Price per Ostrich in Euro	[Euro/ostrich]
$\mathrm{BO}(t)$	Breeding Ostriches	[ostrich]
$\mathrm{LP}(t)$	Producer Leather Price per Ostrich in Dollar	[Dollar/ostrich]
$\mathrm{MO}(t)$	Mature Ostriches	[ostrich]
$\mathrm{MP}(t)$	Producer Meat Price per Ostrich in Euro	[Euro/ostrich]

Flows

r_{BR}	Breeding Rate	[ostrich/year]
r_{BOAR}	Breeding Ostriches Acquisition Rate	[ostrich/year]
r_{BSOR}	Breeding Ostriches Slaughter Rate	[ostrich/year]

r_{CBMP} Change in Baseline Producer Meat Price per Ostrich . . . [Euro/(ostrich ∗ year)]
r_{CLP} Change in Producer Leather Price per Ostrich . . . . [Dollar/(ostrich ∗ year)]
r_{CMP} Change in Producer Meat Price per Ostrich . . . . [Euro/(ostrich ∗ year)]
r_{OSR} Ostrich Slaughter Rate . . . . [ostrich/year]

Reference mode parameters

a_{OSR} Reference Mode Ostrich Slaughter Rate . . . . [ostrich/year]
a_{VL} Reference Mode Gross Producer Value of Leather in SA . . [Rand/year]
a_{VM} Reference Mode Gross Producer Value of Meat in SA . . . [Rand/year]

Equilibrium parameters

c_{DPR} Desired Production Rate . . . . [ostrich/year]
c_{LF} Leather Income Fraction . . . . [unitless]

Exogenous variables

$h_{\text{HICP}}(t)$ European HICP . . . . [unitless]
$h_{\text{RD}}(t)$ Rand Dollar Exchange Rate . . . . [Rand/Dollar]
$h_{\text{RE}}(t)$ Rand Euro Exchange Rate . . . . [Rand/Euro]

PRIMARY PRODUCTION sector parameter assumptions

c_{ABP} Average Breeding Period . . . . [year]
c_{BS} Breeding Seasons per Year . . . . [season/year]
c_{CSF} Net Chick Survival Fraction . . . . [ostrich/chick]
c_{D} Constant Multiplication Factor for Desirability . . . . [ostrich]
c_{EH} Eggs per Hen per Breeding Season . . . . [egg/(hen ∗ season)]
c_{FBS} Fraction of Females in Breeding Stock . . . . [hen/ostrich]
c_{HF} Hatch Fraction . . . . [chick/egg]
c_{MRTT} Minimum Breeding Ostriches Reduction Transfer Time . . [year]
c_{MOFP} Mature Ostrich Feeding Period . . . . [year]
c_{MT} Maturation Time . . . . [year]
c_{TH} Time to Hatch . . . . [year]

PRIMARY PRODUCTION sector endogenous variables

k_{CR} Culling Rate . . . . [ostrich/year]
k_{DBO} Desired Breeding Ostriches . . . . [ostrich]
k_{DBOAR} Desired Breeding Ostriches Acquisition Rate . . . . [ostrich/year]
k_{GPM} Producer Gross Profit Margin per Ostrich . . . . [unitless]

k_{MEB}	Presence of Meat Export Ban from Bird Flu	[unitless]
k_{MATT}	Minimum Breeding Ostriches Acquisition Transfer Time	[year]
k_{ID}	Industry Desirability	[unitless]
k_{PI}	Total Producer Income per Ostrich	[Rand/ostrich]
k_{R}	Culmination of Ostrich Farming Reluctances	[unitless]
k_{RBF}	Reluctance to Farm Ostriches due to Bird Flu Epedemic	[unitless]
k_{RD}	Reluctance to Enter Market after Deregulation	[unitless]
k_{REH}	Rate of Eggs Hatching	[chick/year]
k_{REP}	Rate of Egg Production	[egg/year]
k_{RER}	Reluctance to Farm due to Economic Recession	[unitless]
k_{yield}	Ostrich Yield per Breeding Ostrich per Year	[/year]

Leather Income sector parameter assumptions

c_{BLD}	Baseline Leather Market Demand	[ostrich/year]
c_{FVL}	Floor Value for Leather Price Adjustment	[Dollar/ostrich]
c_{LPAT}	Leather Prive Adjustment Time	[year]
c_{MLAT}	Minimum Leather Value Adjustment Time	[year]
c_{MVL}	Minimum Value of Leather	[Dollar/ostrich]

Leather Income sector endogenous variables

k_{ARSF}	Adjustment Rate to Maintain Reasonable Skin Value	[Dollar/(ostrich ∗ year)]
k_{ERL}	Effect of Worldwide Economic Recession on Leather Demand	[unitless]
k_{JRL}	Effect of Japanese Recession	[unitless]
k_{LDSR}	Leather Demand vs Supply Ratio	[unitless]
k_{LP}	Producer Leather Price per Ostrich in Rand	[Rand/ostrich]
k_{PLMD}	Proposed Leather Market Demand	[ostrich/year]

Meat Income sector parameter assumptions

c_{ACAT}	Absorption Capacity Adjustment Time	[year]
c_{BMPAT}	Baseline Meat Price Adjustment Time	[year]
c_{AMD}	Additional Meat Demand	[ostrich/year]
c_{L}	Percentage of Income Lost due to Export Ban	[unitless]
c_{MMASR}	Maximum Meat Absorption vs Supply Ratio	[unitless]
c_{MPAT}	Meat Price Adjustment Time	[year]

Meat Income sector endogenous variables

k_{BMAC}	Baseline Meat Market Absorption Capacity	[ostrich/year]

- k_{EP} European Market Development attributed to BSE and FMD Panic [unitless]
- k_{MASR} Meat Absorption vs Supply Ratio . . . . [unitless]
- k_{MER} Meat Market Development due to Economic Recession . . [unitless]
- k_{MMD} Meat Market Development . . . . [ostrich/year]
- k_{PM} Producer Meat Price per Ostrich in Rand . . . . [Rand/ostrich]

Producer Cost sector endogenous variables

- k_{OP} Producer Price of Other Products per Ostrich . . . . [Rand/ostrich]
- k_{PC} Producer Cost per Ostrich . . . . [Rand/ostrich]

OIMSA model scenarios

Baseline OIMSA

Open Loop OIMSA

Equilibrated OIMSA

Naturally Equilibrated OIMSA

Chapter 1

Introduction [1]

The term *green economy* was first introduced by Pearce *et al.* (1992) in the Blueprint for a Green Economy. Since the publication of Pearce *et al.* (1992), the interest and demand for the *green transition* is steadily increasing. At a visionary level, the United Nations Environment Programme (UNEP) defines a green economy as an economy where the action of significantly reducing the environmental risks and ecological scarcities directly benefits human well-being and social equity.

In November 2011, South Africa pledged its commitment to sustainably developing a green economy in the face of a global economic crisis, imminent depletion of natural resources, as well as climate change, by committing to a Green Economy Accord (Department of Economic Development, 2011); an agreement between government, industry, labour and trade unions, as well as the greater society. Three reports giving a fair overview on the South African national response on climate change are: the National Climate Change Response Policy, the National Development Plan and the National Strategy for Sustainable Development and Action Plan (DEA, 2011*a*; National Planning Commission, 2012; DEA, 2011*b*). Refer to Appendix D.2 for a summary of each report.

Priority areas for green economy promotion in South Africa is the innovation of new technologies and behaviours, preparation for future flourishing green markets by expanding infrastructure as well as promotion of developing green industries (UNEP, 2013). Lorek and Spangenberg (2014) identify key drivers of a green economy transition as:

- climate change,
- scarcity of material resources,
- rising awareness and threats of peak oil, food, water and financial crises,

[1]Section 1.4 is based on work that was presented at the 33rd International Conference of the System Dynamics Society, 19-23 July, 2015, Cambridge, Massachusetts, USA. See Appendix D.1 for details.

- intergenerational justice, and
- vulnerability of the economy to these factors.

At an operational level, UNEP defines a green economy as an economy that is driven by investments, including investments in human and social capital (UNEP, 2013). The investments are sought to reduce carbon emissions and pollution, enhance energy and resource efficiency and prevent the loss of biodiversity and ecosystem services. Furthermore, the May 2010 Summit Report (DEA, 2010), published by the Department of Environmental Affairs (DEA), states that South Africa defines a green economy as a development path that is sustainable in addition to addressing the interdependence between natural ecosystems, economic growth and social protection.

1.1 Simulation as a tool in the green transition of South Africa

The first national green economy summit, held in 2010, indicated a need for a simulation model that assesses the impacts of green economy investments in different sectors of the South African economy (DEA, 2010). The first integrated system dynamics model examining the transition to a green economy in South Africa, the South African Green Economy Model (SAGEM), was developed by Musango *et al.* (2014*a*). The study showed that green economy interventions could result in a low carbon transition, utilise resources efficiently and create additional jobs without necessarily slowing the economy. UNEP (2011*b*) and Musango *et al.* (2014*b*) concluded that a green economy transition does not have to be implemented at the cost of economic activity and economic growth.

The development of SAGEM was made possible by South Africa's DEA, in partnership with UNEP and with support from United Nations Development Programme and further affirms the South African government's support for a green economy. SAGEM was developed to evaluate national targets and the effects of investing in a green economy in South Africa using a methodology similar to the model proposed in the UNEP Green Economy Report (UNEP, 2011*a*). The Threshold 21 framework, developed by the Millennium Institute, was customised to provide a framework of integrating several sectoral models in the South African context.

SAGEM traces the effects of a proportion of gross domestic product on four of the nine core sectors prioritized to support a green economy for South Africa, namely: natural resource management, agriculture, transport and energy (Musango *et al.*, 2014*a*). Focus areas within the four sectors selected, based on existing country commitments and targets, are tabulated in Table 1.1.

Table 1.1: SAGEM core sectors with corresponding focus areas

Model Core Sector	Model Focus Areas
Natural Resource Management	governmental *working for water* programme
Agriculture	Crop production
	Differentiates between production utilising conventional and organic fertilizer
Transport	Roads infrastructure
	Transport
Energy	Energy production
	Energy demand

Being the first integrated system dynamics model examining the broad topic of the transition to a green economy in South Africa, it is not surprising that SAGEM limited the scope of the agriculture sector to crop production and fertilizer. The bias towards crop farming is at least partially attributed to the fact that the Department of Environmental Affairs was driving the green economy modelling assessment.

1.2 The agriculture sector of SAGEM

The fact that SAGEM identified agriculture as one the four core sectors prioritized to support a green economy for South Africa is intuitive when considering that most developing economies, including South Africa, are highly dependent on their agriculture sectors (Goldblatt, 2012). The agriculture sector has significant influence on the Gross Domestic Production (GDP), food security, social welfare, job creation and ecotourism (Goldblatt, 2012). Even though the predominant agricultural activity in South Africa is livestock farming (Goldblatt, 2012), the only two focus areas of the agriculture sector were identified as crop production and differentiates between production utilising conventional and organic fertilizer.

The only significant reference to livestock in SAGEM is found inside the land module, where crop land and livestock land were modelled individually. SAGEM approximates the effect of the livestock production sector of South Africa in various key modules, for example the employment module, using output generated from crop farming in the agriculture module. The capital agriculture represents the capital for the entire agriculture sector, which includes crop production, livestock production, forestry and fisheries. Capital agriculture follows the Cobb-Douglas production function. If the livestock were to be modelled in detail, then the livestock intensity index and livestock land area would have been used. Even though SAGEM deemed the livestock production sector beyond the scope of the project, the absence of livestock in the agriculture sector of SAGEM results in two shortcomings as listed below.

1. The only focus in the detailed analysis was on crop production yet other studies have shown that livestock is an essential contributor to the green economy (Goldblatt, 2012; Musvoto, 2014).

2. The absence of detailed analysis of livestock production in South Africa through omission of the livestock production sector in SAGEM. The ommission is justified in the context of the specific use of the SAGEM.

Although agriculture was identified as one key contributing factors to the green economy, livestock production was not prioritised in the initial analysis of SAGEM. Livestock production is a significant element of South Africa's green economy, simulation models with regards to the green transition, or the impact of green economy investments, are justified when considering that livestock production is the primary activity in the agriculture sector (Goldblatt, 2012).

Given the absence of detailed analysis of livestock production in South Africa, if a simulation model was commissioned to explain the structure, behaviour, or to evaluate the impact of green economy investments of a specific livestock production industry of South Africa from scratch, a system dynamics model would not necessarily be most effective. The usefulness of a system dynamics model to explain the structure or behaviour varies depending on the amount of dynamics present in each individual livestock production industry.

This study intends to undertake a detailed analysis of a single livestock production industry of South Africa without necessarily integrating the study into the structure of SAGEM, in aid of the industry's sustainable development path addressing the interdependence between natural ecosystems, economic growth and social protection. The ostrich production sector of South Africa is identified as a dynamic system, exhibiting boom and bust behaviour, that could benefit from better understanding of the underlying structure and types of feedback present within the said system. The ostrich industry of South Africa is shown to be a significant contributor to the national total gross value added by animal production and is deemed a crucial element of the green transition of the livestock production industry of South Africa (DAFF, 2013; Goldblatt, 2012).

1.3 Overview of the South African ostrich industry

South Africa is regarded as the undisputed world leader in ostrich production (National Agricultural Marketing Council, 2003). According to the DAFF (2013), South Africa currently accounts for approximately 70% of the global ostrich market. The majority market share means that strong feedback is bound to exist between South African ostrich production and the international commodity cycles of ostrich products; other ostrich producing countries experience the ostrich product markets as exogenous influences.

Figure 1.1: Example of an ostrich, ostrich leather boots and ostrich fillet (Reuters, 2013; Nashville Boot Co., 2012; The Newspaper, 2014)

The modern-day ostrich is produced for its low cholesterol meat and strong, aesthetically unique hides depicted in Figure 1.1 (South African Ostrich Business Chamber, 2002). Ostrich meat is the largest meat export from South Africa in terms of both volume and value (Brand *et al.*, 2011). The South African ostrich industry accounts for an average of 2% of the national total gross value added by animal production (Brand *et al.*, 2011). The industry also adds significant value to the economy by making use of abattoirs, meat processors, tanneries, feather processors and even establishing ostrich agri-tourism. Ostrich production development is not associated with natural resource depletion and the inherent natural resource efficiency of the industry further affirms the importance of the ostrich production industry in the South African green economy.

The ostrich industry is predominantly an export industry, with very few products marketed locally. Besides the exclusivity value of ostrich leather, it is one of the most durable leathers available (ECIAfrica (Pty) Ltd, 2010). Ostrich leather is mainly exported to the United States of America (USA) where it is sold to upscale fashion producers, for example producers of handbags or footwear such as cowboy boots (National Agricultural Marketing Council, 2003). After the deregulation of the ostrich industry in 1993, industry participants built abattoirs that complied with the phyto-sanitary requirements for exporting meat to the EU. Ostrich meat steadily became more popular and a solid secondary source of revenue (ECIAfrica (Pty) Ltd, 2010). Ostrich meat is marketed locally and in the European Union (EU) to wholesalers, supermarkets, foodservices suppliers and restaurants as an every-day, healthy, low-cholesterol alternative to red meat (Brand *et al.*, 2011). Ostrich feathers, considered a minor source of income, are marketed as household dusters and household decorations (National Agricultural Marketing Council, 2003).

The majority of ostrich production in South Africa happens in and around the Klein Karoo (ECIAfrica (Pty) Ltd, 2010). This is attributed to regulation that awarded single channel marketing rights for ostrich products to the Klein Karoo Korporasie between 1959 and 1993 (ECIAfrica (Pty) Ltd, 2010). During the regulatory period, ostrich farming was only allowed to take place in the Klein Karoo region. Section 7 of the Marketing and Agricultural Products Act of 1969 explains that the reason for the procurement of sole marketing rights and strict stipulation of where ostriches may be farmed was to protect farmers in and around the Klein Karoo region since ostrich farming was the only way in which they could earn an adequate living (National Agricultural Marketing Council, 2003). The decision has been widely criticized as being a socio-political decision that was not necessarily in the best interest of the South African ostrich industry (ECIAfrica (Pty) Ltd, 2010). The industry was officially deregulated in November of 1993, reinstating the free market system (National Agricultural Marketing Council, 2003).

Van Zyl (2009) acknowledged that the EU ostrich meat market is grossly undersupplied and has the capacity to absorb meat from more than one million ostriches per year when ostrich meat is promoted as an every-day alternative to red meat, while the income from ostrich leather is highly dependent on historical market supply. The industry-wide future targeted focus area is a highly contentious subject in the South African ostrich community since there is enormous potential for growth in the ostrich meat market while the leather income is highly dependent on the restriction of supply.

Appendix B contains a literature study of the South African primary production sector of the ostrich industry. Value adding activities are also discussed to build understanding of the global ostrich product markets ultimately influencing production.

1.4 Problem statement [2]

Despite the prominent role ostrich production plays in the animal production sector, the ostrich farming industry has shown an extremely unstable pattern of development. Once the free-market system was implemented in 1993, the ostrich industry received a surge of capital investment and expanded rapidly only to suffer devastating production crashes, resulting in many ostrich producers suffering big losses that in turn resulted in them leaving the industry. The industry did not learn from the first collapse and the boom and bust cycles continues to repeat itself, implying that producers may not fully understand the complex system that is the ostrich market. Examination of Figure 1.2 shows patterns of continuous boom and bust cycles in the historical development of the ostrich slaughter rate in South Africa.

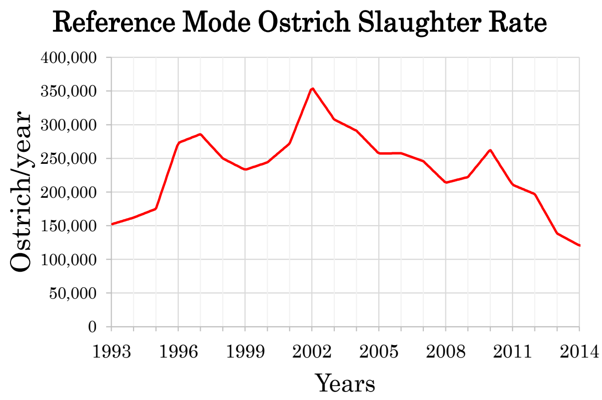

Figure 1.2: Historical development of ostrich slaughter rate in South Africa (National Agricultural Marketing Council, 2003; Lareman, 2015)

The boom and bust behaviour of the ostrich industry has environmental, social and economic implications for the green economy of South Africa. The primary environmental concern regarding ostrich production is the damage of the unique fynbos area of the Klein Karoo if ostriches are kept in large camps. Ostriches are mostly fed using the feedlot system meaning no grazing is intended however, larger birds are prone to vandalise the fynbos due to boredom (see Appendix B). Social implications of the boom and bust cycles are the lack of job security and income stability within the ostrich industry as a whole, including any up-stream value adding activity, as well as the absence of skills-development and career growth required for empowerment. Economic implications include loss in gross domestic production, increased levels or unemployment and accumulation of debt from farm foreclosures.

[2]Section 1.4 is based on work that was presented at the 33rd International Conference of the System Dynamics Society, 19-23 July, 2015, Cambridge, Massachusetts, USA. See Appendix D.1 for details.

In addition to having implications on the sustainability of the green economy of South Africa, instability in the ostrich production industry has serious repercussions for the industry itself. Industry repercussions include logistical and distribution problems, product inconsistency, ineffective market development, weak institutional support, as well as loss of experience, knowledge and business networks. The cause of each industry repercussion is listed below. Most of the causes identified can be considered negative side-effects from premature loss of experience, knowledge and business networks attributed to farmer bankruptcy.

Logistical and distribution problems

- Ineffective supply-chain management during upstream activities.

Product inconsistency

- Inappropriate practice with regards to ostrich health and inefficient production systems.
- Lack of technology innovation.
- Production level employees receive minimal skills development opportunities and mostly untrained.

Ineffective market development

- Non-uniform or confusing message to potential markets.

Weak institutional support

- Absence of a strong institutional framework caused by fragmentation and distrust within the industry.
- Delayed or ineffective government regulations caused by lack of communication between industry and government, as well as the absence of clear EU directives.

Loss of experience, knowledge and business networks

- Premature departure of farmers from the industry due to bankruptcy.

1.4.1 Green transition policy discussions

Green transition policy discussions regarding the ostrich industry is still in its infancy. No policies have been formally developed or proposed for implementation. As mentioned previously, ostrich production is not very resource intensive relative to other livestock production industries; ostriches can be raised in relatively hostile environments. The green transition policy discussion topics regarding the South African ostrich production industry are:

- whether the long term industry focus should be leather or meat,
- the inclusion of new entrant black farmers,
- transitioning from the current flock breeding production system, to the small camp production system (see Appendix B.1),
- the introduction of carbon tax on all livestock (relative to the amount of carbon emissions produced), as well as
- the introduction of water tax on all irrigated crops (implying an additional tax on ostrich feed).

1.5 Research objectives and questions

Sterman (2000) considers a clear purpose to be the single most important element of a successful modelling study. The primary research objectives of this thesis are listed below.

1. Development of a system dynamics model named Ostrich Industry Model of South Africa (OIMSA) that represents the ostrich production industry of South Africa,
2. To ultimately use OIMSA to assess the impact of a change in individual exogenous elements identified as affecting the ostrich production industry of South Africa, and
3. To ultimately use OIMSA as a tool in assessing the impact of policies regarding the green economy transition.

From the research objectives, the following research questions are formulated to guide this research.

1. What is the underlying structure of the ostrich production industry of South Africa causing the behaviour exhibited in Figure 1.2?
2. Which exogenous elements impact the ostrich production industry of South Africa, and what is the long term and short term impact of each exogenous element identified?
3. What is the long term and short term impacts of potential policies regarding the green economy transition?

1.6 Research strategy

Figure 1.3 shows a graphic representation of the research strategy followed during this study. The main elements of the study are identified as the green economy transition, system dynamics modelling, agricultural commodity cycles, as well as the ostrich production industry of South Africa.

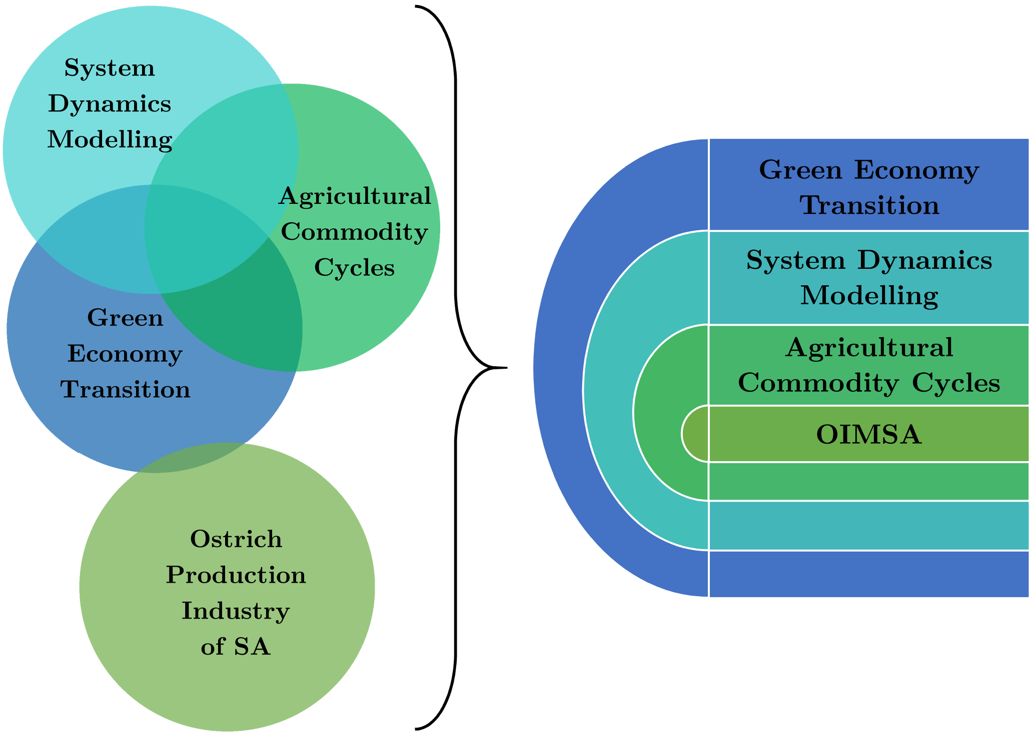

Figure 1.3: General overview of research strategy

As shown on the right-hand-side of Figure 1.3, existing literature to be investigated should show considerable mutual overlap between the topics: green economy transition, system dynamics modelling and agricultural commodity cycles. Since the only before mentioned topic that has any overlap with existing literature on the ostrich production industry of South Africa is green economy transition, the emphasis should be on ostrich production literature that includes topics regarding the green economy transition. Next, the research should be applied to create the Ostrich Industry Model of South Africa (OIMSA). As shown on the right-hand-side of Figure 1.3, OIMSA is to be based off of known system dynamics models regarding livestock commodity cycles where the overall goal is sustainable production, or a green economy transition.

1.7 Scope, limitations or delimitations

The availability and reliability of data regarding ostrich production is one of the main limitations of the study. Another limitation is the ostrich industry's limited willingness to engage in the study via email or telephonic correspondence since geographical constraints prohibited the author from visiting ostrich industry players for the majority of the study's duration.

The ostrich production industry of South Africa is investigated through the perspective of ostrich producers. Ostrich producers are paid per bird upon slaughter and are assumed to have no involvement in any value-adding activities of ostrich products. Ostrich product commodity markets are considered beyond the scope of the study however, the income received by ostrich producers upon slaughter will be investigated. It is assumed that value-adding sectors uses the previous value of the ostrich product, combined with the current exchange rates, food safety concerns and economic welfare to determine the current payment to ostrich producers upon slaughter. No inferences about the final selling price of the commodities on international markets were are made. The study assumes that ostrich producers base their decision on future production levels on their profit margin, the presence of bird flu, as well as the presence of economic hardship.

The study is specific to the South African ostrich industry and cannot be universally applied to ostrich production sectors in other countries, or different livestock industries in South Africa. This is firstly because South Africa supplies the overwhelming majority of the global market with ostrich products, implying that the global market conditions are considered endogenous for South Africa, but exogenous for economies with a fractional market share. Secondly, the ostrich production sector is in the unique situation where the majority of income is attributed to export: leather is exported to the USA while meat is exported to the EU. This implies that two different markets, product types and countries are considdered concurrently.

1.8 Thesis chapter layout

Chapter 1 **Introduction**

Introduces the research problem, objectives, scope and outline of the study.

Chapter 2 **Research methodology**

Introduces the system dynamics research method, evaluates the chosen research method's feasibility and lays out the custom methodological framework followed during this study.

Chapter 3 **Literature study**

Provides a literature study of system dynamics modelling and agricultural commodity cycles. Also shows that the ostrich production industry adheres to the understanding of commodity cycles.

Chapter 4 **Dynamic model of the ostrich industry**

Focusses on the development of the Ostrich Industry Model of South Africa (OIMSA).

Chapter 5 **Results**

Shows simulation results of OIMSA with validation and verification of the model. Scenario testing and policy analysis is provided as well as the applications, limitations and challenges of OIMSA.

Chapter 6 **Conclusion**

Provides concluding remarks on OIMSA and various scenarios and policies investigated, as well as on the underlying structure of the ostrich production industry of South Africa.

Figure 1.4: General content of thesis chapters

Chapter 2

Research methodology

This chapter develops a custom research method based on the P'HAPI framework for the problem introduced in Section 1.4. First, the chapter investigates research methodologies in aid of developing a custom research method for this project. This chapter reviews the discipline of mathematical modelling, concentrating on system dynamics modelling. The problem's suitability towards the system dynamics modelling method is confirmed using a feasibility checklist after which the limitations of the modelling method is discussed. The classic variations of system dynamics model research methodologies are investigated before customizing the P'HAPI research method for this project.

2.1 Research and research methodology

Research is commonly considered to be the pursuit for knowledge. Sahu (2013) defines research as the scientific process by which new facts, ideas and theories could be established or proved in any field of study. According to Kothari (2004), research is the activity of searching for knowledge objectively and systematically in aid of finding a solution to a problem or answering a question. In accordance with the before mentioned definitions of research, research methodology is defined as the systematic process of solving a research problem (Sahu, 2013).

2.2 Research objectives

Each individual scientific research project possesses its own unique research objectives than can be identified as one of the following four research objective groupings: exploratory, descriptive, diagnostic and hypothesis-testing (Kothari, 2004). Exploratory research studies are studies with the objective of gaining understanding of a research topic or achieving new insights into any phenomenon (Sahu, 2013). Descriptive research studies have the objective of providing accurate depictions of particular situations, individuals or groups while diagnostic research studies determine the frequency of occurrences (Kothari, 2004). Hypothesis-testing research studies are studies that test hypotheses of causal relationships between variables (Kothari, 2004). In the context of the before mentioned definition, the research objective of this study is considered to be hypothesis-testing in nature.

2.3 Overview of Modelling [1]

Many of today's managerial problems in the public and private sector are too complex to solve without some form of optimization. Often management resorts to some form of modelling since the symptoms of a problem in a large system often seems unrelated to the actual problem and behave counter to human intuition. Furthermore, previous policy interventions may have unintended outcomes since the complexity and interconnectivity of the system is in many cases not properly addressed. This section introduces the discipline of mathematical modelling and compares analytical and numerical models.

Modelling is often used to determine the outcome of a specific scenario without testing it in reality. Managerial or technical decisions are often based on the results of one or more different type of models in an array of disciplines. Eykhoff (1974) defined a model as:

> *"...a representation of the essential aspects of an existing system (or a system to be constructed) which presents knowledge of that system in a usable form."*

Models can be either physical or theoretical (Eykhoff, 1974). Mathematical modelling is a common theoretical modelling method used to describe any system, defined as an integrated set of individual elements related through interaction or interdependence, with a fixed framework consisting of pre-defined rules and outlines using mathematical concepts and language Lawson (2014). A mathematical model therefore returns numerical outputs that describe reality as accurately as required within given constraints (Gershenfeld, 1999).

Common forms of mathematical models include dynamic systems, statistical models, differential equations, or game theory models (Klamkin, 1980). Mathematical models very often integrate elements of several forms within different structures of the model to accurately describe the complex nature of most systems.

[1] Section 2.3 is based on work that was presented at the 24th International Association for Management of Technology (IAMOT), 8-11 June, 2015, Cape Town, South Africa. See Appendix D.2 for details.

2.4 Simulation research approach

The simulation research approach entails constructing and operating an artificial numerical environment that represents the structure of a dynamic process (Sahu, 2013). Simulation research approaches can create multiple observations in future under varying conditions, parameters and exogenous variables Sahu (2013). The reason for selecting the simulation research approach is a fundamental decision based on factors relating to the purpose of the model, desired outcomes and future scenarios to be explored.

Dooley (2005) sub-divides simulation into three main practices: discrete event simulation, agent based simulation and system dynamics simulation. Discrete event simulation models describe a system as a set of entities that are executed sequentially and probabilistically over time (Dooley, 2005). Agent based simulation consists of agents determined by schema that interacts and learns from other agents and resources to maximize their utility (Dooley, 2005). System dynamics simulation identifies the key system variables and their interaction with one-another as explicitly defined differential equations (Dooley, 2005).

2.4.1 System dynamics modelling feasibility checklist [2]

The aim of this study is to understand the ostrich production industry of South Africa, which is in line with the commonly listed purpose for development of a system dynamics models found in Barlas and Carpenter (1990) and Sterman (2000). Duminy *et al.* (2015) devised a checklist to test whether a system is suitable for system dynamics modelling as a potential tool to avoid wasting resources using a modelling method unsuited to the problem at hand.

The checklist was developed using various definitions of system dynamics modelling in classic literature (Forrester, 1961; Coyle, 1996; Wolstenholme, 1990). From the results of the checklist, shown in Figure 2.1, the study, as defined in Chapter 1.4, is deemed a feasible candidate for the system dynamics research methodology.

[2]Section 2.4.1 is based on work that was presented at the 24th International Association for Management of Technology (IAMOT), 8-11 June, 2015, Cape Town, South Africa. See Appendix D.2 for details.

System dynamics modelling feasibility checklist

The *checklist requirements* are stated in italics underneath the heading of each sub-section of the checklist. Each sub-section's requirement is to be satisfied for system dynamics modelling to be a feasible modelling method. It can be noted that, even if all the requirements are met according to the checklist, the system at hand might still be better described using a different method of modelling.

Desired output from model:

At least one of the two boxes is to be checked

- ☐ Model describing the system output as accurately as required within given constraints
- ☑ Understanding of the functionality and control policies of the system

Characteristics of the system to be modelled:

Both boxes are to be checked

- ☑ Time dependent
- ☑ Managed system

Model behaviour governed by:

Box to be checked

- ☑ Information feedback

Type of model required:

At least one of the two boxes is to be checked

- ☐ Qualitative
- ☑ Quantitative

Desired solution approach:

At least one of the two boxes is to be checked

- ☑ Simulation and
- ☐ Optimization

Figure 2.1: Completed system dynamics feasibility checklist (Duminy *et al.*, 2015)

2.4.2 Limitations of system dynamics modelling

According to Sterman (1991), the extent of a model's usefulness is determined by the underlying assumptions that make up any model. Three common limitations of modelling techniques are the estimation of parameters, sensitivity testing and the assessment of model validity (Meadows, 1976). Each limitation is discussed in terms of system dynamic modelling:

- **Estimation of parameters:** the process of parameter estimation is less formal than in other modelling methods and seldom include the use of statistics or other formal procedures of parameter estimation (Ford, 2010).
- **Sensitivity analysis:** a model is meant to be used for its qualitative behavioural characteristics rather than for quantitative predictions. A model is said to be sensitive to a given parameter only if a change in the numerical value of the parameter changes the entire behaviour of the model (Meadows, 1976).
- **Model validity:** the system dynamics modelling paradigm usually handles the problem of model validity qualitatively and informally. No rigorous procedure or theory governs the process of sensitivity analysis for system dynamics modelling (Meadows, 1976). Model validity is often left up to the intuition of the modeller.

In addition to the technical limitations of the system dynamics paradigm, modellers are often the cause of limitations in any study. Common limitations involving system dynamics modellers are listed below.

- A new modeller who has a basic understanding of a SD modelling software is likely to be overconfident in his/her model output without understanding the model structure (Sterman, 1991).
- Due to the convenience of system dynamics modelling software, modellers are prone to apply endless small alterations to the model rather than to analyse and understand the system structure as well as the reason for any particular system behaviour (Sterman, 1991).
- The mechanical simplicity of adding new features to a model can easily result in an over complex, uncontrollable structure (Sterman, 1991).
- System dynamists are prone to assume that most problems, like most model elements, are endogenous to the system. They could conclude that the problem is caused by the internal structure and the decision making process in any system, even if it is not the case (Meadows, 1976).

- Solutions offered after analysing a problem using the system dynamics models often result in a structural disturbance in the system analysed. A resistance to change and the nature of public decision making will probably always be a factor hindering the practical use of system dynamics in the policy world (Meadows, 1976).

The nature of some problems are more compatible with the limitations of system dynamics modelling than others. An important element in deciding on a modelling method is to make sure that the limitations any potential method is compatible with the nature of the problem.

2.5 The system dynamics research approach

System dynamics modelling is chosen as the simulation research approach to achieve the objective of understanding the ostrich production industry of South Africa. According to Luna-Reyes and Andersen (2003), classic variations of the research method followed when developing a system dynamics model can be found in Randers (1980), Richardson and Pugh III (1981), Roberts *et al.* (1983), Wolstenholme (1990) and Sterman (2000). Even though each proposed research method consisted of a different number of stages, Luna-Reyes and Andersen (2003) identified common activities between the authors as shown in Table 2.1. Luna-Reyes and Andersen (2003) further noted that all five authors described their method to be iterative in nature.

Table 2.1: Variations of the system dynamics research method (Luna-Reyes and Andersen, 2003)

<table>
<tr><th>Randers (1980)</th><th>Richardson and Pugh (1981)</th><th>Roberts et al. (1983)</th><th>Wolstenholme (1990)</th><th>Sterman (2000)</th></tr>
<tr><td rowspan="2">Conceptualization</td><td>Problem definition</td><td>Problem definition</td><td rowspan="2">Diagram construction and analysis</td><td>Problem articulation</td></tr>
<tr><td>System conceptialization</td><td>System conceptialization</td><td>Dynamic hypothesis</td></tr>
<tr><td>Formulation</td><td>Model formulation</td><td>Model representation</td><td rowspan="3">Simulation phase (Stage 1)</td><td>Formulation</td></tr>
<tr><td rowspan="2">Testing</td><td>Analysis and model behaviour</td><td>Model behaviour</td><td rowspan="2">Testing</td></tr>
<tr><td>Model evaluation</td><td>Model evaluation</td></tr>
<tr><td rowspan="2">Implementation</td><td>Policy analysis</td><td rowspan="2">Policy analysis and model use</td><td rowspan="2">Simulation phase (Stage 2)</td><td rowspan="2">Policy formulation and evaluation</td></tr>
<tr><td>Model use</td></tr>
</table>

2.6 P'HAPI research method

A variation to the classic system dynamics research methods discussed in Section 2.5 was used throughout the project. The research method presented by Moxnes (2009) is termed the P'HAPI method. An overview of the framework can be found in Figure 2.2, followed by a brief custom methodological description of each step. Note that the process flow depicts an iterative framework.

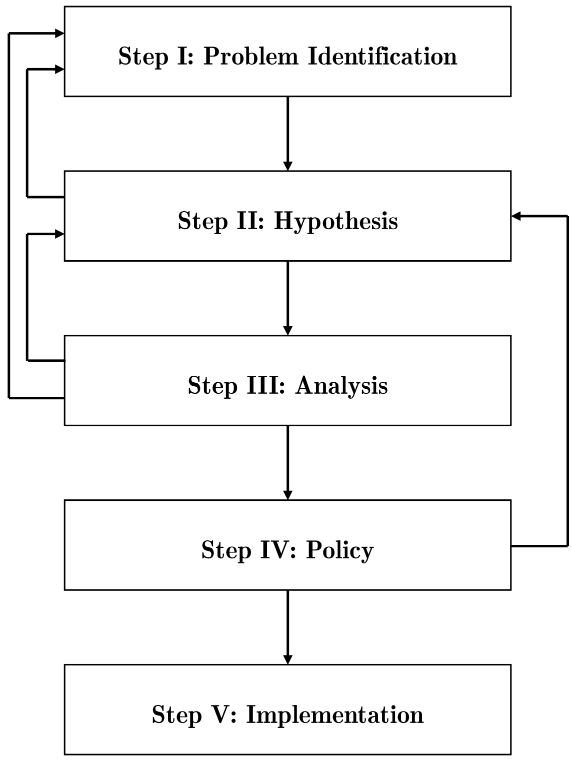

Figure 2.2: Custom methodological framework

Step I: Problem identification

- Identify the problem behaviour exhibited by the ostrich production industry over time. Also identify any potential green economy policies regarding the ostrich production industry to ground model development.
- Confirm the appropriateness of system dynamics as a modelling tool. This confines the problem scope of this thesis to using system dynamics modelling as the tool for analysis.
- Identify an appropriate historical reference mode and reliable historical data showing the development of the reference mode over time.

- Define the project scope, parameters, system boundaries and exogenous variables.

Step II: Hypothesis

- Once the problem identification stage is perceived as sufficient, formulate the hypothesis in the form of a causal loop diagram.
- Develop the suspected system structure using a stock and flow model.
- During the hypothesis stage, the problem identification is adapted iteratively.

Step III: Analysis

- Upon hypothesis formalization, the model endures a series of structural and behavioural tests. The hypothesis is then either rejected or not rejected.
- If the hypothesis was rejected, anything from a revision of parameter values (return to Step II) to rejecting the entire hypothesis (return to Step III) could ensue.

Step IV: Policy development

- Given a useful hypothesis, policies regarding the green economy transition is discussed.
- The process of coming up with feasible policies cycle through Step II and III iteratively.

Step V: Implementation

- Once potential policies have been identified and tested, implementation is to be critically discussed in terms of its cost, fairness, risk and stakeholder perception.

2.7 Summary

This chapter investigates research methodologies in aid of developing a custom research method for this project. This study reviews the discipline of mathematical modelling with emphasis on system dynamics modelling. The problem's suitability towards the system dynamics modelling method is confirmed using a feasibility checklist before the limitations of the modelling method is discussed. After evaluating the classic variations of system dynamics modeling research methodologies, the P'HAPI research method is customized for this project.

The following chapter, Chapter 3, contains a literature study of system dynamics modelling as well as commodity cycle applications of system dynamics modelling. Finally, the chapter concludes that the problem introduced in Section 1.4 adheres to the understanding of commodity cycles within the context of system dynamics modelling.

Chapter 3

Literature study [1] [2]

This chapter contains a literature study of system dynamics modelling, as well as commodity cycle applications of system dynamics modelling. The main purpose of this study is to understand the ostrich production industry of South Africa. A secondary purpose it to determine the long-term focus of the ostrich production industry, as well as policy design relating to carbon and tax as well as transition from flock breeding to small camp breeding for environmental sustainability. Chapter 2 investigated research methodologies and deemed system dynamics modelling most suitable for the problem described in Chapter 1.4. There is a need for literature reviews in aid of creating a dynamic hypothesis and model structure in Chapter 4.

Section 3.1 gives an overview of the fundamentals of system dynamics modelling as background for the dynamic hypothesis, as well as the model structure and equations in Chapter 4. Topics covered this section include system feedback, Causal Loop Diagrams (CLDs), Stock and Flow Diagrams (SFDs) and the fundamentals of dynamic model behaviour.

After system dynamics modelling, Section 3.2 contains a literature study of commodity cycle applications in the system dynamics discipline. Due to the nature of the ostrich industry of South Africa, explained in Section 1.3, the literature study places emphasis on agricultural commodity cycles.

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[1] Sections 3.1.1, 3.1.2, 3.1.4 and 3.1.5 is based on work that was presented at the 24th International Association for Management of Technology (IAMOT), 8-11 June, 2015, Cape Town, South Africa. See Appendix D.2 for details.

[2] Section 3.2 is based on work that was presented at the 33rd International Conference of the System Dynamics Society, 19-23 July, 2015, Cambridge, Massachusetts, USA. See Appendix D.1 for details.

3.1 Fundamentals of system dynamics modelling

This section gives an overview of the fundamentals of system dynamics modelling in aid of developing a dynamic hypothesis as well as the model structure and equations for the South African ostrich production industry in Chapter 4. Concepts covered in this section include system feedback, Causal Loop Diagrams (CLDs), Stock and Flow Diagrams (SFDs) and the fundamentals of dynamic model behaviour.

3.1.1 Defining system dynamics modelling [3]

System dynamics is one of many techniques that can be used to facilitate quantitative simulation modelling and analysis in complex systems (Wolstenholme, 1990), and is currently being applied in aid of policy analysis and design in both the public and private sector. In Forrester (1961), the founder of system dynamics, J. W. Forrester, defined the technique as:

> *"... the investigation of the information-feedback characteristics of [managed] systems and the use of models for the design of improved organizational form and guiding policy"*

Forrester's original description however, does not give any reference to time. R. G. CoyleCoyle (1996) proposes a thorough definition compiled by combining existing definitions from Coyle (1996), Forrester (1961) and Wolstenholme (1990):

> *"System dynamics deals with the time-dependent behaviour of managed systems with aim of describing the system and understanding, through qualitative and quantitative models, how information feedback governs its behaviour, and designing robust information feedback structures and control polices through simulation and optimization."*

It is noted that, in this definition of a system, a system can fail to achieve its required outcome due to any number of reasons, including: design flaws, problems with implementation, problems with integrating parts, inadequate policies or even an external force (Sterman, 2000). A dynamic system is described as a system that changes behaviour as time passes. This description allows for the idea that system dynamics can be a useful tool when deciding on new policy to be implemented due to changes in the existing system over an extended period of time, thereby avoiding system failure.

[3] Section 3.1.1 is based on work that was presented at the 24th International Association for Management of Technology (IAMOT), 8-11 June, 2015, Cape Town, South Africa. See Appendix D.2 for details.

3.1.2 System feedback [4]

Both the before mentioned definitions of system dynamics modelling refer to system feedback. This section introduces the concept of model feedback with emphasis on closed system feedback.

Closed systems have outputs that can both react to, and influence their respective inputs (Ford, 2010). Open systems have no influence upon their inputs. Open systems may only have outputs that respond to their respective inputs (Ford, 2010).

For a closed system a feedback path includes a stock, information about the stock, and a decision rule that is influences the flow strictly in the order that it is mentioned (Coyle, 1996; Sterman, 2000). Coyle (1996) uses an information/action/consequences paradigm schematic, coupled with a systematic procedure, to explain the basic principles of feedback in System Dynamic modelling.

Feedback loops are considered to be either positive, or negative (Meadows, 2008). Positive feedback loops, or reinforcing loops, reinforces the actions and results along loops resulting in a vicious or virtuous cycle. Positive feedback is responsible for growth or decline of systems, often up to the point of destabilization (Meadows, 2008). Negative feedback loops works on bringing a system as close as possible to its desired state. Negative feedback either stabilizes the system, or causes oscillation (Meadows, 2008).

3.1.3 Causal loop diagrams

This section introduces the causal loop diagramming method. CLDs are one of the many diagramming tools used to capture the structure of a system. CLDs traditionally provide a basis for developing stock-and-flow diagrams. The CLD method is explained while emphasizing the concept of reinforcing and balancing feedback, introduced in the previous section, using the simple population CLD.

According to Sterman (2000), CLDs are particularly useful for:

- capturing your hypothesis about causes of dynamics quickly and effectively,
- development of mental models of individuals or groups, and
- effective communication of a dynamic hypothesis without the need for any technical background.

[4]Section 3.1.2 is based on work that was presented at the 24th International Association for Management of Technology (IAMOT), 8-11 June, 2015, Cape Town, South Africa. See Appendix D.2 for details.

Sterman (2000) and Maani and Cavana (2007) use a simple CLD of a population, shown in Figure 3.1, to explain the basic principles of causal loop diagramming.

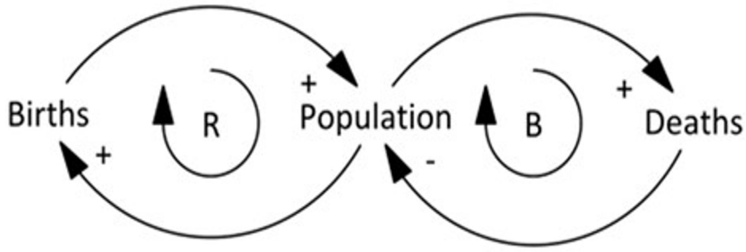


Figure 3.1: Simple population causal loop diagram, Source: Sterman (2000); Maani and Cavana (2007)

In the CDL shown in 3.1, variables are related by *causal links*, shown as arrows pointing from the cause to the effect. The links are assigned either a positive or negative polarity, shown as either a "+" or a "-" next to the head of the arrow (Sterman, 2000; Maani and Cavana, 2007). A positive link indicates that any change in the cause will cause a similar change in the effect, while a negative link indicates that any change in the cause will cause an opposite change in the effect (Sterman, 2000; Maani and Cavana, 2007). In the case of a system with feedback, at least one closed loop should be identified. Important loops in a system are identified as either reinforcing or balancing (Sterman, 2000; Maani and Cavana, 2007). Reinforcing loops are loops where a disturbance in any one of the elements in the loop causes the initial disturbance to be reinforced through the system's dynamic feedback, whereas balancing loops would counteract any disturbance (Sterman, 2000; Maani and Cavana, 2007). Note that not all links in a loop has to have a positive polarity for the loop to be typed as a reinforcing loop. Instead, the nature of the feedback on the disturbed element is observed: if the disturbance is reinforced, the loop is considered to be reinforcing in nature, whereas, if the disturbance is counteracted, the loop is considered to be balancing.

3.1.3.1 Reinforcing loop

The reinforcing loop is labelled using an "R" in Figure 3.1. The polarity of the *causal links* in Figure 3.1 indicate that Births has a similar effect on Population; Population has a similar effect on Births. As Births increase, the Population increases; as the Population increases, Births will increase. Therefore, a disturbance in either Births or Population, would result in reinforcing feedback, ultimately reinforcing the disturbance.

3.1.3.2 Balancing loop

The balancing loop is labelled using an "B" in Figure 3.1. The polarity of the *causal links* in Figure 3.1 indicate that Deaths has an opposite effect on Population; Population has a similar effect on Deaths. As Death increases, the Population decreases; as the Population increases, Death increases. Therefore, a disturbance in either Deaths or Population, would result in balancing feedback, ultimately counteracting the disturbance.

3.1.4 Stock and flow diagrams [5]

CLDs are useful for capturing mental models and the initial capturing of interdependencies and feedback (Sterman, 2000). Since CLDs are unable to capture the inherent stock and flow structure of dynamic systems, a SFD is usually created using a CLD as its basis.

This section introduces the basic components of a SFDs in aid of capturing the structure of a dynamic system. The section focusses on the differences between stocks and flows. Stock accumulation and the rate of change of a system is discussed. After identifying all components of a model, dynamic behaviour of models over time is discussed. Dynamic behaviour is attributed to the *Principle of Accumulation* that states that all dynamic behaviour occurs when flows accumulate in stocks (Radzicki and Taylor, 1997).

3.1.4.1 Diagramming notation for SFDs

According to Sterman (2000), SFDs are governed by the notations listed below.

- Stocks are represented by rectangles
- Inflows are represented by an arrow pointing to a stock
- Outflows are represented by arrows pointing out of the stock
- Valves shown on the flows control said flow
- Clouds represent sources and sinks of flows, indicating flow originating/terminating outside the model boundary

[5] Section 3.1.4 is based on work that was presented at the 24th International Association for Management of Technology (IAMOT), 8-11 June, 2015, Cape Town, South Africa. See Appendix D.2 for details.

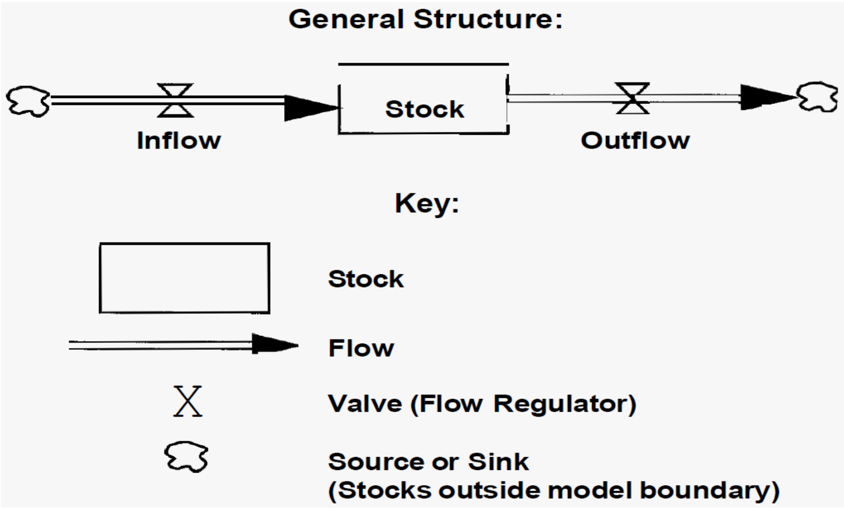


Figure 3.2: General SFD Structure, Source: (Sterman, 2000)

A graphic example of a simple stock and flow structure is shown in Figure 3.2. In this example, the system consists of one stock with one inflow and one outflow. Forrester (1961) uses a hydraulic metaphor to explain this simple SFD configuration. Sterman (2000) reduces the metaphor to a bathtub (stock) with one faucet (inflow) and one drain (outflow).

In system dynamics modelling, both informational and physical entities can flow through the pipe and faucet assembly to accumulate in the stocks. A stock can have an unlimited amount of both inflows and outflows since the principal of accumulation holds regardless of the number of inflows or outflows.

If the inflow is more than the outflow at a given point in time, the stock is increasing while, if the outflow is less than the inflow, the stock is decreasing. The system is in a state of dynamic equilibrium if the inflow and the outflow are equal.

3.1.4.2 Identifying stocks and flows

A fundamental skill when building a system dynamics model, that beginners often find challenging, is correctly identifying each stock and flow in a particular system. This section introduces a solid guideline is to distinguish between variables defining the state and the variables defining the changes in state. Variables responsible for defining the state are considered the system stocks while variables responsible for defining the changes in states are considered the system flows (Radzicki and Taylor, 1997). Differences between stocks and flows have been tabulated from Coyle (1996) and Ford (2010).

Table 3.1: Differences between stocks and flows, Source: Coyle (1996); Ford (2010)

Stocks	**Flows**
Usually represented by nouns, for example *debt*	Usually represented by verbs, for example *deficit*
If a hypothetical snapshot of a system were to be taken, stocks remain constant at the value observed in the moment of the snapshot	If a hypothetical snapshot of a system were to be taken, all flows would be considered zero
Source of information about the system state to the rest of the system	Source of information about the state of the stock to the particular stock

Radzicki and Taylor (1997) identified four individual stock characteristics that are responsible for the dynamic behaviour in systems. The first characteristic is that stocks have memory. In the above example of the water tank, if both the inflow and outflow are shut off, the amount of stock stays as is until an inflow or outflow is re-introduced. The fallacy of shutting off an inflow to stop a population over-supply can be discredited using the characteristic of memory: shutting off inflow doesn't address the amount of entities currently in stock. A good example of the influence this characteristic can have on a system can be found in Meadows *et al.* (1992).

The second characteristic is that the nature of the flow is determined by the derivative of stock. Mathematically this means that flow rate at t, Flow(t), is the derivative of the stock at t, Stock(t), with respect to time, where Flow(t) is defined as the sum of all inflows, Inflow(t), minus the sum of all outflows, Outflow(t), at t (Sterman, 2000).

$$\frac{d(\text{Stock})}{dt} = \text{Inflow}(t) - \text{Outflow}(t) \tag{3.1.1}$$

Equation 3.1.1 can be converted to an integral equation (Sterman, 2000).

$$\text{Stock}(t) = \int_{t_0}^{t} \Big(\text{Inflow}(t) - \text{Outflow}(t)\Big) dt + \text{Stock}(t_0) \tag{3.1.2}$$

A thorough discussion of this characteristic can be found in Forrester (1968).

The third characteristic is that stocks "decouple" flows and allow disequilibrium behaviour at the stocks. Therefore, regardless of stock level, the inflow does not necessarily have to equal the outflow. This also means that the inflows and outflows can be controlled by different sources of information that do not necessarily relate to each other at all (Radzicki and Taylor, 1997).

The final characteristic of stocks are that they create delays in the system and therefore enables analysis over time. Identifying delays is an important step in the modelling process due to the significant impact on the system. It is not always easy to perceive a connection between cause and effect if there is a significant delay between the two.

3.1.5 Fundamental models of dynamic behaviour [6]

After identifying all components of a model, the next step is to identify key patterns of behaviour over time. The performance of crucial components or system variables, over time, is defined as the system variable's time path. This section describes a basic systems' dynamic behaviour, or time paths. The types of time paths identified are linear, exponentially growing, goal seeking, S-shaped, oscillating, growing with overshoot, or overshoot and collapse (Sterman, 2000; Ford, 2010).

Complex time paths can be described as exhibiting a combination of several traits where the traits can be combined concurrently. Traits of the basic time paths are explained below and shown graphically in Figure 3.3 from Sterman (2000).

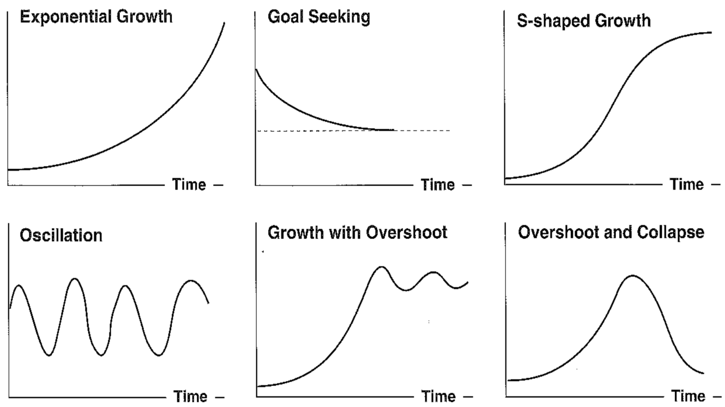


Figure 3.3: Common modes of behaviour in dynamic systems, Source: (Sterman, 2000)

Linear

Linear time paths are categorised as growing, declining, or in a state of equilibrium. Systems are seldom in a state of perfect balance. System equilibrium implies that all state variables are exhibiting equilibrium time paths simultaneously. System dynamics modelling method recognises that it is unlikely that a system would ever achieve equilibrium in

[6] Section 3.1.5 is based on work that was presented at the 24th International Association for Management of Technology (IAMOT), 8-11 June, 2015, Cape Town, South Africa. See Appendix D.2 for details.

reality, in contrast to much of modern economics and management science that uses the assumption of equilibrium as a basis for their models. System dynamics models are only placed in an artificial state of equilibrium to study their behaviour to the implementation of policy changes.

Exponential growth

Figure 3.3 shows an instance of exponential growth over time. Exponential growth is a result of reinforcing feedback (Sterman, 2000). Wagenaar and Sagaria (1975), Wagenaar and Timmeri (1978) and Wagenaar and Timmeri (1979) show that most systems have exponential time paths rather than linear time paths. In practice, problems consisting exclusively of pure linear time paths usually contain no feedback and are likely not to conform to the definition of a system in the context of system dynamics. The problems are therefore most likely better described using a different method of applied mathematics or operations research.

Goal seeking

Goal-seeking time paths are paths that iteratively move as close as possible to a certain target-value over time using a balancing feedback loop (Sterman, 2000). An exponential time path, where the exponent is negative, as shown in Figure 3.3, is an example of a path seeking a goal since the time path asymptotically moves closer to a certain goal y-value.

"S"-shaped growth

Time paths that grow in an "S"-shape over time have both exponential and goal-seeking attributes. The time path is shown graphically in Figure 3.3. The time path initially grows or declines exponentially before becoming goal-seeking when the system approaches its limit or carrying capacity (Sterman, 2000).

Oscillations

Similar to goal seeking behaviour, oscillations, shown in Figure 3.3, are caused by negative feedback. According to Sterman (2000), oscillations are a result of constant overshooting of corrective action caused by long system delays. Oscillating time paths can be sustained, damped, exploding or chaotic in nature (Radzicki, 1990).

"S"-shaped growth and overshoot

As mentioned previously, "S"-shaped growth requires both initial exponential growth (reinforcing feedback) and goal-seeking (balancing feedback) characteristics as the system reaches its carrying capacity (Sterman, 2000). When long delays are present in the balancing feedback loop, overshoot and oscillations are created, as shown in Figure 3.3.

Overshoot and collapse

A critical assumption of any regular "S"-shaped time path is that the carrying capacity remains fixed over time (Sterman, 2000). In reality, the carrying capacity of a system is often depleted by over-utilizing a resource. In the event where an overshoot in resource utilization, initially exhibiting "S"-shaped growth, results in a permanent depletion of the system's carrying capacity, the initial overshoot will be followed by a drastic decrease in resource utilization as shown in Figure 3.3.

3.2 Commodity cycle literature review[7]

Upon the conclusion of the fundamentals of system dynamics modelling in the previous section, Section 3.1.4, the reader will possess enough background information to be able to follow a literature study of commodity cycle applications in the system dynamics discipline. Due to the nature of the ostrich industry of South Africa, explained in Section 1.3, the literature study places emphasis on agricultural commodity cycles.

Commodity cycles are a result of industry-wide market forces or feedbacks between supply and demand. Market forces can either attenuate or amplify shocks to a supply-chain, often resulting in cycles in production and prices, each with characteristic periods, amplitudes, and phases (Sterman, 2000). Commodity cycles, or oscillations, are most prevalent in industries with long time delays as well as relatively strong negative feedback forces, the most common of which is price seeking to equilibrate supply and demand (Sterman, 2000). Examples of industries with strong cyclical dynamics attributed to long construction or production delays are real estate, shipbuilding, paper and coffee.

An example of one of the first large-scale system dynamics models dealing with natural resource depletion is the Club of Rome's attempt to address The Limits to Growth problem (Meadows *et al.*, 1972). Shortly thereafter, Michigan State University developed a collection of large-scale and country-based agricultural sector models for various regions of the world (Harrison *et al.*, 1974; Michigan State University, 1971).

3.2.1 Agricultural commodity cycle literature review

The model proposed by Meadows (1969) serves as a significant building block for most system dynamics models of livestock commodity cycles published. It analyses the dynamic cycle theory of producing products, citing the cyclical fluctuations in the U.S. hog population prices (Meadows, 1969). Meadows (1969) uses the model simulation to define how commodity markets could be

[7] Section 3.2 is based on work that was presented at the 33rd International Conference of the System Dynamics Society, 19-23 July, 2015, Cambridge, Massachusetts, USA. See Appendix D.1 for details.

balanced. Ford (2015) later adapted the model to represent the modern livestock commodity cycle. The model adaptation is specifically produced for ease of understanding for educational purposes. Conrad (2004) included production and prices of dairies (milk production and demand) and grains (feed) in the cattle breeding-related model and considered the disruption caused by a FMD epidemic. McDermott *et al.* (2005) made the distinction between dairy cattle and fattening cattle when modelling New Zealand's livestock industry and value chain. Ross *et al.* (2011) modelled the entire beef production process in great detail to analyse the beef supply network in a bid to gain greater understanding in the livestock production process.

Meadows (1970) developed a system dynamics model of commodity cycles, applying the model to livestock production. The model was later refined by Sterman (2000). In Sterman's generic structure for commodity markets, he proposes three principle feedbacks to equilibrate supply and demand: B1, B2 and B3 (Sterman, 2000). B1 regulates the commodity selling price relative to its substitutes. B2 regulates the utilization of existing production capacity while B3 develops additional capacity if required (Sterman, 2000). Sterman (2000) also proposes changes to his generic structure of commodity markets for livestock applications. In the case of animal production, a decrease in immediate production will result in an increase in long-term production and vice-versa (Sterman, 2000).

Cloutier (2001) modelled the economic and production system of the maple sap production industry in Quebec using the structure introduced by Meadows (1970). The macro behaviour of the industry was simulated using the microstructure of maple sap collection and syrup production as input.

Osorio and Aramburo (2009) used system dynamics modelling to examine the long term cyclical behaviour of the price of coffee. The model was based on the structures developed by Meadows (1970), Deaton and Laroque (1996) and Deaton and Laroque (2003). The internal structure of the system proposed by Osorio and Aramburo (2009) includes price, investment, demand and capacity. Another example of a model based on the before mentioned structures, Bantz and Deaton (2006), evaluates the biodiesel industry of the United States of America. Bantz and Deaton (2006) used the supply-demand-price model, spread out through two sections, capacity and production inventory, to explain the feedback mechanisms and dynamics involved.

Applanaidu *et al.* (2009) combines the system dynamics approach proposed by Meadows (1970), Deaton and Laroque (1996) and Deaton and Laroque (2003) with econometric methods in modelling the Malaysian cocoa market. Haghighi (2009) also used the combination of econometric and system dynamics methods to determine the optimal employment and production policies in the agricultural sector of Iran.

3.3 Compatibility system dynamics as modelling tool

No previous research could be found on the topic of using any kind of "systems thinking" tool to analyse the ostrich industry of South Africa. Analysis of ostrich leather and meat as commodities are also lacking. ECIAfrica (Pty) Ltd (2010) is the most conclusive document on the current state of the ostrich industry, as well as the value-chain of the ostrich industry. The contribution of the South African ostrich industry to the national economy is discussed in Brand *et al.* (2011) while the financial state and cost benefit analysis of the ostrich industry of South Africa can also be found in Klein Karoo International Proprietary Limited (2014) and Mugido (2011) respectively. National Agricultural Marketing Council (2003) and South African Ostrich Business Chamber (2002) offer background on the process of deregulation of the ostrich industry.

See Appendix B for a detailed litirature study on the South African ostrich production industry. As stated in Appendix B, South African ostrich leather and meat are both exported, implying that commodity prices are determined by the global market, and then heavily influence by the Rand vs. Dollar and Rand vs. Euro exchange rates rather than country-specific endogenous factors. It is common knowledge by the industry that the price of ostrich leather as a commodity has a strong dependence on previous global supply (ECIAfrica (Pty) Ltd, 2010; Klein Karoo International Proprietary Limited, 2014; National Agricultural Marketing Council, 2003; Brand *et al.*, 2011).

Strong dependence on previous market supply levels is indicative of strong dependence on system feedback in the global ostrich industry. Since the South African ostrich industry accounts for approximately 70% of the global ostrich market (DAFF, 2013), the global market supply can be considered endogenous. Therefore, a strong feedback exists between the ostrich production in South Africa and income received by ostrich producers for leather. Research indicated that ostrich meat is considered a consumer item that is marketed as a healthy alternative to red meat (ECIAfrica (Pty) Ltd, 2010; Van Zyl, 2009). The international meat market price is therefore fixed to the, fairly stable, price of beef in the EU. In contrast to the ostrich leather market, the meat market has the capacity to undergo virtually endless market exploration (Van Zyl, 2009). Therefore ostrich meat and ostrich leather adheres to the understanding of commodity cycles in Section 3.2.1 and system dynamics modelling is deemed appropriate for this investigation.

3.4 Summary of Chapter 3

This concludes the literature study of system dynamics modelling, commodity cycle applications of system dynamics modelling, as well as the South African ostrich industry. Section 3.1 gives an overview of the fundamentals of system dynamics modelling as background for the dynamic model, as well as the model structure and equations in Chapter 4. Topics covered this section include system feedback, Causal Loop Diagrams (CLDs), Stock and Flow Diagrams (SFDs) and the fundamentals of dynamic model behaviour.

After system dynamics modelling, Section 3.2 contains a literature study of commodity cycle applications in the system dynamics discipline, with emphasis on agricultural commodity cycles due to the nature of the ostrich industry shown in Section 1.3. From Section 3.2.1 it is clear that Meadows (1969) serves the most significant building block in agricultural commodity cycle applications of system dynamics.

In conclusion, Section 3.3 shows that ostrich leather and ostrich meat adheres well to the understanding of commodity cycles and deems system dynamics modelling an appropriate tool of investigation.

The following chapter, Chapter 4, shows the Ostrich Industry Model of South Africa (OIMSA). OIMSA is made up of an CLD as well as a SFD. After the key assumptions of OIMSA is listed in Section 4.1, the structure of the ostrich production industry of South Africa is explained by an aggregate CLD in Section 4.2. Finally, the SDF structure and equations are introduced in Section 4.3.

Chapter 4

Dynamic Ostrich Industry Model of South Africa (OIMSA) [1]

Chapter 4 uses the inherent nature of the system being analysed, along with the problem statement, is used to determine the structure of the system and the model boundary.

It is crucial that system assumptions be stated clearly before developing the dynamic model or model structure to avoid any design ambiguity. Section 4.1 states all major assumptions made during the construction of OIMSA. The nature of the assumptions included specifying the model perspective on the international ostrich product markets, determining desired production levels, the absence of dynamics in determining production cost, food safety concerns, as well as economic welfare.

After the key assumptions governing OIMSA is defined, Section 4.2 proposes a dynamic structure used to explain the problem at hand. The dynamic model developed in Section 4.2, formulated with the help of an aggregate causal loop diagram, attempts to provide an endogenous explanation to the boom-and-bust nature of the ostrich production industry of South Africa. Section 4.2 first introduces and classifies key system variables as an introduction to explaining OIMSA's dynamic model. The explanation of the dynamic model then starts with the Primary Production sector, followed by the Leather Income and Meat Income sectors. The explanation emphasizes the major feedback loops governing OIMSA.

Finally, the structure and equations of OIMSA is introduced in Section 4.3. Before OIMSA's structure is introduced, the main structural differences between OIMSA and the model it was based off of, Meadows (1970), is discussed in Section 4.3.1. Next, the model reference mode and exogenous variables are introduced in, Sections 4.3.2 and 4.3.3 respectively, as an introduction to defining the model structure and equations. The OIMSA stock and flow dia-

[1] Sections 4.1 and 4.2 are based on work that was presented at the 33rd International Conference of the System Dynamics Society, 19-23 July, 2015, Cambridge, Massachusetts, USA. See Appendix D.1 for details.

gram consists of four model sectors and no sub-models. The sectors represent various aspects of the ostrich production industry of South Africa: primary production (including decision-making on production levels), as well as factors identified as influencing said decision-making process: income received and expenses incurred. The sectors are Primary Production, Leather Income, Meat Income, and Producer Cost in Sections 4.3.4, 4.3.5, 4.3.6, and 4.3.7 respectively.

4.1 OIMSA key assumptions [2]

The inherent nature of the system being analysed, along with the problem statement, is used to determine the structure of the system and the model boundary. This section contains assumptions used during the design of the dynamic model in Section 4.2, as well as the model structure and equations, in Section 4.3. Assumptions regarding the model perspective on international markets (Section 4.1.1), factors influencing farmers' target production-levels (Section 4.1.2), absence of feedback in the production cost sector (Section 4.1.3), food safety concerns (Section 4.1.4) as well as economic welfare (Section 4.1.5) are covered in this section.

4.1.1 Model perspective on international ostrich product markets

The process of breeding ostriches is simulated along with the producers' decision-making process about the number of ostriches produced. The primary producer receives his/her income upon slaughter and is usually not involved in the value-adding activities or the export of ostrich products (National Agricultural Marketing Council, 2003). In the same way leather and meat income in OIMSA is defined as the income that the farmer (primary producer) receives from the ostrich value-adding sector upon slaughter from stakeholders from the value-adding sector.

Both the before mentioned sectors are influenced by their respective market-related variables. The value-chain and final selling price of ostrich leather and meat on international markets are not modelled since the markets are considered to be outside the model boundary. When reference is made to the international ostrich market prices in this chapter, it does not refer to the final selling price of ostrich products to the consumer, but rather to the price the farmer receives for slaughter ready ostriches, or the fraction of the selling price accounted for by the cost of the unprocessed product paid to the pri-

[2]Section 4.1 is based on work that was presented at the 33rd International Conference of the System Dynamics Society, 19-23 July, 2015, Cambridge, Massachusetts, USA. See Appendix D.1 for details.

mary producer. For simplicity, the fraction of the total cost is assumed to be constant.

It is assumed that the value-adding sectors use their current and historical market performance along with exogenous variables relating to exchange rates, food safety concerns, and economic welfare to determine the price payed to primary producers.

4.1.2 Factors influencing farmers' target production-level

The model structure assumes that the only endogenously created feedback that influences ostrich producers' decision to increase or decrease production is the producers' current perceived profit margin per ostrich. The profit margin per ostrich is determined mostly by the income received from ostrich leather and meat, and the expense incurred from feed. By using the profit margin rather than the gross profit, the effect of inflation does not have to be taken into account.

Exogenous factors negatively influencing the primary producers' target production level are assumed to be the economic welfare of South Africa, as well as the presence of bird flu in South Africa. Farmers may not have the financial backing to enter the ostrich production market, or expand on current production, during periods of economic recession. Furthermore, farmers are deterred from entering or expanding the ostrich market during periods of bird flu due to the instantaneous market instability from mandatory cullings and meat export bans associated with the epidemic.

4.1.3 Absence of feedback in the production cost sector

It is assumed that there is no feedback present in determining the cost of producing a single ostrich. Refer to Appendix B.1.4 for the appropriate ostrich feed mix ratio. The section also states that feed accounts for approximately 70% of the total variable cost per ostrich. For simplicity, the cost is defined as $(\frac{1}{70\%})$ times the total cost of feed.

The cost of feed is considered exogenous to the system. Even though feed prices have a considerable effect on the ostrich production industry, the South African ostrich industry has no effect on feed production or prices. This is because ostrich feed is the primary cost when farming ostriches, while the ostrich industry accounts for a very small fraction of the total feed production industry's market.

4.1.4 Food safety concerns

Food safety concerns are considered exogenous, therefore OIMSA does not predict when, or how severe, the food-safety concerns will be. It does, however, assess the impact of such an occurrence. The two food safety concerns were identified as affecting income received by ostrich producers from the ostrich meat are the outbreak of bird flu in South Africa and concerns regarding BSE and FMD outbreaks in beef products produced in the EU.

According to Appendix B.2, raw meat products are banned from being exported to the EU during periods where bird flu is prevalent in South Africa. It is assumed that an export ban due to bird flu results in an instantaneous reduction in income from meat received by the primary producer as well as mandatory culling of a portion of the ostrich population. The fraction of the total ostrich population culled is also considered exogenous to the model.

In practice, the ostrich population is spread out uniformly throughout the country in terms of their age distribution rather than having a concentration of either breeding stock or young chicks in particular parts of South Africa. Bird flu is contained by culling all ostriches in the vicinity of the affected area. It is therefore assumed that the entire ostrich population is subjected to culling uniformly in terms of their age distribution.

In contrast, concerns regarding BSE and FMD outbreaks in beef products produced in the EU has a positive impact on the ostrich meat price received by the ostrich producer since the concerns increase the demand for safe alternatives to beef which subsequently increases the price.

4.1.5 Economic welfare

All variables indicative of the general economic state of South Africa, Japan, or the world, are considered exogenous to the OIMSA. OIMSA can, however, assess the impact of such an economic occurrences such as a change in exchange rates or the prolonged presence of an economic recession.

Both global and local economic climates have a tangible influence on the welfare of the ostrich production market of South Africa. Even though South Africa accounts for approximately 70% of the global ostrich market (DAFF, 2013), the ostrich industry accounts for a negligible fraction of the South African national economy - by accounting for only 2% of the national total gross value added by animal production (Brand *et al.*, 2011). The global ostrich industry accounts of an even smaller proportion of the global economy. It is therefore assumed that even the most significant of disturbances in the ostrich production industry of South Africa will not have a notable influence on the economic state of South Africa or the world, implying that the economic climate is exogenous to the system at hand.

In contrast to ostrich leather that is considered a luxury product, ostrich meat is considered a household consumable. Ostrich meat prices are therefore sensitive to the consumer inflation rates subjected to their target market. It is also assumed that the EU consumer inflation rate is exogenous to OIMSA.

4.1.6 Summary of Section 4.1

Section 4.1 states all major assumptions made during the construction of OIMSA in Sections 4.2 and 4.3. The nature of the assumptions included specifying the model perspective on the international ostrich product markets, determining desired production levels, the absence of dynamics in determining production cost, food safety concerns, as well as economic welfare.

Section 4.1.1 stipulates that OIMSA does not model the international ostrich product markets. It does, however, incorporate respective market-related variables since said variables have an influence on the income received by primary producers. When reference is made to the international ostrich market prices in this chapter, it does not refer to the final selling price of ostrich products to the consumer, but rather to the price the farmer receives upon delivering slaughter-ready ostriches to the abattoir.

The next section, Section 4.1.2, discusses factors influencing the primary producer's target production level. OIMSA assumes that the only endogenously created feedback that influences ostrich producers' decision to increase or decrease production is the producers' current perceived profit margin per ostrich.

According to Section 4.1.3, there is no endogenous system feedback influencing the cost of production in OIMSA. This is since feed accounts for the overwhelming majority of the total variable cost per ostrich and feed prices are considered to be exogenous to OIMSA.

Section 4.1.4 defines all food safety concerns to be exogenous to OIMSA. OIMSA does not predict when, or how severe, the impact of food safety concerns will be. The two food safety concerns implemented in OIMSA are the outbreak of bird flu in South Africa and the concerns regarding BSE and FMD in beef products produced in the EU.

The final section, Section 4.1.5, defines the general economic state, both of South Africa, and in relevant global markets, to be exogenous. OIMSA can assess the impact of changes in the general economic environment but cannot predict such an occurrence.

Upon conclusion of Section 4.1, the next section, Section 4.2, shows the dynamic model of OIMSA using a system aggregate CLD.

4.2 Dynamic model [3]

This section proposes a structure used to explain the ostrich production industry of South Africa. "Dynamic" in the term "dynamic model" indicates that a system's underlying feedbacks and interactions would result in a dynamic system to explain the problem at hand. The dynamic model developed in this section, formulated with the help of an aggregate causal loop diagram, attempts to provide an endogenous explanation to the boom-and-bust nature of the ostrich production industry of South Africa.

Key system variables are introduced and classified as either endogenous or exogenous to OIMSA in Section 4.2.1 before the dynamic model of the Primary Production sector is formalised in Section 4.2.2. The Leather Income and Meat Income sectors are then introduced in aid of explaining OIMSA's major feedback loops in Sections 4.2.3 and 4.2.4 respectively.

4.2.1 Definition and classification of key system variables used in the dynamic model

This section defines key variables identified as influencing OIMSA either endogenously or exogenously. The purpose of which is to aid of introducing the dynamic model through the aggregate causal loop diagram shown in Figure 4.1.

Even though the nature of the discipline of system dynamics modelling is to create system behaviour endogenously using feedback over time, exogenous parameters were identified as having significant influence on the system. An example of variables having considerable influence over the model, that could not be recreated endogenously, is the exchange rate between the Rand and both the Euro and Dollar. Refer to Section 4.1 for assumptions resulting in variables being classified as either endogenous or exogenous. A non-exhaustive list of key endogenous and exogenous variables are shown in Table 4.1.

Parameters excluded from the model include production capacity constraints, environmental constraints and resource constraints.

[3]Section 4.2 is based on work that was presented at the 33rd International Conference of the System Dynamics Society, 19-23 July, 2015, Cambridge, Massachusetts, USA. See Appendix D.1 for details.

Table 4.1: Classification of key variables (Duminy, 2015)

Endogenous Variables	**Exogenous Variables**
Baseline Producer Meat Price per Ostrich in Euro	Beef BSE and FMD Panic in Europe
Breeding Ostriches	European HICP
Breeding Ostriches Acquisition Rate	Japanese Recession
Leather Demand vs Supply Ratio	Presence of Export Ban from Bird Flu
Mature Ostriches	Producer Cost per Ostrich
Meat Absorption vs Supply Ratio	Rand vs Dollar Exchange Rate
Ostrich Slaughter Rate	Rand vs Euro Exchange Rate
Perceived Optimal Number of Ostriches Produced	Worldwide Economic Recession
Producer Gross Profit Margin per Ostrich	
Producer Leather Price per Ostrich in Dollar	
Producer Leather Price per Ostrich in Rand	
Producer Meat Price per Ostrich in Euro	
Producer Meat Price per Ostrich in Rand	

The dynamic model of OIMSA can be summarised using the aggregate causal loop diagram shown in Figure 4.1. Even though the CLD doesn't capture all the dynamic behaviours OIMSA, all major feedback loops are shown. Figure 4.1 is used to explain the dynamics of OIMSA throughout the rest of Section 4.2.

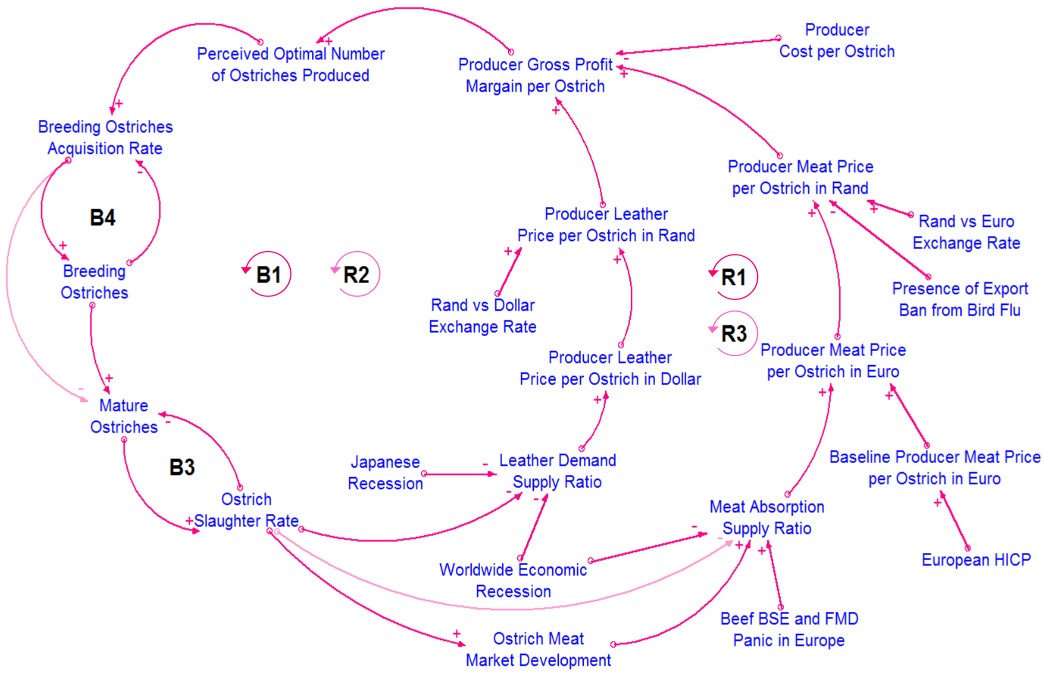


Figure 4.1: Aggregate Causal Loop Diagram of OIMSA

This concludes of the section that introduced the key variables used in OIMSA's dynamic model. The following section, Section 4.2.2 defines the dynamic model of the PRIMARY PRODUCTION sector.

4.2.2 PRIMARY PRODUCTION sector

The PRIMARY PRODUCTION sector involves all activities related to breeding, or producing, ostriches that are ready for slaughter. The PRIMARY PRODUCTION sector of the aggregate CLD shown in Figure 4.1 refers to all causal relationships between Producer Gross Profit Margin per Ostrich and Ostrich Slaughter Rate.

In accordance to the model assumptions stated in Section 4.1.2, Figure 4.1 shows that Producer Gross Profit Margin is influenced by three variables, each from a different sector of the model: Producer Leather Price per Ostrich in Rand, Producer Meat Price per Ostrich in Rand and Producer Cost per Ostrich. The dynamic model of Producer Leather Price per Ostrich in Rand and Producer Meat Price per Ostrich in Rand is discussed in Section 4.2.3 and Section 4.2.4 respectively.

Section 4.1.2 also assumes that, as ostrich farming becomes more lucrative, existing ostrich farmers would want to increase their ostrich production levels and new farmers would enter the industry. This is indicated in the aggregate CLD, shown in Figure 4.1, by Producer Gross Profit Margin per Ostrich having a similar effect on Perceived Optimal Number of Ostriches Produced.

Once producers decide to change their desired production rate, indicated by Perceived Optimal Number of Ostriches Produced, they do so by changing the breeding stock population to desired levels since "it takes hogs to make hogs" (Sterman, 2000). It is assumed that ostrich producers always follow a *worse-before-better* production plan, where a decrease in immediate production will result in an increase in long-term production (and vice-versa).

An example of the *worse-before-better* assumption, in reference to the aggregate CLD in Figure 4.1, is if the Perceived Optimal Number of Ostriches Produced is greater than the number of ostriches that the current flock of Breeding Ostriches is able to produce, producers increase Breeding Stock Acquisition Rate, resulting in a short-term decrease in Mature Ostriches, since Mature Ostriches are withheld from slaughter to be groomed as future Breeding Ostriches. The Breeding Ostriches eventually increases as the birds reach sexual maturity (after a delay of approximately two years), increasing the Ostrich Slaughter Rate sustainably. Using the same principle, Breeding Ostriches are slaughtered to decrease production.

In Figure 4.1, the causal link between Breeding Ostriches Acquisition Rate and Mature Ostriches is shown in a lighter colour than the two links forming the pathway between Breeding Ostriches Acquisition Rate and Mature Ostriches through Breeding Ostriches. This is to signify that the lighter causal link dominates in the short term, while the other pathway, consisting of two causal links, is dominant in the long term.

An example of the opposite, *better-before-worse* production plan, not implemented in the model, is producers sending all Mature Ostriches to slaughter in the current season, effectively supplying the perceived optimal number of ostriches in the short term rather than increasing, or replenishing, the Breeding Ostriches population. Breeding Ostriches are sent to slaughter if the stock, Mature Ostriches, is depleted. This policy is unsustainable since the decrease in Breeding Ostriches decreases the production capacity in the long term, causing the producer to carry on slaughtering Breeding Ostriches at an increasing rate until the stock, Breeding Ostriches, is depleted and no further ostrich production is possible.

In addition to the systems' major balancing feedback loop discussed in preceding paragraphs, the system has two minor feedback loops, shown as **B2** and **B3** in Figure 4.1. Balancing loop **B2** attempts to equilibrate the stock, Breeding Ostriches, using its bidirectional inflow, Breeding Ostriches Acquisition Rate. Similarly, Balancing loop **B3** attempts to equilibrate the stock, Mature Ostriches, by regulating its outflow, Ostrich Slaughter Rage. This is intuitive to the inherent nature of any first-order minor feedback loop with a constant adjustment time.

The four most influential major feedback loops present in OIMSA is shown in the aggregate CLD in Figure 4.1 as **B1**, **R1**, **R2** and **R3**. Of the major feedback loops listed, only one feedback loop, **B1**, is balancing in nature. The nature, and sector of influence, of the major feedback loops in OIMSA is summarised in Table 4.2.

Table 4.2: Nature of major feedback loops shown in the Aggregate CLD

	Leather Income	Meat Income
Seeking long-term dominance	Loop **B1**	Loop **R1**
Seeking short-term dominance	Loop **R2**	Loop **R3**

The proposed system is equilibrated through the two long term major feedback loops regulating leather and meat income, **B1** and **R1** in the aggregate CLD shown in Figure 4.1, respectively. **B1** and **R1** both compete for dominance in the long term (see Sections 4.2.3 and 4.2.4 respectively). The long term nature of the feedback is accounted for by the fact that both loops are linked between Breeding Ostriches Acquisition Rate and Mature Ostriches through Breeding Ostriches.

In contrast, OIMSA's behaviour is reinforced in the short term by two major reinforcing feedback loops regulating leather and meat income, **R2** and **R3** in Figure 4.1, respectively. **R2** and **R3** both compete for dominance in the short term (see Sections 4.2.3 and 4.2.4 respectively). The short term nature of the feedback is accounted for by the fact that both loops are directly linked between Breeding Ostriches Acquisition Rate and Mature Ostriches.

This concludes the explanation surrounding the dynamic model of the Primary Production sector of OIMSA. The following section, Section 4.2.3, explains the dynamic model of the Leather Income sector. Section 4.2.3 refers back to this section, Section 4.2.2, to define the major feedback loops **B1** and **R2**. The section after Section 4.2.3, Section 4.2.4, also refers back to this section, Section 4.2.2, to define the major feedback loops **R1** and **R3**.

4.2.3 Major feedback loops B1 and R2: Leather Income sector

The Leather Income sector of the aggregate CLD in Figure 4.1 refers to all causal relationships between Leather Demand Supply Ratio and Producer Leather Price per Ostrich in Rand. This causal pathway connects with the before mentioned Primary Production sector causal pathway, defined in Section 4.2.2, to form the system major feedback loops.

Ostrich leather is sold in US Dollars. It is marketed as an exclusive product in the fashion and lifestyle industry. It accounts for 50% to 70% of the total income per bird (National Agricultural Marketing Council, 2003). The income per ostrich skin is relatively high, but since it is used predominantly in luxury products, the market is sensitive to economic welfare. In accordance to the assumptions stated in Section 4.1.1, ostrich leather is assumed to be a niche product where the price of ostrich leather per square meter decreases endogenously as product availability increases.

Under normal economic conditions the desirability of ostrich leather, Leather Demand Supply Ratio, decreases as the number of ostriches supplied to the market, Ostrich Slaughter Rate, increases. As shown in Figure 4.1, Ostrich Slaughter Rate therefore has an opposite effect on the Leather Demand Supply Ratio. Under extreme market conditions, exogenous influences on Leather Demand Supply Ratio are identified as economic downturns of potential ostrich leather markets. The presence of economic hardship, represented by the binary, exogenous variables, Japanese Recession and Worldwide Economic Recession, where 1 represents a period of recession, also has an opposite effect on the Leather Demand Supply Ratio. The assumption is also stated in Section 4.1.5.

The Leather Demand Supply Ratio has a similar effect on the ostrich leather selling price on the international market, Producer Leather Price per Ostrich in Dollar. See Section 4.1.1 for a conclusive definition of variables related to the price of leather.

Producer Leather Price per Ostrich in Dollar and the Rand vs Dollar Exchange Rate both have a similar effect on the income received by primary producers, Producer Leather Price per Ostrich in Rand.

The Rand vs Dollar Exchange Rate influences the income received by ostrich producers in South Africa per ostrich skin, Producer Leather Price per Ostrich in Rand, without having any direct effect on the selling price of the international ostrich leather market, indicated as Producer Leather Price per Ostrich in Dollar. The aggregate CLD in Figure 4.1 clearly shows the structure of the before mentioned concept: both Rand vs Dollar Exchange Rate and Producer Leather Price per Ostrich in Dollar have a similar effect on Producer Leather Price per Ostrich in Rand while there is no direct causal link between Rand vs Dollar Exchange Rate and Producer Leather Price per Ostrich in Dollar.

The high volatility of the Rand vs Dollar Exchange Rate potentially misrepresents the state of the international ostrich leather market to ostrich producers in South Africa. Ostrich producers have historically flooded ostrich leather supply intentionally, anticipating that international ostrich leather market, depicted by Producer Leather Price per Ostrich in Dollar would plummet, on account of a drastic, temporary, increase in the Rand vs Dollar Exchange Rate due to the favourable profit margin.

Finally, the Producer Leather Price per Ostrich in Dollar has a similar effect on Producer Gross Profit Margin per Ostrich. Since there is only one unique pathway between Leather Demand Supply Ratio and Producer Leather Price per Ostrich in Rand, no further discussion is required. Refer to Section 4.2.2 for the Primary Production section describing the causal loops **B1** and **R2**. Refer to Table 4.2 for a summary of the nature of the Leather Income sector's major feedback loops.

This concludes the explanation surrounding the dynamic model of the Leather Income sector of OIMSA. This section, Section 4.2.3, refers back to Section 4.2.2 to define the major feedback loops **B1** and **R2**. The following section, Section 4.2.4, explains the dynamic model of the Meat Income sector.

4.2.4 Major feedback loops R1 and R3: Meat Income sector

The Meat Income sector of the aggregate CLD in Figure 4.1 refers to all causal relationships between, either Meat Absorption Supply Ratio or Ostrich Meat Market Development, and Producer Meat Price per Ostrich in Rand. This causal pathway connects with the before mentioned Primary Production sector causal pathway, defined in Section 4.2.2, to form the system major feedback loops.

Ostrich meat is currently marketed as an every-day, healthy alternative to red meat and accounts for between 30% to 45% of the total income per ostrich (National Agricultural Marketing Council, 2003). With the deregulation of the ostrich industry in 1993 came the conception of an export meat market. This was made possible with the establishment of the first abattoir complying with the strict phyto-sanitary requirements (ECIAfrica (Pty) Ltd, 2010). Unlike the ostrich leather market, the ostrich meat market is robust towards fluctuations in market supply. Instead, the ostrich meat market is anchored to a baseline value that is similar to the value of red meat in the EU, and then influenced by the long-term market development. Exogenous variables identified as influencing the MEAT INCOME sector is food-safety concerns (see Section 4.1.4), as well as the exchange rate, and economic welfare (see Section 4.1.5).

As with any consumer product, an ongoing market development and brand presence is crucial to capture retail market share. Long-term market development is indicated by long-term historical market absorption rates, or historical retail presence, corresponding to long-term historical production rates, or Ostrich Meat Market Development. Ostrich Slaughter Rate has a slow-acting, similar effect on Ostrich Meat Market Development, which in turn has a similar effect on Meat Absorption Supply Ratio. A sudden increase in Ostrich Slaughter Rate means the retail market is flooded with more ostrich meat than what the consumer is used to absorbing, negatively influencing the price. Therefore Ostrich Slaughter Rate has an opposite effect on Meat Absorption Supply Ratio in the short term (referring to the direct causal link between Ostrich Slaughter Rate and Meat Absorption Supply Ratio), and a similar effect on Meat Absorption Supply Ratio in the long term (referring to the causal link between Ostrich Slaughter Rate and Meat Absorption Supply Ratio through Ostrich Meat Market Development). The direct causal link between Ostrich Slaughter Rate and Meat Absorption Supply Ratio is shown in light pink in Figure 4.1 to symbolise its short-term effect on the system.

Under normal economic conditions the absorption capability of ostrich meat, shown by Meat Absorption Supply Ratio in Figure 4.1, is most affected by food safety concerns from beef produced in the EU. The surge in Producer Meat Price is modelled using the exogenous, binary, variable, Beef BSE and FMD Panic in Europe, where 1 represents the presence of panic, which has a similar effect on the Meat Absorption Supply Ratio. During extreme economic conditions the Meat Absorption Supply Ratio is decreased by the presence of the Worldwide Economic Recession. The presence of economic hardship, represented by the exogenous, binary, variable Worldwide Economic Recession, where 1 represents a period of recession, has an opposite effect on the Meat Absorption Supply Ratio. Note that the effect of the Worldwide Economic Recession on the MEAT INCOME sector is less severe than on the LEATHER INCOME sector.

The Meat Absorption Supply Ratio has a similar effect on the ostrich meat price on the international market, Producer Meat Price per Ostrich in Euro, that is otherwise fixed to the Baseline Producer Meat Price per Ostrich in Euro. Baseline Producer Meat Price per Ostrich in Euro therfore has a similar effect on Producer Meat Price per Ostrich in Euro. Ostrich meat is marketed and priced to compete with red meat in the EU. Baseline Producer Meat Price per Ostrich in Euro anchors the Producer Meat Price per Ostrich in Euro to the, fairly robust, price of red meat in the EU. Since meat is considered a household consumable, the inflation rate, European HICP, also has a similar effect on the price of beef and Baseline Producer Meat Price per Ostrich in Euro alike.

Finally, Producer Meat Price per Ostrich in Rand is shown to be influenced by the ability to export raw ostrich meat to the EU. The ability to export raw ostrich meat is indicated by a binary, exogenous variable, Presence of Export Ban from Bird Flu, where 1 represents the presence of bird flu, translating to a period of export bans and drastic losses of income. This means that Presence of Bird Flu in South Africa has an opposite effect on Producer Meat Price per Ostrich in Rand. The other two factors, both having similar effects on Producer Meat Price per Ostrich in Rand, is Producer Meat Price per Ostrich in Euro and the Rand vs Euro Exchange Rate.

As shown in Figure 4.1, the structure between Producer Meat Price per Ostrich in Euro and Producer Meat Price per Ostrich in Rand is similar to the structure between Producer Leather Price per Ostrich in Dollar and Producer Leather Price per Ostrich in Rand. Refer to Section 4.2.3 for a discussion on the nature of the structure type.

Finally, the Producer Meat Price per Ostrich in Rand has a similar effect on Producer Gross Profit Margin per Ostrich.

Since there are two unique pathways in the Meat Income sector that connect with variables in the Primary Production sector to create primary feedback loops, further analysis into the nature of the two pathways is warranted. Earlier in this section, the pathway from Ostrich Slaughter Rate to Meat Absorption Supply Ratio through Ostrich Meat Market Development (shown in dark pink in the aggregate CLD in Figure 4.1) is said to compete for dominance in the long term - similar to the causal link between Breeding Ostriches Acquisition Rate and Mature Ostriches through Breeding Ostriches in Section 4.2.2. The reinforcing feedback loop going though both long-term causal links, therefore traveling through only dark pink causal links, is defined as **R2**. The major feedback loop **R2** therefore competes for dominance in the long term.

Similarly, the pathway directly from Ostrich Slaughter Rate to Meat Absorption Supply Ratio (shown in light pink in the aggregate CLD in Figure 4.1) is said to compete for dominance in the short term - similar to the causal link between Breeding Ostriches Acquisition Rate and Mature Ostriches (see Section 4.2.2). The reinforcing feedback loop going though both short-term causal links, therefore traveling through both light pink causal links, is defined as **R3**. The major feedback loop **R3** competes for dominance in the short term. Refer to Table 4.2 for a summary of the nature of the Meat Income sector's major feedback loops.

This concludes the explanation surrounding the dynamic model of the Meat Income sector of OIMSA. This section, Section 4.2.4, refers back to Section 4.2.2 to define the major feedback loops **R1** and **R3**.

This section also concludes the explanation surrounding the dynamic model of OIMSA. The following section, Section 4.2.5, summarises Section 4.2.

4.2.5 Summary of Section 4.2

This section proposes a structure used to explain the ostrich production industry of South Africa. The dynamic model developed in this section, formulated with the help of an aggregate causal loop diagram, provides an endogenous explanation of the ostrich production industry of South Africa. Before introducing the dynamic model of OIMSA, key system variables were defined and classified as either endogenous or exogenous in nature in Section 4.2.1. The section also introduces the aggregate causal loop diagram used throughout the rest of Section 4.2.

Section 4.2.2 discusses the dynamic relationships present in the PRIMARY PRODUCTION section of OIMSA. The section shows the relationship between profit and production. The concept of a *worse-before-better* production plan was introduced and shown to be a sustainable way for primary producers to change production. The two minor feedback loops shown in the CLD attempts to equilibrate Breeding Ostriches and Mature Ostriches with Breeding Ostriches Acquisition Rate and Ostrich Slaughter Rate respectively. Finally, Section 4.2.2 shows how different causal pathways in the PRIMARY PRODUCTION sector influence the nature of the four major feedback loops in OIMSA. Two major feedback loops (**B1** and **R1**) compete for long-term dominance while two major feedback loops (**R2** and **R3**) compete for short-term dominance.

Section 4.2.3 focusses on the causal pathway through the LEATHER INCOME sector that links to the PRIMARY PRODUCTION sector to create two primary feedback loops: **B1** and **R2**. Endogenous behaviour influencing the income received from ostrich leather is governed by a Leather Demand Supply Ratio. The ratio dictates that a market demand has a similar effect on the selling price of leather in the international market, while supply, corresponding to Ostrich Slaughter Rate, has an opposite effect on the selling price of leather in the international market. Other factors influencing the price of ostrich leather on the international market is identified as the economic welfare of the ostrich leather customer base. The section also emphasises the large influence that the Rand vs Dollar Exchange Rate has on the income received by the primary producer in South Africa, without influencing the price of ostrich leather in the international market.

The final section, Section 4.2.4, focusses on the causal pathway through the MEAT INCOME sector that links to the PRIMARY PRODUCTION sector to create two primary feedback loops: **R1** and **R3**. The MEAT INCOME sector is less affected by model feedback, and shows less endogenous behaviour than that of the LEATHER INCOME sector, since ostrich meat is priced to stay competitive with red meat in the EU. Endogenous behaviour influencing the income received from ostrich meat is governed by the effect of Meat Absorption Supply Ratio on the Baseline Producer Meat Price per Ostrich in Euro. Section 4.2.4 explains how Meat Absorption Supply Ratio is affected by a the Ostrich Slaughter Rate in both the short and the long term, effectively creating two causal pathways that enable major feedback. Loop **R1** is traced through the causal pathway competing for dominance in the long term while loop **R3** is traced through the causal pathway competing for dominance in the short term. Other factors influencing the price of ostrich meat on the international market is identified as the economic welfare of the ostrich meat customer base as well as food safety concerns over beef products produced in the EU. The section also emphasises the large influence that the Rand vs Euro Exchange Rate, and the presence of bird flu in South Africa, has on the income received by the primary producer in South Africa, without influencing the price of ostrich meat in the international market.

This section, Section 4.2.5, summarizes the explanation surrounding the dynamic model of OIMSA. In the following section, Section 4.3, the structure and equations of the OIMSA stock and flow diagram is defined. The SFD is based on the dynamic model explained in Section 4.2.

4.3 OIMSA structure and equations

This section contains the structure and equations of OIMSA. Only variables used during the baseline scenario where OIMSA replicates the reference mode, is introduced in Section 4.3. See Appendix C for a detailed description of the entire OIMSA model developed. Before OIMSA's structure is introduced, the main structural differences between OIMSA and the model it was based off of, Meadows (1970), is discussed in Section 4.3.1. Next, the model reference mode and exogenous variables are introduced in, Sections 4.3.2 and 4.3.3 respectively, as an introduction to defining the model structure and equations. The OIMSA stock and flow diagram consists of four model sectors and no sub-models. The sectors represent various aspects of the ostrich production industry of South Africa: primary production (including decision-making on production levels), as well as factors identified as influencing said decision-making process: income received and expenses incurred. The sectors are Primary Production, Leather Income, Meat Income, and Producer Cost in Sections 4.3.4, 4.3.5, 4.3.6, and 4.3.7 respectively.

4.3.1 Structural differences between OIMSA and Meadows (1970)

OIMSA is based on the agricultural commodity cycle proposed by Meadows (1970). This section discusses the structural changes made to the Meadows (1970) model to best represent the South African ostrich industry.

The first significant structural change compared to the Meadows (1970) model was to distinguish between the slaughtering of breeding stock once fertility decreases and the slaughtering of ostriches that reach the age at which optimum yield is received upon slaughter. Ostriches reach optimum yield, and are therefore slaughter-ready, at 11 months of age (ECIAfrica (Pty) Ltd, 2010). Sexual maturity is reached after more than triple the age that produces optimum yield, at an average of 3 years of age. Ostriches remain fertile for an average of 10 years (South African Ostrich Business Chamber, 2006). This structural change was decided upon because the generic livestock commodity cycle is designed for livestock that reproduces before, or at least relatively close to, the slaughter age of the animal. Due to the age discrepancy of more than a factor of 10, the quality of meat and leather from slaughtered breeding stock differs drastically from that of mature ostriches. The difference is so prominent that income received from slaughtered breeding stock is negligible relative to that of slaughter-ready ostriches. It is therefore significant to keep the two different slaughter rates separate in contrast to most of the commonly used livestock production system dynamic models.

The second significant structural change made to the Meadows (1970) model is that the breeding process is not simulated with stocks, in other words, a stock for eggs, chicks and juvenile ostriches have not been added. The expected stocks are replaced with converters with time-delay functions as shown in Appendix C. The motivation for this decision is two-fold. Firstly, the admission of such stocks is considered a reasonable way of simplifying the model since the stocks do not add much analytical value to the main objective of the project. Secondly, admission of the stocks in favour of fixed time-delay functions is a more accurate depiction of reality since the hatching process is dependent on fixed parameters rather than average times. A function delayed with a set prescribed time is a more realistic than a stock being adjusted by a *adjustment time* converter that subsequently creates a first-order system when depicting this specific situation.

This concludes the discussion around the structural differences between OIMSA and Meadows (1970). The following section, Section 4.3.2, introduces the reference mode parameters describing the ostrich production industry of South Africa.

4.3.2 OIMSA reference mode

System dynamics models can be either quantitative/numerical or qualitative/conceptual in nature (Dolando, 2011). Quantitative modelling, in this case stock and flow modelling, is constrained by the availability and accuracy of data. This section formalises the reference mode parameters describing the ostrich industry of South Africa.

Availability, as well as large discrepancies in the data received between the different sources, proved to be a big constraint throughout the model building process. No single data source could be identified as having data relevant to the model reference mode available for the entire period of study. Due to large discrepancies reported by different stakeholders in the ostrich industry, the minimum amount of exogenous variables have been identified for use during the reference mode. The criteria when deciding which combination of data sources to use as a reference mode was:

- reliability of the data source,
- minimising data discrepancies, and
- using least number of sources.

Based on the above criteria, three different reference mode parameters were identified from two sources: Ostrich Slaughter Rate, Gross Producer Value of Leather in SA and Gross Producer Value of Meat in SA. The reference mode parameters used are listed in Table 4.3 with their corresponding sources. The annual values of the reference mode variables can be found in Appendix C.

National Agricultural Marketing Council (2003) was used for data on all three parameters from 1993 to 2002. Personal correspondence with Lareman (2015), Financial Manager of Klein Karoo International Ltd., yielded data on the total number of ostriches slaughtered for the period: 2003-2014. Furthermore, Lareman (2015) provided data on the income received from ostrich leather and meat for the period 2005-2014 resulting in the income received in 2003 and 2004 being extrapolated.

Table 4.3: Variables indicative of the reference mode

Parameter	Type	Source
Reference Mode Ostrich Slaughter Rate	Time series	National Agricultural Marketing Council (2003) Lareman (2015)
Reference Mode Gross Producer Value of Leather in SA	Time series	National Agricultural Marketing Council (2003) Lareman (2015)
Reference Mode Gross Producer Value of Meat in SA	Time series	National Agricultural Marketing Council (2003) Lareman (2015)

Two more reference mode parameters are defined as a combination of the before mentioned parameters. No additional data was used to generate Producer Price of Leather per Ostrich and Producer Price of Meat per Ostrich (see Appendix C). See Table 4.4 for a list of reference mode parameters with their corresponding endogenously created OIMSA variables.

Table 4.4: OIMSA reference mode parameters with corresponding model variables

Reference Mode Parameter	Corresponding model variable
Reference Mode Ostrich Slaughter Rate	Ostrich Slaughter Rate
Reference Mode Gross Producer Value of Leather in SA	Gross Producer Value of Leather in SA
Reference Mode Producer Price of Leather per Ostrich	Producer Leather Price per Ostrich in Rand
Reference Mode Gross Producer Value of Meat in SA	Gross Producer Value of Meat in SA
Reference Mode Producer Price of Meat per Ostrich	Producer Meat Price per Ostrich in Rand

Note that reference mode parameters are only used for initialising stocks in Section 4.3 - never to create dynamic behaviour in the model.

This concludes the introduction of reference mode parameters describing the ostrich production industry of South Africa. In the following section, Section 4.3.3, the exogenous variables that influence OIMSA are explicitly defined.

4.3.3 OIMSA exogenous variables

Exogenous variables are variables that exist outside the boundary of the model (therefore is not influenced by the dynamics of the model), but still influences the model behaviour (Sterman, 2000). This section explicitly defines all the variables exogenous to OIMSA.

Section 4.2.1 introduced key system variables in Table 4.1, classified as either endogenous or exogenous, in aid of explaining the dynamic model. For the next step, introducing the OIMSA structure and equations, a conclusive list of parameters identified as exogenous is listed, with references, in Table 4.5. Values can be found in Appendix C. The exogenous nature of each variable in Table 4.5 is covered by the assumptions in Section 4.1.

Table 4.5: Exogenous variables used in OIMSA

Parameter	Type	Source
Cost of Lucerne per kg	Time series	DAFF (2013)
Cost of Maize per kg	Time series	DAFF (2013)
Cost of Sunflower Seeds per kg	Time series	DAFF (2013)
Presence of Japanese Recession	Time series	National Agricultural Marketing Council (2003)
Presence of Worldwide Economic Recession	Time series	National Bureau of Economic Research, Inc. (2010)
Rand Dollar Exchange Rate	Time series	Quantec EasyData (2015*b*)
Rand Euro Exchange Rate	Time series	Quantec EasyData (2015*a*)
European HICP	Time series	Triami Media BV (2015)
Presence of BSE and FMD in Europe	Time series	National Agricultural Marketing Council (2003)
Presence of the 2004 Bird Flu Epidemic	Time series	Center for Infectious Disease Research and Policy (2004)
Presence of the 2011 Bird Flu Epidemic	Time series	Curnow and Kermeliotis (2012)
Number of Ostriches Culled in the 2004 Bird Flu Epidemic	Constant	BBC (2004)
Number of Ostriches Culled in the 2011 Bird Flu Epidemic	Constant	Curnow and Kermeliotis (2012)
Duration of the 2004 Bird Flu Epidemic	Constant	Center for Infectious Disease Research and Policy (2004)
Duration of the 2011 Bird Flu Epidemic	Constant	Curnow and Kermeliotis (2012)

This concludes the section explicitly defining exogenous variables influencing OIMSA. In the following section, Section 4.3.4, OIMSA's PRIMARY

Production sector structure and equations are defined.

4.3.4 OIMSA Primary Production sector structure and equations

The Primary Production sector forms the backbone of the model. This section defines the structure and equations of the Primary Production sector of OIMSA. It is the only sector that has input variables from all other model sectors. Refer to Table 4.6 for a list of input variables with corresponding sectors of origin. All Primary Production sector parameter assumptions are listed in Table 4.7 with their corresponding sources. See Appendix C for the numerical values of the listed parameter assumptions.

Table 4.6: Primary Production sector input variables

Variable Name	Sector of Origin
Producer Cost per Ostrich	Producer Cost
Producer Price of Other Products per Ostrich	Producer Cost
Producer Leather Price per Ostrich in Rand	Leather Income
Producer Meat Price per Ostrich in Rand	Meat Income
Presence of Worldwide Economic Recession	Meat Income

Table 4.7: Primary Production sector parameter assumptions

Parameter	Source
Breeding Seasons per Year	South African Ostrich Business Chamber (2006)
Fraction of Females in Breeding Stock	South African Ostrich Business Chamber (2006)
Eggs per Hen per Breeding Season	South African Ostrich Business Chamber (2006)
Hatch Fraction	South African Ostrich Business Chamber (2006)
Time to Hatch	South African Ostrich Business Chamber (2006)
Net Chick Survival Fraction	South African Ostrich Business Chamber (2006)
Maturation Time	South African Ostrich Business Chamber (2006)
Age of Sexual Maturity	South African Ostrich Business Chamber (2006)
Average Breeding Period	South African Ostrich Business Chamber (2006)
Mature Ostrich Feeding Period	South African Ostrich Business Chamber (2006)
Constant Multiplication Factor for Desirability	-
Minimum Breeding Ostriches Reduction Time	-

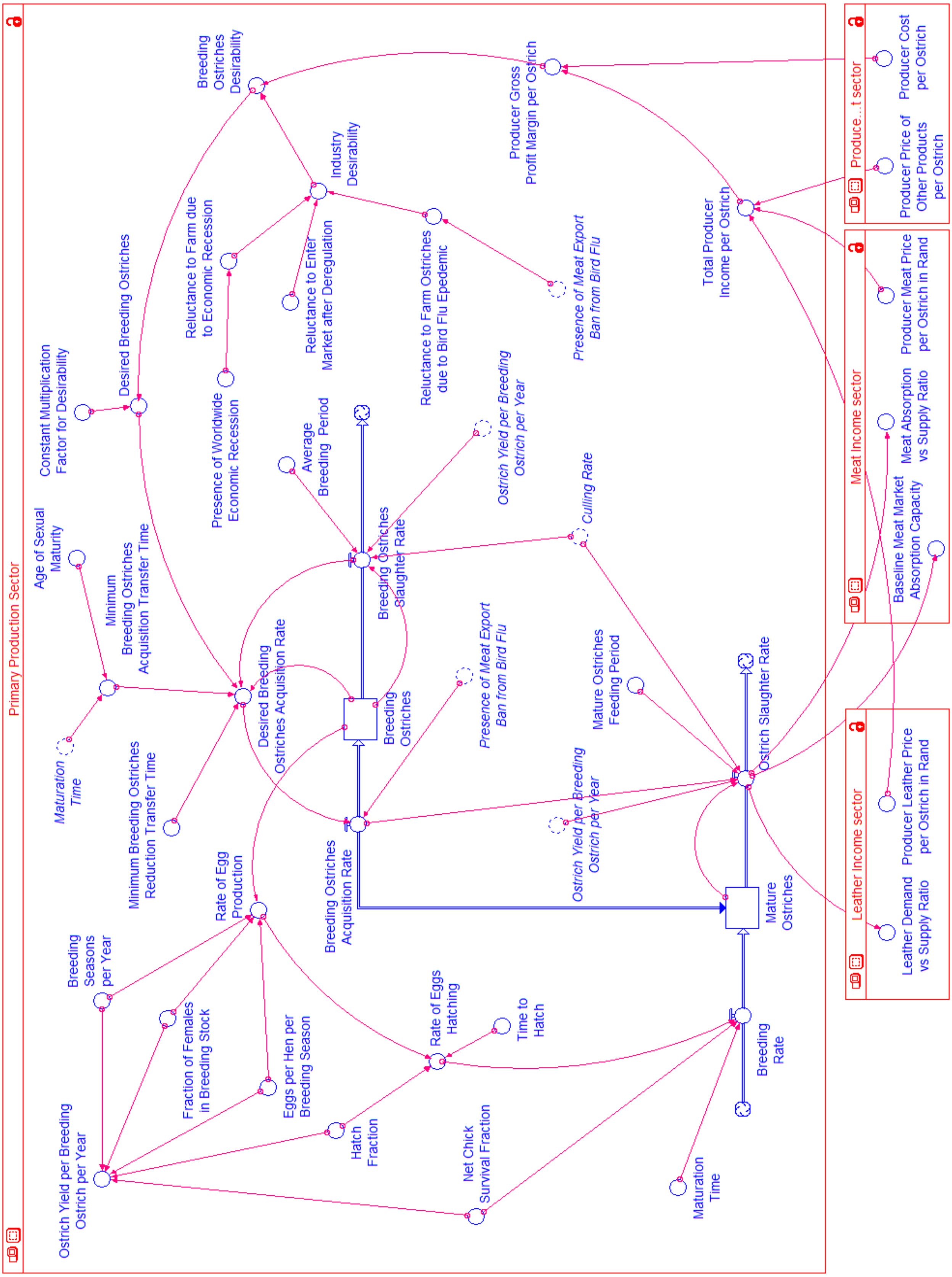


Figure 4.2: Stock and flow diagram of the PRIMARY PRODUCTION sector of OIMSA

The Primary Production sector consists of two stocks and four flows, as shown in Figure 4.2. The stocks, Breeding Ostriches ($\mathrm{BO}(t)$, in ostrich) and Mature Ostriches ($\mathrm{MO}(t)$, in ostrich), are connected through the flow Breeding Ostriches Acquisition Rate (r_{BOAR}, in ostrich/year).

4.3.4.1 Breeding Ostriches stock

The non-negative stock, Breeding Ostriches ($\mathrm{BO}(t)$, in ostrich), is connected to two flows: a uniflow positioned as an outflow, Breeding Ostriches Slaughter Rate (r_{BOSR}, in ostrich/year), and a biflow positioned as an inflow, Breeding Ostriches Acquisition Rate (r_{BOAR}, in ostrich/year). The dynamics of $\mathrm{BO}(t)$, in (ostrich), is defined as

$$\mathrm{BO}(t) = \mathrm{BO}(t_0) + \int_{t_0}^{t} \Big(r_{\mathrm{BOAR}} - r_{\mathrm{BOSR}} \Big) dt \tag{4.3.1}$$

where $\mathrm{BO}(t_0)$ (in ostrich) representing the reference mode is defined using the reference mode parameter listed in Table 4.3, Reference Mode Ostrich Slaughtered Rate in SA ($a_{\mathrm{OSR}}(t)$, in ostrich/year) at time, t_0, and the endogenously calculated converter, Ostrich Yield per Breeding Ostrich per Year (k_{yield}, in /year) that is defined as the product of constant parameter assumptions. Both $a_{\mathrm{OSR}}(t)$ (in ostrich/year) and k_{yield} (in /year) is defined in Appendix C.

$$\mathrm{BO}(t_0) = \frac{a_{\mathrm{OSR}}(t_0)}{k_{\mathrm{yield}}} \tag{4.3.2}$$

See Equation 4.3.47 in Section 4.3.8.2 for the definition of $\mathrm{BO}(t_0)$ (in ostrich) resulting in model equilibrium. Even though k_{yield} (in /year), is a constant value, it is defined as an equation rather than a derived constant to add robustness to the model. k_{yield} (in /year) is automatically adjusted when any of the variables making up k_{yield} (in /year), namely Net Chick Survival Fraction (c_{CSF}, in ostrich/chick), Hatch Fraction (c_{HF}, in chick/egg), Breeding Seasons per Year (c_{BS}, in season/year), Fraction of Females in Breeding Stock (c_{FBS}, in hen/ostrich), or Eggs per Hen per Breeding Season (c_{EH}, in eggs/(hen $\times$ season)), is changed during the policy-testing.

$$k_{\mathrm{yield}} = c_{\mathrm{CSF}} \times c_{\mathrm{HF}} \times c_{\mathrm{BS}} \times c_{\mathrm{FBS}} \times c_{\mathrm{EH}} \tag{4.3.3}$$

Breeding Ostriches Slaughter Rate flowrate

The Breeding Ostriches Slaughter Rate (r_{BOSR}, in ostrich/year) is made up of two components. The first component, r'_{BOSR} (in ostrich/year), represents the rate at which old breeding stock is slaughtered once their fertility starts declining and is determined using the stock defined in Equation 4.3.1, $\mathrm{BO}(t)$ (in ostrich), and the adjustment time, Average Breeding Period (c_{ABP}, in year), defined as a constant parameter assumption in Table 4.7.

$$r'_{\text{BOSR}} = \frac{\text{BO}(t)}{c_{\text{ABP}}} \tag{4.3.4}$$

The second component, r''_{BOSR} (in ostrich/year), represents the rate at which BO(t) (in ostrich), is culled during bird flu outbreaks. Section 4.1.4 assumes that culling is to affect the entire ostrich population uniformly. Under normal conditions the population fraction between BO(t) (in ostrich), and ostriches intended for slaughter,

$$\text{BO}(t) : \text{ostriches intended for slaughter}, \tag{4.3.5}$$

is assumed to be

$$1 : k_{\text{yield}}. \tag{4.3.6}$$

Therefore the fraction of the total Culling Rate (k_{CR}, in ostrich/year) that is to originate from BO(t) (in ostrich) is

$$r''_{\text{BOSR}} = k_{\text{CR}} \times \frac{1}{k_{\text{yield}} + 1}. \tag{4.3.7}$$

The rest of k_{CR} (in ostrich/year) originates from the stock MO(t) (in ostrich), as shown in Section 4.3.4.2.

By combining the two components, r_{BOSR} (in ostrich/year) is defined as

$$r_{\text{BOSR}} = \frac{\text{BO}(t)}{c_{\text{ABP}}} + k_{\text{CR}} \times \frac{1}{k_{\text{yield}} + 1}. \tag{4.3.8}$$

Breeding Ostriches Acquisition Rate flowrate

Section 4.2.2 explains how the PRIMARY PRODUCTION sector uses a *worse-before-better* approach during production planning. In accordance to the *worse-before-better* approach, production of slaughter-ready ostriches are increased by withholding Mature Ostriches from slaughter to increase the Breeding Ostriches sustainably in the long term. This concept in implemented in the OIMSA's SFD, shown in Figure 4.2, by defining Breeding Ostriches Acquisition Rate as the primary outflow of Mature Ostriches and Ostrich Slaughter Rate as the secondary outflow. This behaviour is defined mathematically through the secondary outflow, Ostrich Slaughter Rate, in Section 4.3.4.2. There is no mathematical implication on Breeding Ostriches Acquisition Rate.

The Breeding Ostriches Acquisition Rate (r_{BOAR}, in ostrich/year) is dependent on the endogenously determined variables listed in Table 4.7, Desired Breeding Ostriches Acquisition Rate (k_{DBOAR} (in ostrich/year) and Presence of Meat Export Ban from Bird Flu ($k_{\text{MEB}}(t)$, in dimensionless units). r_{BOAR} (in ostrich/year) is mathematically expressed as

$$r_{\text{BOAR}} = k_{\text{DBOAR}} \times (1 - k_{\text{MEB}}(t)) \tag{4.3.9}$$

where $k_{\text{MEB}}(t)$ (in dimensionless units), defined mathematically in Appendix C, is a binary variable so that:

$$k_{\text{MEB}}(t) = \begin{cases} 1, & \text{during periods of EU meat export ban;} \\ 0, & \text{otherwise.} \end{cases} \tag{4.3.10}$$

The endogenous converter, k_{DBOAR} (in ostrich/year), is a goal-seeking function that attempts to reconcile MO(t) (in ostrich) with the endogenous converter, Desired Breeding Ostriches (k_{DBO}, in ostrich). k_{DBOAR} (in ostrich/year) uses the difference between k_{DBO} (in ostrich) and BO(t) (in ostrich) as the goal. As discussed in Section 4.2.2, a different adjustment time is used depending on the direction of the flow. During instances where there is a positive difference between k_{DBO} (in ostrich) and BO(t) (in ostrich), the Minimum Breeding Ostriches Acquisition Transfer Time (k_{MATT}, in year), corresponding to the time it takes MO(t) (in ostrich) to reach sexual maturity, is used as adjustment time. During instances where there is a negative difference, Minimum Breeding Ostriches Reduction Transfer Time (c_{MRTT}, in year), corresponding to the time it takes the primary producer to act on the desire to decrease the Breeding Ostriches population, is used. The converter also takes the outflow from BO(t) (in ostrich), expressed as r_{BOSR} (in ostrich/year) in Section 4.3.8, into account to compensate for the loss associated with slaughtering Breeding Ostriches due to decline in fertility.

$$k_{\text{DBOAR}} = \begin{cases} \dfrac{k_{\text{DBO}} - \text{BO}(t)}{k_{\text{MATT}}} + r_{\text{BOSR}}, & \text{if } (k_{\text{DBO}} - \text{BO}(t)) \geq 0; \\ \dfrac{k_{\text{DBO}} - \text{BO}(t)}{c_{\text{MRTT}}} + r_{\text{BOSR}}, & \text{if } (k_{\text{DBO}} - \text{BO}(t)) < 0. \end{cases} \tag{4.3.11}$$

4.3.4.2 Mature Ostriches stock

The SFD in Figure 4.2 shows the non-negative stock, Mature Ostriches (MO(t), in ostrich), is connected to three flows - one inflow and two outflows - while Breeding Ostriches (BO(t), in ostrich) is shown to be connected to a single inflow and outflow. The inflow, Breeding Rate (r_{BR}, in ostrich/year), and the outflow, Ostrich Slaughter Rate (r_{OSR}, in ostrich/year), are both unidirectional in nature while the second outflow, Breeding Ostriches Acquisition Rate (r_{BOAR}, in ostrich/year), is bidirectional. r_{BOAR} (in ostrich/year) connects MO(t) (in ostrich) with BO(t) (in ostrich). The stock, MO(t) (in ostrich), is defined as

$$\text{MO}(t) = \text{MO}(t_0) + \int_{t_0}^{t} \Big(r_{\text{BR}} - r_{\text{BOAR}} - r_{\text{OSR}}\Big)dt. \tag{4.3.12}$$

where $\text{MO}(t_0)$ (in ostrich) representing the reference mode is initialised using the reference mode parameter shown in Table 4.3, Reference Mode Ostrich Slaughtered Rate in SA ($a_{\text{OSR}}(t)$, in ostrich/year) from the year the model was initialised at t_0 and multiplied by the constant parameter assumption, Mature Ostrich Feeding Period (c_{MOFP}, in year), defined in Table 4.7.

$$\text{MO}(t_0) = a_{\text{OSR}}(t_0) \times c_{\text{MOFP}} \tag{4.3.13}$$

See Equation 4.3.45 in Section 4.3.8.2 for the definition of $\text{MO}(t)$ (in ostrich) for model equilibrium. It is worth noting that r_{BOAR} (in ostrich/year) is considered an outflow of $\text{MO}(t)$ (in ostrich) and an inflow of $\text{BO}(t)$ (in ostrich) however, since the flow is defined as bidirectional, the flow can be measured as negative, translating into ostriches flowing from $\text{BO}(t)$ to $\text{MO}(t)$.

Breeding Rate flowrate

Section 4.3.1 makes the argument for not using any stocks when simulating the breeding process. Instead, the process is represented by endogenously defined converters using the fixed time-delay function in the iThink® software. The exogenous input variables are listed in Table 4.7 and defined mathematically in Appendix C. Ostrich breeding is simulated in three different steps and is explained from the third step to the first step.

The third and final step of ostrich breeding is the grow-out of chicks into slaughter-ready ostriches, shown as Breeding Rate (r_{BR}, in ostrich/year). r_{BR} (in ostrich/year) is dependent on the second phase of ostrich breeding, represented by the Rate of Eggs Hatching (k_{REH}, in chick/year), delayed by the constant parameter assumption, Maturation Time (c_{MT}, in year). r_{BR} (in ostrich/year) is multiplied by the constant parameter assumption, Net Chick Survival Fraction (c_{CSF}, in ostrich/chick). r_{BR} (in ostrich/year) is defined using the constant delay function built into the iThink® software:

$$r_{\text{BR}} = \text{DELAY}(k_{\text{REH}}, c_{\text{MT}}) \times c_{\text{CSF}}. \tag{4.3.14}$$

The second step of ostrich breeding entails incubation and hatching of eggs and is represented by k_{REH} (in chick/year). k_{REH} (in chick/year) is dependent on the Rate of Egg Production (k_{REP}, in egg/year), delayed by Time to Hatch (c_{TH}, in year) and multiplied by Hatch Fraction (c_{HF}, in chick/egg). Both constant parameter assumptions are defined in Table 4.7. k_{REH} (in egg/year) is defined using iThink®'s constant delay function:

$$k_{\text{REH}} = \text{DELAY}(k_{\text{REP}}, c_{\text{TH}}) \times c_{\text{HF}}. \tag{4.3.15}$$

The first step of ostrich breeding is laying eggs. The rate at which eggs are lain is defined as Rate of Egg Production (k_{REP}, in egg/year). The three constant parameter assumptions from - Breeding Seasons per Year (c_{BS}, in season/year), Fraction of Females in Breeding Stock (c_{FBS}, in hen/ostrich), and Eggs per Hen per Breeding Season (c_{EH}, in eggs/(hen × season)) - are used along with one stock, BO(t) (in ostrich), to calculate k_{REP} (in egg/year).

$$k_{\mathrm{REP}} = \mathrm{BO}(t) \times c_{\mathrm{BS}} \times c_{\mathrm{FBS}} \times c_{\mathrm{EH}} \tag{4.3.16}$$

Ostrich Slaughter Rate flowrate

The Ostrich Slaughter Rate (r_{OSR}, in ostrich/year) is one of two outflows originating at the MO(t) (in ostrich) stock. r_{OSR} (in ostrich/year) is comprised of two components, resembling that of r_{BOSR} (in ostrich/year), shown in Section 4.3.4.1. The first section represents the slaughter of slaughter-ready ostriches while the second represents the rate at which slaughter-ready ostriches are culled during periods of bird flu.

The first component, r'_{OSR} (in ostrich/year), is calculated using the stock, MO(t) (in ostrich), and the adjustment time, Mature Ostrich Feeding Period (c_{MOFP}, in year), listed as a constant parameter assumption in Table 4.7 and defined mathematically in Appendix C.

As mentioned in Section 4.2.2, OIMSA assumes that a *worse-before-better* policy is used by the farmer to plan ostrich production levels. This policy is implemented in the SFD by defining r_{OSR} (in ostrich/year) as the secondary outflow of the stock, MO(t) (in ostrich). This means that the Breeding Ostriches Acquisition Rate (r_{BOAR}, in (ostrich/year), always receives preference if MO(t) (in ostrich), does not have enough stock to satisfy both flows. Mathematically, r'_{OSR} (in ostrich/year), is shown as

$$r'_{\mathrm{OSR}} = \begin{cases} \dfrac{\mathrm{MO}(t)}{c_{\mathrm{MOFP}}} - r_{\mathrm{BOAR}}, & \text{if } r_{\mathrm{BOAR}} \geq 0; \\ \dfrac{\mathrm{MO}(t)}{c_{\mathrm{MOFP}}}, & \text{if } r_{\mathrm{BOAR}} < 0. \end{cases} \tag{4.3.17}$$

As stated in Section 4.1.4, culling of ostriches is assumed to affect the entire ostrich population uniformly. From Section 4.3.4.1 deduces that the second component of r_{OSR}, defined as r''_{OSR} in (ostrich/year), is equal to

$$r''_{\mathrm{OSR}} = k_{\mathrm{CR}} \times \left(1 - \frac{1}{k_{\mathrm{yield}} + 1}\right) = k_{\mathrm{CR}} \times \frac{k_{\mathrm{yield}}}{k_{\mathrm{yield}} + 1}. \tag{4.3.18}$$

Combining Equations 4.3.17 and 4.3.18, r_{OSR}, in (ostrich), is defined as

$$r_{\mathrm{OSR}} = \begin{cases} \dfrac{\mathrm{MO}(t)}{c_{\mathrm{MOFP}}} - r_{\mathrm{BOAR}} + \dfrac{k_{\mathrm{CR}} \times k_{\mathrm{yield}}}{(k_{\mathrm{yield}} + 1)}, & \text{if } r_{\mathrm{BOAR}} \geq 0; \\ \dfrac{\mathrm{MO}(t)}{c_{\mathrm{MOFP}}} + \dfrac{k_{\mathrm{CR}} \times k_{\mathrm{yield}}}{(k_{\mathrm{yield}} + 1)}, & \text{if } r_{\mathrm{BOAR}} < 0. \end{cases} \tag{4.3.19}$$

4.3.4.3 System driving force

The Producer Gross Profit Margin per Ostrich (k_{GPM}, in unitless dimension) is one of the key drivers determined endogenously. It is defined by the Total Producer Income per Ostrich (k_{PI}, in Rand/ostrich), and the input variable from the Production Cost sector, Producer Cost per Ostrich (k_{PC}, in Rand/ostrich), as listed in Table 4.6. Using a delay function, k_{GPM} (in unitless dimensions) is calculated as:

$$k_{\text{GPM}} = \frac{k_{\text{PI}}}{\text{DELAY}(k_{\text{PC}}, 1)}. \tag{4.3.20}$$

A second key driver is the Culmination of Ostrich Farming Reluctances (k_{R}, in unitless dimensions), shown in Figure 4.3, indicates the reluctance of farmers to produce ostriches as a percentage where 100% indicates no reluctance and 0% indicates absolute reluctance. Reluctance to farm ostriches is discussed in Section 4.1.2.

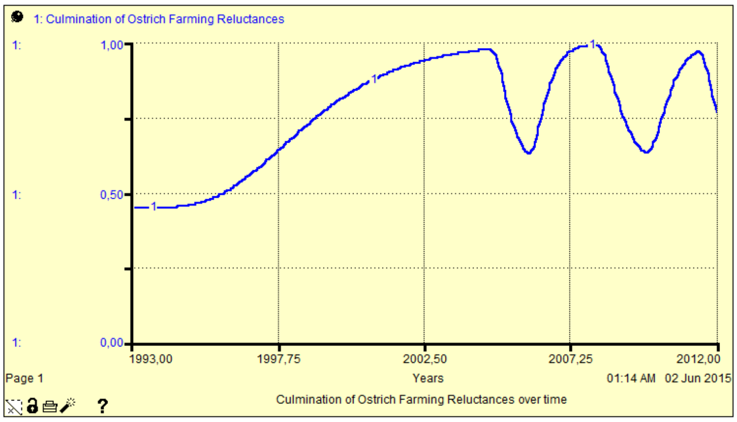


Figure 4.3: Development of (k_{R}, in unitless dimensions) over time

k_{R} (in unitless dimensions), is defined by the product of three different endogenous variables defined in Appendix C, namely: Reluctance to enter Market after Deregulation (k_{RD}, in unitless dimensions), Reluctance to Farm Ostriches due to Bird Flu Epidemic (k_{RBF}, in unitless dimensions), and the Reluctance to Farm due to Economic Recession (k_{RER}, in unitless dimensions).

k_{R} (in unitless dimensions) is used along with k_{GPM} (in unitless dimension), to determine the Industry Desirability (k_{ID}, in unitless dimension):

$$k_{\text{ID}} = k_{\text{GPM}} \times k_{\text{R}}. \tag{4.3.21}$$

The system driving force, identified as the endogenous parameter, Desired Breeding Ostriches (k_{DBO}, in ostrich), is defined using k_{BSD} (in unitless dimension) and a constant parameter assumption, Constant Multiplication Factor for Desirability (c_D, in ostrich), defined in Appendix C.

$$k_{\mathrm{DBO}} = k_{\mathrm{BSD}} \times c_{\mathrm{D}} \tag{4.3.22}$$

4.3.4.4 Primary Production sector output variables

The sector supplies output variables to the two commodity sectors, Meat Income and Leather Income, as shown in Table 4.8. The Primary Production sector forms part of all four major feedback loops **B1**, **R2**, **R1** and **R3** through the output variable Ostrich Slaughter Rate.

Table 4.8: Primary Production sector output variables

Variable Name	Sector Destination
Ostrich Slaughter Rate	Leather Income
Ostrich Slaughter Rate	Meat Income
Presence of Meat Export Ban from Bird Flu	Meat Income

This concludes the section defining the structure and equations of OIMSA's Primary Production sector. In the following section, Section 4.3.5, OIMSA's Leather Income sector structure and equations are defined.

4.3.5 OIMSA Leather Income sector structure and equations

Income from ostrich leather has been the dominant driving force in determining ostrich production since de-regulation in 1993 (ECIAfrica (Pty) Ltd, 2010). Since ostrich products are considered luxury goods, the income per ostrich from ostrich leather is dependent on the amount of ostrich leather in the market, therefore the quantity produced, as well as the economic climate (National Agricultural Marketing Council, 2003; Mugido, 2011). This section defines the structure and equations of OIMSA's Leather Income sector.

4.3.5.1 Leather Income sector input variables and parameter assumptions

The Leather Income sector input variables are listed in Table 4.9. The input variable, Ostrich Slaughter Rate (r_{OSR}, in ostrich/year), from the Primary Production sector, feeds into the Leather Income sector via k_{LDSR} (in unitless dimension), shown in Equation 4.3.27, forming part of a major feedback loop in the system. All Leather Income sector parameter assumptions are listed in Table 4.10 with their corresponding sources. See Appendix C for the numerical values of the listed parameter assumptions.

Table 4.9: LEATHER INCOME sector input variables

Variable Name	Sector of Origin
Ostrich Slaughter Rate	PRIMARY PRODUCTION
Presence of Worldwide Economic Recession	MEAT INCOME

Table 4.10: LEATHER INCOME sector parameter assumptions

Parameter
Leather Price Adjustment Time
Baseline Leather Market Demand
Minimum Value of Leather
Floor Value for Leather Price Adjustment
Minimum Leather Value Adjustment Time

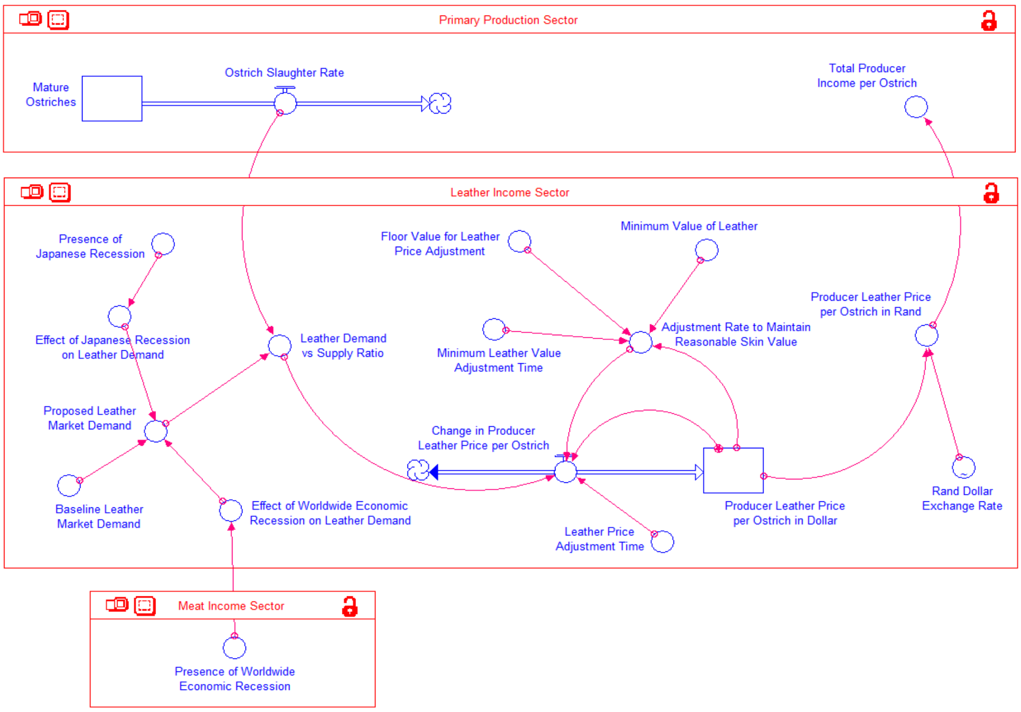


Figure 4.4: Stock and flow diagram of the LEATHER INCOME sector of OIMSA

4.3.5.2 Producer Leather Price per Ostrich in Dollar stock

The LEATHER INCOME sector consists of one non-negative stock, Producer Leather Price per Ostrich in Dollar (LP(t), in Dollar/ostrich) and one regulating biflow, Change in Producer Leather Price per Ostrich (r_{CLP}, in Dollar/(ostrich × year)). The dynamics of LP(t) (in Dollar/ostrich), is mathematically represented as:

$$\text{LP}(t) = \text{LP}(t_0) + \int_{t_0}^{t} \Big(r_{\text{CLP}}\Big)\, dt. \tag{4.3.23}$$

Where LP($_0$) (in Dollar/ostrich) representing the reference mode, is initialised using reference mode parameters shown in Table 4.3: Reference Mode Gross Producer Value of Leather in SA ($a_{VL}(t)$, in Rand) and Reference Mode Ostrich Slaughter Rate ($a_{OSR}(t)$, in ostrich/year), as well as the exogenous variable shown in Table 4.5: Rand Dollar Exchange Rate ($h_{RD}(t)$, in Rand/Dollar). The time-series value corresponding to the time t_0 for all three abovementioned variables are used to initialize LP(t_0) as

$$\text{LP}(t_0) = \frac{a_{VL}(t_0)}{a_{OSR}(t_0) \times h_{RD}(t_0)}. \tag{4.3.24}$$

See Equation 4.3.55 in Section 4.3.8.2 for the definition of LP(t_0) (in Dollar/ostrich) for model equilibrium.

Change in Producer Leather Price per Ostrich flowrate

r_{CLP} (in Dollar/(ostrich × year)) is comprised of two separate minor feedback loops. The first minor feedback loop adjusts LP(t), in (Dollar/ostrich), according to the endogenous parameter, Leather Demand vs Supply Ratio (k_{LDSR}, in unitless dimensions), with a parameter assumption adjustment time, Leather Price Adjustment Time (c_{LPAT}, in year). The second major feedback loop relies on the endogenously defined parameter, Adjustment Rate to Maintain Reasonable Skin Value (k_{ARSV}, in Dollar/(ostrich × year)). Combined, r_{CLP}, in (Dollar/(ostrich × year)) is defined as:

$$r_{CLP} = \frac{k_{\text{LDSR}} \times \text{LP}(t) - \text{LP}(t)}{c_{\text{LPAT}}} + k_{\text{ARSV}}. \tag{4.3.25}$$

k_{ARSV} (in Dollar/(ostrich × year)), is defined using the built-in iThink® software's first-order delay function, DELAY1, with an adjustment time of 1 year. The delay function input is defined as a MAX function that contains the stock, LP(t) (in Dollar/ostrich), as well as the parameter assumptions, Minimum Value of Leather (c_{MVL}, in Dollar), Minimum Leather Value Adjustment Time (c_{MLAT}, in year) and Floor Value for Leather Price Adjustment (c_{FVL}, in Dollar), defined in Table 4.10:

$$k_{\text{ARSV}} = \frac{\text{DELAY}\left[\text{MAX}(c_{\text{MVL}} - \text{LP}(t), c_{\text{FVL}}), 1\right]}{c_{\text{MLAT}}}. \tag{4.3.26}$$

k_{LDSR} (in unitless dimension), is the ratio between the leather supply rate, relating to the input variable, r_{OSR} (in ostrich/year) from the PRIMARY PRODUCTION sector, and the Proposed Leather Market Demand (k_{PLMD}, in ostrich/year) defined in Section 4.3.5.2. k_{LDSR} (in unitless dimension) is defined as:

$$k_{\text{LDSR}} = \begin{cases} 1, & \text{if } r_{OSR} = 0; \\ \dfrac{k_{\text{PLMD}}}{r_{OSR}}, & \text{otherwise.} \end{cases} \tag{4.3.27}$$

Proposed Leather Market Demand endogenous variable

The South African Ostrich Business Chamber recommended a annual total national production rate of 25000 ostriches for leather to retain its exclusivity under normal economic conditions (ECIAfrica (Pty) Ltd, 2010). The most prominent deviations from normal market conditions, affecting the market size for ostrich leather, has been the Japanese recession in the 1900's and the world-wide economic recession in 2009 (National Agricultural Marketing Council, 2003; ECIAfrica (Pty) Ltd, 2010).

The endogenous converter, Proposed Leather Market Demand (k_{PLMD}, in ostrich/year), is defined as the product of the constant parameter assumption, Baseline Leather Market Demand (c_{BLD}, in ostrich/year), and the endogenously determined, Effect of Japanese Recession on Leather Demand (k_{JRL}, in unitless dimension), and Effect of Worldwide Economic Recession on Leather Demand (k_{ERL}, in unitless dimension). k_{PLMD} (in ostrich/year) is shown graphically in Figure 4.5. Mathematically k_{PLMD} (in ostrich/year) is shown as:

$$k_{\text{PLMD}} = c_{\text{BLD}} \times k_{\text{JRL}} \times k_{\text{ERL}}. \tag{4.3.28}$$

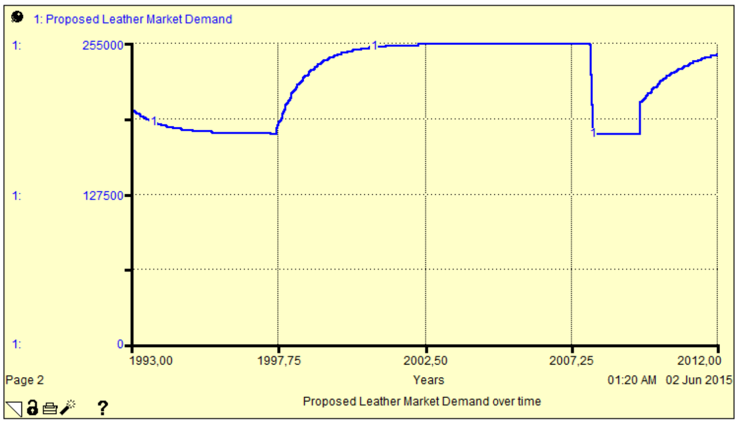


Figure 4.5: Development of k_{PLMD} (in ostrich/year) over time

Where c_{BLD} (in ostrich/year) is defined in Table 4.10 as 102% of the value recommended by ECIAfrica (Pty) Ltd (2010).

Upon deregulation of the South African ostrich industry, the Japanese ostrich leather market - the main market for ostrich leather products at the time - started declining as a result of the Japanese economy being in a recession since 1993 to the late 1990's (National Agricultural Marketing Council, 2003). k_{JRL} (in unitless dimension) is modelled using the iThink® software's first-order delay function as shown in Appendix C.

Over time, the main ostrich leather market shifted to the United States of America for nieche applications like cowboy boots and other luxury items and was therefore heavily affected by the worldwide economic recession (ECIAfrica (Pty) Ltd, 2010; National Agricultural Marketing Council, 2003). k_{ERL} (in unitless dimension) is modelled using the iThink® software's first-order delay function in conjunction with a MAX function to combine instantaneous and accumulative effects of the recession, as shown in Appendix C.

4.3.5.3 Leather Income sector output variables

The Leather Income sector output variables are listed in Table 4.11. The output variable, Producer Leather Price per Ostrich in Rand (k_{LP}, in Rand/ostrich), forms part of a major feedback loop in the system. k_{LP} (in Rand/ostrich) is defined by converting $\text{LP}(t)$, in (Dollar/ostrich), into Rand using the exogenous variable $h_{\text{RD}}(t)$, in (Rand/Dollar):

$$k_{\text{LP}} = \text{LP}(t) \times h_{\text{RD}}(t). \quad (4.3.29)$$

Table 4.11: Leather Income sector output variables

Variable Name	Sector Destination
Producer Leather Price per Ostrich in Rand	Primary Production

This concludes the section defining the structure and equations of OIMSA's Leather Income sector. In the following section, Section 4.3.6, OIMSA's Meat Income sector structure and equations are defined.

4.3.6 OIMSA Meat Income sector structure and equations

The Baseline Meat Market Absorption Capacity is considered to be the size of the market, in other words the amount of ostrich meat that people want to buy, which changes as the system changes. The reason the definition is formulated in reference to the quantity of ostriches instead of the quantity of people wanting to buy ostrich meat is so that the units (ostrich/year) match that of the Ostrich Slaughter Rate.

Since deregulation of the market in 1993, ostrich meat has grown to become a solid secondary source of income through development of both an export and local market (National Agricultural Marketing Council, 2003). The ostrich meat market is considered to be more robust then the ostrich leather market (ECIAfrica (Pty) Ltd, 2010). This section defines the structure and equations of OIMSA's Meat Income sector.

4.3.6.1 Meat Income sector input variables and parameter assumptions

The Meat Income sector input variables are listed in Table 4.12. The input variable, Ostrich Slaughter Rate (r_{OSR}, in ostrich/year), from the Primary Production sector, feeds into the Meat Income sector via k_{MASR} (in unitless dimension), shown in Equation 4.3.33, forming part of a major feedback loops **R2** and **R3** in the system. All Meat Income sector parameter assumptions are listed in Table 4.13. See Appendix C for the numerical values of the listed parameter assumptions.

Table 4.12: Meat Income sector input variables

Variable Name	Sector of Origin
Ostrich Slaughter Rate	Primary Production
Presence of Meat Export Ban from Bird Flu	Primary Production

Table 4.13: MEAT INCOME sector parameter assumptions

Parameter
Percentage of Income Lost Due to Export Ban
Meat Price Adjustment Time
Baseline Meat Price Adjustment Time
Maximum Meat Absorption vs Supply Ratio
Absorption Capacity Adjustment Time
Meat Absorption Capacity Time Delay
Initial Meat Market Capacity
BSE and FMD Panic Time Delay
Aditional Meat Demand

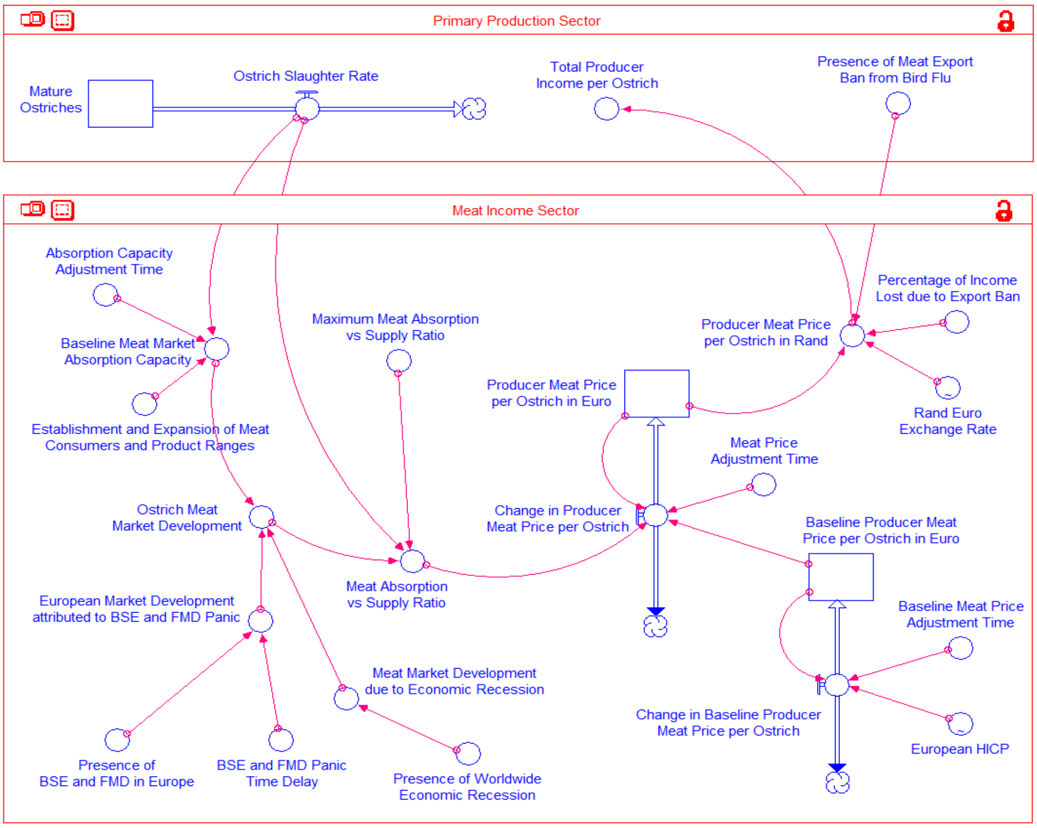


Figure 4.6: Stock and flow diagram of the MEAT INCOME sector of OIMSA

4.3.6.2 Producer Meat Price per Ostrich in Euro stock

The MEAT INCOME sector consists of two non-negative stocks, only one of which forms part of a major feedback loop: Producer Meat Price per Ostrich in Euro (MP(t), in Euro/ostrich) and one regulating biflow, Change in Producer Meat Price per Ostrich (r_{CMP}, in Euro/(ostrich × year)). The dynamics of MP(t) (in Euro/ostrich), is represented mathematically as

$$\text{MP}(t) = \text{MP}(t_0) + \int_{t_0}^{t} \Big(r_{\text{CMP}}\Big) dt. \tag{4.3.30}$$

Where MP(t) in (Euro/ostrich) representing the reference mode is initialised using reference mode parameters shown in Table 4.3: Reference Mode Gross Producer Value of Meat in SA ($a_{VM}(t)$, in Rand), Reference Mode Ostrich Slaughter Rate ($a_{OSR}(t)$, in ostrich/year), as well as the exogenous variable, Rand Euro Exchange Rate ($h_{RE}(t)$, in Rand/Euro) from Table 4.5. The time-series values corresponding to the time t_0 for all three abovementioned variables are used to initialize MP(t) (in Euro/ostrich):

$$\text{MP}(t_0) = \frac{a_{VM}(t_0)}{a_{OSR}(t_0) \times h_{RE}(t_0)}. \tag{4.3.31}$$

See Equation 4.3.53 of Section 4.3.8.2 for the definition of MP(t_0), in (Euro/ostrich) for model equilibrium.

Change in Producer Meat Price per Ostrich flowrate

The r_{CMP} (in Dollar/(ostrich × year)) is comprised of a single minor feedback loop that adjusts MP(t) (in Euro/ostrich), according to the anchor, Baseline Producer Meat Price per Ostrich in Euro (BMP(t), in Euro/ostrich) and the endogenous converter, Meat Absorption vs Supply Ratio (k_{MASR}, in unitless dimensions), as well as an assumed adjustment time, Meat Price Adjustment Time (c_{MPAT}, in year).

$$r_{CMP} = \frac{k_{\text{MASR}} \times \text{BMP}(t) - \text{MP}(t)}{c_{\text{MPAT}}} \tag{4.3.32}$$

k_{MASR}, in (unitless dimension), is the ratio between the meat supply rate, relating to the input variable, r_{OSR}, in (ostrich/year), from the PRIMARY PRODUCTION sector, and the endogenous parameter, Market Meat Absorption Capacity (k_{MMAC}, in ostrich/year), constrained to a maximum value of Maximum Meat Absorption vs Supply Ratio c_{MMASR}, in (unitless dimension), defined in Appendix C as:

$$k_{\text{MASR}} = \begin{cases} 1, & \text{if } r_{OSR} = 0; \\ \text{MIN}\left[\dfrac{k_{\text{MMD}}}{r_{OSR}}, c_{\text{MMASR}}\right], & \text{otherwise.} \end{cases} \tag{4.3.33}$$

Meat Market Absorption Capacity endogenous variable

The most significant factors affecting the market absorption capacity is the market development by representatives of the South African ostrich industry, concern over the safety of red meat produced in the EU, and the worldwide economic recession (ECIAfrica (Pty) Ltd, 2010).

The endogenous converter, Meat Market Development (k_{MMD}, in ostrich/year) is defined as a product of the endogenous variables - Baseline Meat Market Absorption Capacity (k_{BMAC}, in ostrich/year), Meat Market Development due to Economic Recession (k_{MER}, in unitless dimension), and the European Market Development attributed to BSE and FMD Panic (k_{EP}, in unitless dimension):

$$k_{MMD} = k_{\text{BMAC}} \times k_{\text{MER}} \times k_{\text{EP}}. \tag{4.3.34}$$

In the period where mad cow and foot-and-mouth disease was prevalent in livestock produced in the EU, the European consumer sought safer alternatives to traditional red meat. A temporary increase in the demand of ostrich meat was observed during the time of panic (Mugido, 2011). The temporary increase is modelled as k_{EP} (in unitless dimension) using the iThink® programme's first-order delay function, in Appendix C.

The worldwide economic recession had a negative impact on the ostrich meat market to a lesser degree than the leather industry (National Agricultural Marketing Council, 2003). k_{MER} (in unitless dimension) as an instantaneous converter, as shown in Appendix C. The influence of the economic recession on the market absorption capacity, shown as k_{MER} (in unitless dimension), relates to the presence of the economic recession instantaneously, rather than accumulatively, as shown in Appendix C.

The Baseline Meat Market Absorption Capacity (k_{BMAC}, in ostrich/year) is endogenously defined using r_{OSR}, in (ostrich/year), and the parameter assumptions, Aditional Meat Demand (c_{AMD}, in ostrich/year) and Absorption Capacity Adjustment Time (c_{ACAT}, in year) below.

$$k_{BMAC} = \text{DELAY1}[r_{OSR} + c_{\text{AMD}}, c_{\text{ACAT}}] \tag{4.3.35}$$

4.3.6.3 Baseline Producer Meat Price per Ostrich in Euro stock

The second stock in the Meat Income sector, that does not for part of any major feedback in the system, MP(t) (in Euro/ostrich) and one regulating biflow, Change in Baseline Producer Meat Price per Ostrich (r_{CBMP}, in Euro/(ostrich × year)). The dynamics of BMP(t) (in Euro/ostrich), is represented mathematically as

$$\text{BMP}(t) = \text{BMP}(t_0) + \int_{t_0}^{t} \Big(r_{\text{CBMP}} \Big) dt. \tag{4.3.36}$$

Where BMP(t) in (Euro/ostrich) representing the reference mode is initialised using reference mode parameters shown in Table 4.3: Reference Mode Gross Producer Value of Meat in SA ($a_{VM}(t)$, in Rand), Reference Mode Ostrich Slaughter Rate ($a_{OSR}(t)$, in ostrich/year), as well as the exogenous variable, Rand Euro Exchange Rate ($h_{RE}(t)$, in Rand/Euro) from Table 4.5. The time-series values corresponding to the time t_0 for all three abovementioned variables are used to initialize MP(t) (in Euro/ostrich):

$$\mathrm{BMP}(t_0) = \frac{a_{VM}(t_0)}{a_{OSR}(t_0) \times h_{RE}(t_0)}. \tag{4.3.37}$$

See Equation 4.3.53 of Section 4.3.8.2 for the definition of BMP(t_0), in (Euro/ostrich) for model equilibrium.

Change in Baseline Producer Meat Price per Ostrich flowrate

The r_{CBMP} (in Dollar/(ostrich $\times$ year)) is comprised of a single minor feedback loop that adjusts BMP(t) (in Euro/ostrich), according to the exogenously defined European HICP ($h_{\mathrm{HICP}}(t)$, in unitless dimensions), as well as an assumed adjustment time, Baseline Meat Price Adjustment Time (c_{BMPAT}, in year).

$$r_{CBMP} = \frac{\mathrm{BMP}(t) \times (1 + h_{\mathrm{HICP}}(t)) - \mathrm{BMP}(t)}{c_{\mathrm{BMPAT}}} \tag{4.3.38}$$

4.3.6.4 Sector output variables

The Meat Income sector output variables are listed in Table 4.14. The output variable, Producer Meat Price per Ostrich in Rand (k_{MP}, in Rand/ostrich), that forms part of a major feedback loop in the system, is defined by converting MP(t), in (Euro/ostrich), into Rand using the exogenous variable, $h_{\mathrm{RE}}(t)$, in (Rand/Euro) and decreasing the income received during periods of bird flu - using Percentage of Income Lost Due to Export Ban (c_{L}, in unitless dimension) as well as the input variable from the Primary Production sector, Presence of Meat Export Ban from Bird Flu ($k_{\mathrm{MEB}}(t)$, in unitless dimension):

$$k_{\mathrm{MP}} = \mathrm{MP}(t) \times h_{\mathrm{RE}}(t) \times (1 - c_{\mathrm{L}} \times k_{\mathrm{MEB}}(t)). \tag{4.3.39}$$

Table 4.14: Meat Income sector output variables

Variable Name	Sector Destination
Producer Meat Price per Ostrich in Rand	Primary Production
Presence of Worldwide Economic Recession	Primary Production, Leather Income

This concludes the section defining the structure and equations of OIMSA's Meat Income sector. In the following section, Section 4.3.7, OIMSA's Producer Cost sector structure and relevant equations are defined.

4.3.7 OIMSA Producer Cost sector structure and equations

This section defines the structure and equations of OIMSA's Producer Cost sector. The Producer Cost sector of the model is the only sector made up exclusively of converters and no stocks, as well as no input variables from other sectors, as seen in Figure 4.7. Therefore the sector has no accumulative properties and contains only instantaneous relationships. Table 4.15 lists the sector's parameter assumptions while mathematical formulations of all Producer Cost sector converters can be found in Appendix C.

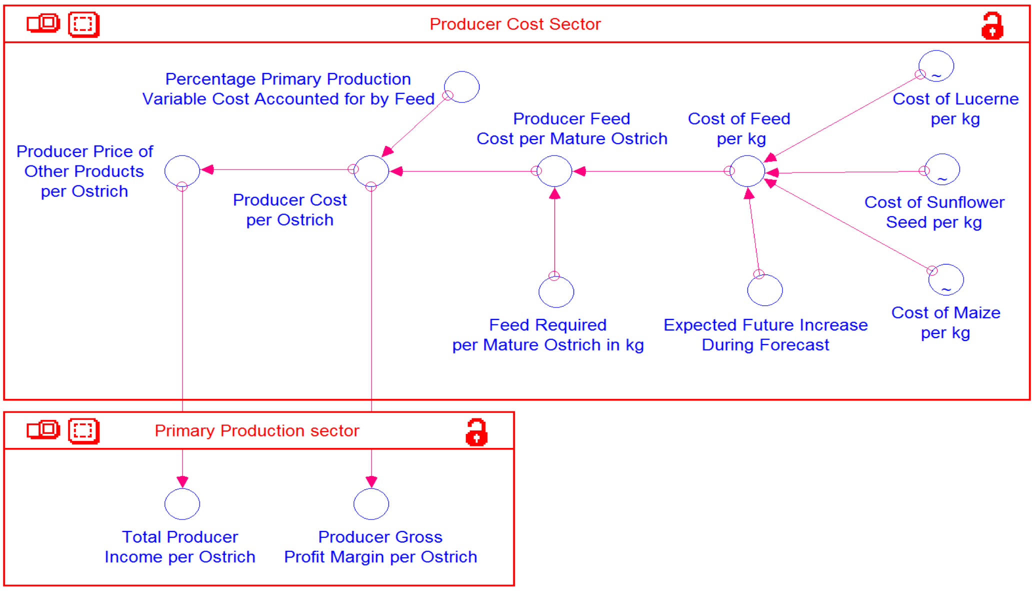


Figure 4.7: Stock and flow diagram of the Producer Cost sector of OIMSA

Table 4.15: Producer Cost sector parameter assumptions

Parameter	Source
Percentage Primary Production Variable Cost Accounted for by Feed	South African Ostrich Business Chamber (2006)
Feed Required per Mature Ostrich in kg	South African Ostrich Business Chamber (2006)

4.3.7.1 Producer Cost sector output variables

The Producer Cost sector output variables are listed in Table 4.15. The two output variables from the Primary Production sector is the Producer Cost per Ostrich (k_{PC}, in Rand/ostrich) and the Producer Price of Other Products per Ostrich (k_{OP}, in Rand/ostrich). k_{PC} (in Rand/ostrich) is a significant input into the Primary Production section converter defined in Equation 4.3.20, Producer Gross Profit Margin per Ostrich (k_{GPM}, in unitless dimension). k_{GPM}, in (unitless dimension), forms part of what is described as the system driving force of the entire dynamic model in Section 4.3.4.3.

Table 4.16: Producer Cost sector output variables

Variable Name	Sector Destination
Producer Cost per Ostrich	Primary Production
Producer Price of Other Products per Ostrich	Primary Production

This concludes the section defining the structure and equations of OIMSA's Producer Cost sector. In the following section, Section 4.3.8, the model is defined in equilibrium using first principles.

4.3.8 Defining model equilibrium using first principles

This section initializes OIMSA in equilibrium using first principles. This means that stocks are defined using formulas instead of a numerical value to create system equilibrium. The advantage is that complete flexibility is given during scenario testing. Note that nothing in the model structure has changed.

4.3.8.1 Exogenous variables redefined as constants to create model equilibrium

To achieve system equilibrium, certain parameter assumptions, exogenous from the dynamic model behaviour, would have to be defined as constants instead of time-dependant, for example, the Rand Dollar Exchange Rate. Even though it is not an accurate depiction of reality for said variables to be defined as constants, it gives insight into how the system reacts to particular disturbances.

Once the model is in equilibrium, a disturbance (through a step function) in the constant parameter assumption would give insight into inherent model behaviour.

Values that accurately depict the current state were chosen. Since they can be changed in the user-interface in the iThink® software, the values are not listed.

Table 4.17: Time-dependant exogenous influences used in OIMSA

Parameter	Sector of Origin
Cost of Lucerne per kg	PRODUCER COST
Cost of Maize per kg	PRODUCER COST
Cost of Sunflower Seeds per kg	PRODUCER COST
Presence of Japanese Recession	LEATHER INCOME
Minimum Value of Leather	LEATHER INCOME
Rand Dollar Exchange Rate	LEATHER INCOME
Presence of Worldwide Economic Recession	MEAT INCOME
Rand Euro Exchange Rate	MEAT INCOME
European HICP	MEAT INCOME
Presence of BSE and FMD in Europe	MEAT INCOME
Presence of the 2004 Bird Flu Epidemic	PRIMARY PRODUCTION
Presence of the 2011 Bird Flu Epidemic	PRIMARY PRODUCTION
Number of Ostriches Culled in the 2004 Bird Flu Epidemic	PRIMARY PRODUCTION
Number of Ostriches Culled in the 2011 Bird Flu Epidemic	PRIMARY PRODUCTION
Duration of the 2004 Bird Flu Epidemic	PRIMARY PRODUCTION
Duration of the 2011 Bird Flu Epidemic	PRIMARY PRODUCTION
Reluctance to Enter Market after Deregulation	PRIMARY PRODUCTION

4.3.8.2 Re-defining model variables and initial values of stocks for model equilibrium

Two new variables are defined to control the model equilibrium since equilibrium is defined out of first-principles rather than numeric values. Changing either one of these two variables will change the values at which the model will equilibrate. Both variables can be changed in the iThink® software user interface.

The first variable introduced is Desired Production Rate (c_{DPR}, in ostrich/year). In OIMSA, c_{DPR}, in (ostrich/year), translates to the desired Ostrich Slaughter Rate that the user wants the model to have during equilibrium. Therefore, during equilibrium the following statement holds:

$$c_{\text{DPR}} = r_{\text{OSR}}. \tag{4.3.40}$$

The second variable introduced is Leather Income Fraction (c_{LF} in unitless dimension) and is defined as the percentage of the total income accounted for by ostrich leather, defined as k_{LF}, in (Rand/ostrich), in OIMSA.

When a SFD is in equilibrium, all stocks remain constant. Flows do not necessarily have to be constant. For a stock to be constant, the sum of the stock's inflows has to be equal to the sum of it's outflows.

$$\sum r_{\text{Stock Inflows}} = \sum r_{\text{Stock Outflows}} \tag{4.3.41}$$

A second condition is that the sum of a system's inflows have to be equal to the sum of it's outflows.

$$\sum r_{\text{System Inflows}} = \sum r_{\text{System Outflows}} \tag{4.3.42}$$

Initializing Mature Ostriches stock in equilibrium

Equation 4.3.41 is applied to the stock, $\mathrm{MO}(t)$, in (ostrich):

$$r_{\mathrm{BR}} = r_{\mathrm{BOAR}} + r_{\mathrm{OSR}}. \tag{4.3.43}$$

Since stocks remain constant throughout equilibrium, r_{BR} (in ostrich/year) can be defined in terms of $\mathrm{BO}(t)$, in (ostrich), without any DELAY functions. From Equations 4.3.3, 4.3.14, 4.3.15 and 4.3.16 the Breeding Rate, r_{BR} (in ostrich/year), during equilibrium conditions is defined as

$$r_{\mathrm{BR}} = k_{\text{yield}} \times \mathrm{BO}(t). \tag{4.3.44}$$

Incorporating Equations 4.3.44 and 4.3.19 into Equation 4.3.43, $\mathrm{MO}(t)$, in (ostrich), is initialized as

$$\mathrm{MO}(t_0) = \mathrm{BO}(t_0) \times k_{\text{yield}} \times r_{\mathrm{MOFP}}. \tag{4.3.45}$$

Initializing Breeding Ostriches stock in Equilibrium

If the same strategy (Equation 4.3.41) were applied to determining the initial value of the Breeding Ostriches stock, it would result in an invalid circular connection. Therefore Equation 4.3.42 is applied to the entire PRIMARY PRODUCTION sector:

$$r_{\mathrm{BR}} = r_{\mathrm{BOSR}} + r_{\mathrm{OSR}}. \tag{4.3.46}$$

Equations 4.3.8 and 4.3.40 are incorporated into Equation 4.3.46 to initialize $\mathrm{BO}(t)$, in (ostrich), as

$$\mathrm{BO}(t_0) = \frac{c_{\mathrm{DPR}} \times c_{\mathrm{ABP}}}{k_{\text{yield}} \times c_{\mathrm{ABP}} - 1}. \tag{4.3.47}$$

Note that $\mathrm{BO}(t)$ (in ostrich) is defined as a combination of constants (see Equation 4.3.3) and not in terms of any other stocks in the PRIMARY PRODUCTION sector, avoiding invalid circular connections.

Initializing Baseline Producer Meat Price per Ostrich in Euro stock in Equilibrium

During equilibrium conditions the stock Breeding Ostriches ($\mathrm{BO}(t)$, in ostrich) will be equal to Desired Breeding Ostriches (k_{DBO}, in ostrich). Equation 4.3.22 is therefore equated to Equation 4.3.47 to determine the equilibrium value of Desired Breeding Ostriches (k_{DBO}, in ostrich).

$$k^{e}_{\mathrm{DBO}} = \frac{c_{\mathrm{DPR}} \times c_{\mathrm{ABP}}}{(k_{\mathrm{yield}} \times c_{\mathrm{ABP}} - 1) \times c_{\mathrm{D}}} \tag{4.3.48}$$

Note that k_{DBO} (in ostrich) will be equal to k^{e}_{DBO} during equilibrium. The converter k_{DBO} (in ostrich) is still defined as Equation 4.3.22 in OIMSA.

No industry reluctances, k_{R}, in (unitless dimensions) are assumed to be present during equilibrium. Therefore, Equation 4.3.20 can be incorporated into Equation 4.3.48 to determine the equilibrium value of k_{GPM} (in unitless dimensions).

$$k^{e}_{\mathrm{GPM}} = \frac{c_{\mathrm{DPR}} \times c_{\mathrm{ABP}}}{(k_{\mathrm{yield}} \times c_{\mathrm{ABP}} - 1) \times c_{\mathrm{D}}} \tag{4.3.49}$$

As with Equation 4.3.48, k_{GPM}, in (unitless dimensions), will be equal to k^{e}_{GPM} during equilibrium. The converter k_{GPM} (in unitless dimensions) is still defined as Equation 4.3.22 in OIMSA.

OIMSA calculates Total Producer Income per Ostrich as

$$k_{\mathrm{PI}} = k_{\mathrm{LP}} + k_{\mathrm{MP}} + 0,1 \times k_{\mathrm{PC}}. \tag{4.3.50}$$

In model equilibrium Equation 4.3.20 can be expressed without the DELAY function, incorporating Equation 4.3.50, as

$$k^{e}_{\mathrm{GPM}} = \frac{k_{\mathrm{LP}} + k_{\mathrm{MP}} + 0,1 \times k_{\mathrm{PC}}}{k_{\mathrm{PC}}}. \tag{4.3.51}$$

Finally Equations 4.3.49, 4.3.49, 4.3.39 and 4.3.32 are equated to define the equilibrium value of Baseline Meat Producer Price per Ostrich in Euro ($\mathrm{BMP}(t)$, in Euro/ostrich).

$$\mathrm{BMP}(t_0) = \frac{k_{\mathrm{PC}}}{h_{\mathrm{RE}}} \times \frac{c_{\mathrm{DPR}} \times c_{\mathrm{ABP}} - 0,1 \times c_{\mathrm{D}} \times (k_{\mathrm{yield}} \times c_{\mathrm{ABP}} - 1)}{(k_{\mathrm{yield}} \times c_{\mathrm{ABP}} - 1) \times c_{\mathrm{D}}} - \frac{k_{\mathrm{LP}}}{h_{\mathrm{RE}}} \tag{4.3.52}$$

Initializing Producer Meat Price per Ostrich in Euro stock in Equilibrium

During equilibrium, the equilibrium value of Meat Producer Price per Ostrich in Euro ($\mathrm{MP}(t)$, in Euro/ostrich) simply equal to the equilibrium value of Meat

Producer Price per Ostrich in Euro (BMP(t), in Euro/ostrich) since 4.3.32 should equal zero.

$$\mathrm{MP}(t_0) = \mathrm{BMP}(t_0) \tag{4.3.53}$$

Initializing Producer Leather Price per Ostrich in Dollar stock in Equilibrium

Equation 4.3.53 defines the equilibrium value of Meat Producer Price per Ostrich in Euro (MP(t), in Euro/ostrich) in terms of Leather Producer Price per Ostrich in Dollar by using k_{LP} (in Rand/ostrich). This restricts the initialization of LP(t), in (Dollar/ostrich), to something that does not create a circular connection with MP(t), in (Euro/ostrich).

Neither Equation 4.3.41 nor Equation 4.3.42 gives any further description of the stock, LP(t), in (Dollar/ostrich). Furthermore, since k_{GPM} (in unitless dimensions) is defined as a fraction between the total income and gross expenditure, there are infinite possible points of equilibrium for LP(t) (in Dollar/ostrich) and MP(t) (in Euro/ostrich).

The fraction of income received from leather is defined explicitly using the second variable introduced in the beginning of the section. Leather Income Fraction, c_{LF}, in (unitless dimensions), is defined as the percentage of the total income accounted for by ostrich leather, defined as (k_{LP} in Rand/ostrich), in OIMSA.

$$c_{\mathrm{LF}} = \frac{k_{\mathrm{LP}}}{k_{\mathrm{LP}} + k_{\mathrm{MP}} + 0,1 \times k_{\mathrm{PC}}} \tag{4.3.54}$$

Combining Equations 4.3.53 and 4.3.54, LP(t) (in Euro/ostrich) is initialised independent from MP(t) (in Dollar/ostrich) as

$$\mathrm{LP}(t_0) = \frac{k_{\mathrm{PC}} \times c_{\mathrm{LF}}}{k_{\mathrm{RD}}} \times \left[\frac{c_{\mathrm{DPR}} \times c_{\mathrm{ABP}} - 0,1 \times c_{\mathrm{D}}(k_{\mathrm{yield}} \times c_{\mathrm{ABP}} - 1)}{(k_{\mathrm{yield}} \times c_{\mathrm{ABP}} - 1)c_{\mathrm{D}}} + 0,1\right]. \tag{4.3.55}$$

4.3.8.3 Redefining Baseline Leather Market Demand

Section 4.3.8.1 redefines time-dependant exogenous influences as constants to enable equilibrium. During the previous section, Section 4.3.8.2, the equilibrium value of OIMSA's stocks were defined. No other system variables were redefined in Section 4.3.8.2.

The final variable to be redefined to have model equilibrium from first principles is Baseline Leather Market Demand. During model reference mode, c_{BLD} (in ostrich/year), is defined as a constant - 102% of the value recommended by ECIAfrica (Pty) Ltd (2010).

To enable model equilibrium while allowing production rates to be determined by the user, the Baseline Leather Market Demand is to be defined as dynamic - equal to Desired Production Rate. When the model is initialized in equilibrium conditions, Baseline Leather Market Demand is defined as

$$c_{\mathrm{BLD}} = c_{\mathrm{DPR}}. \tag{4.3.56}$$

This section also concludes the explanation surrounding OIMSA's structure and equations. The following section, Section 4.3.9, summarises Section 4.3.

4.3.9 Summary of Section 4.3

This section summarizes Section 4.3. The section begins with Section 4.3.1 discussing the structural differences between OIMSA and the model OIMSA was based off of: Meadows (1970). The first significant structural change compared to the Meadows (1970) model was to distinguish between the slaughtering of breeding stock once fertility decreases and the slaughtering of ostriches upon optimum yield for leather and meat production. The second significant structural change made to the Meadows (1970) model is that the breeding process is not simulated with stocks, in other words, a stock for eggs, chicks and juvenile ostriches is not present in OIMSA.

Section 4.3.2 formalises the reference mode parameters describing the ostrich industry of South Africa. Criteria when deciding which combination of data sources to use were the reliability of the data source, minimising data discrepancies, and the using least number of sources. The three reference mode parameters identified, Reference Mode Ostrich Slaughter Rate, Reference Mode Gross Producer Value of Leather in SA and Reference Mode Gross Producer Value of Meat in SA, originated from two sources: National Agricultural Marketing Council (2003) and Lareman (2015).

Section 4.3.3 identifies a conclusive list of exogenous variables, meaning all variables that exist outside the boundary of the model (therefore is not influenced by the dynamics of the model), but still influences model behaviour. Exogenous parameters are tabulated with their corresponding sources in Section 4.3.3.

Section 4.3.4 defines the structure and equations of the PRIMARY PRODUCTION sector of OIMSA. The PRIMARY PRODUCTION sector is the only sector that contains input variables from all other sectors of OIMSA. The PRIMARY PRODUCTION sector defines two stocks and four flows as well as the system driving force. The sector also supplies output variables, forming part of OIMSA's major feedback loops, to both the LEATHER INCOME and MEAT INCOME sectors.

Section 4.3.5 defines the structure and equations of the LEATHER INCOME sector of OIMSA. The only input variable that is part of the major feedback of the system comes form the PRIMARY PRODUCTION sector. The LEATHER

Income sector defines one stock and one flow as well as the ratio between demand and supply that influences the price of leather. The only sector that the Leather Income sector supplies with an output variables that form part of OIMSA's system feedback is the Primary Production sector.

Section 4.3.6 defines the structure and equations of the Meat Income sector of OIMSA. The only input variable that is part of the major feedback of the system comes form the Primary Production sector. The Meat Income sector defines one stock and one flow as well as the ratio between market absorption and supply that influences the price of meat. The only sector that the Meat Income sector supplies with an output variables that form part of OIMSA's system feedback is the Primary Production sector.

Section 4.3.7 defines the structure and equations of the Producer Cost sector of OIMSA. The Producer Cost sector is the only sector made op exclusively of converters and no stocks, as well as no input variables from other sectors. There is no accumulative properties, feedback or dynamics present in the Producer Cost sector. The Producer Cost sector does, however, supply output variables to the system driving force in the Primary Production sector and therefore has great influence over the dynamics of OIMSA.

Finally, Section 4.3.8.2 initializes OIMSA in equilibrium using first principles. The necessary exogenous variables to be redefined as constants are identified before determining the equilibrium values of all the stocks of the system. Two new parameter assumptions were defined to allow the user full control over the model equilibrium in iThink®: Desired Production Rate and Leather Income Fraction. The section in concluded by redefining a single exogenous variable, Baseline Leather Market Demand, using the newly defined parameter assumptions.

In summary, Section 4.3 discusses the structural differences between OIMSA and Meadows (1970), the reference mode identified, as well as variables identified as being exogenous of OIMSA. The section also defines the structure and equations of OIMSA's four sectors: Primary Production, Leather Income, Meat Income and Producer Cost. A chapter summary concludes Chapter 4 in Section 4.4.

4.4 Summary or Chapter 4

Chapter 4 uses the problem statement in Chapter 1 and literature study in Chapter 3 to determine the structure of the system and the model boundary. This chapter proposed an aggregate CLD and SFD able to produce baseline, equilibrated, and open system model outputs

After the key assumptions governing OIMSA is defined, Section 4.2 proposes a dynamic structure used to explain the problem at hand. The dynamic model developed in Section 4.2, formulated with the help of an aggregate causal loop diagram, attempts to provide an endogenous explanation to the boom-and-bust nature of the ostrich production industry of South Africa. Section 4.2 first introduces and classifies key system variables as an introduction to explaining OIMSA's dynamic model. The explanation of the dynamic model then starts with the PRIMARY PRODUCTION sector, followed by the LEATHER INCOME and MEAT INCOME sectors. The explanation emphasizes the major feedback loops governing OIMSA.

Finally, the structure and equations of OIMSA is introduced in Section 4.3. Before OIMSA's structure is introduced, the main structural differences between OIMSA and the model it was based off of, Meadows (1970), is discussed in Section 4.3.1. Next, the model reference mode and exogenous variables are introduced in, Sections 4.3.2 and 4.3.3 respectively, as an introduction to defining the model structure and equations. The OIMSA stock and flow diagram consists of four model sectors and no sub-models. The sectors represent various aspects of the ostrich production industry of South Africa: primary production (including decision-making on production levels), as well as factors identified as influencing said decision-making process: income received and expenses incurred. The sectors are PRIMARY PRODUCTION, LEATHER INCOME, MEAT INCOME, and PRODUCER COST in Sections 4.3.4, 4.3.5, 4.3.6, and 4.3.7 respectively. The next chapter, Chapter 5, discusses the results OIMSA.

Chapter 5

Ostrich Industry Model of South Africa (OIMSA) results

This chapter shows results of the Ostrich Industry Model of South Africa (OIMSA), that was defined in the previous chapter, Chapter 4. Chapter 4 proposed an aggregate CLD and SFD able to produce baseline, equilibrated, and open system model outputs, all to be tested in this chapter. The baseline results are compared to the open system results and reference mode parameters. All key indicators, namely Ostrich Slaughter Rate, Producer Leather Price per Ostrich in Rand, Producer Meat Price per Ostrich in Rand, Producer Leather Price per Ostrich in Rand and Producer Meat Price per Ostrich in Rand are evaluated. The model validation and verification methods utilized are listed; all model outputs are deemed acceptable to aid in a qualitative explanation of the system.

Next, the equilibrated OIMSA is validated and calibrated for the purpose of scenario testing and policy analysis. The first phase of the process of scenario testing and policy analysis was to rank the short and long term effects of each exogenous influence compared to all other influences to indicate the relative severity of each type of impact. In conclusion, disturbances in exchange rates, market demands, product values, food safety concerns, production costs, as well as economic climate is explored. In the following final chapter, Chapter 6, the study is concluded.

5.1 Replicating reference mode[1]

The main purpose of this study is to gain insight into the ostrich production industry of South Africa. The OIMSA model aims to represent the proposed of the ostrich production industry.

[1]Section 5.1 is based on work that was presented at the 33rd International Conference of the System Dynamics Society, 19-23 July, 2015, Cambridge, Massachusetts, USA. See Appendix D.1 for details.

The reference mode data is given in the before mentioned format. All sources discussing the performance of the ostrich industry also refer to the total income received by primary producers. From an industry evaluation and policy implementation perspective, the user of OIMSA, considered the client, would have more interest in the development of the total income received by primary producers. Gross Producer Value of Leather in SA and Gross Producer Value of Meat in SA is considered the most important indicator of the Leather Income and Meat Income sector respectively when reporting to the model developer. However, the dynamics of OIMSA is dependent on the income per ostrich rather than the total income received by primary producers.

The Producer Leather Price per Ostrich in Rand and Producer Meat Price per Ostrich in Rand is the second-most important key indicator of the Leather Income and Meat Income sectors. It is most useful when analysing and designing the structure of the system (therefore most useful for the creator and technical analysts of the model). The Producer Leather Price per Ostrich in Rand forms part of the system's major feedback loop while Gross Producer Value of Leather in SA is derived for the user and is not used to create model dynamics.

The baseline scenario, referred to as **Baseline OIMSA**, represents the historical performance of the ostrich production industry and forecasts into the future, as is often the case for explanatory models. **Baseline OIMSA**'s model behaviour is plotted with the reference mode parameters introduced in Section 4.3.2 along with **Open Loop OIMSA** introduced in the section below.

5.1.1 Testing individual model sectors as open loop systems

A system dynamics model's behaviour is driven by system feedback. Model behaviour is either reinforced or counteracted, depending on state of the system. In contrast, an open system is a system with no feedback (Sterman, 2000). An open system's output is therefore dependant on input that is exogenous. Sector receiving system feedback is tested as open systems to judge each individual sector's performance under the condition of receiving the correct input. Sterman (2000) refers to such a test as a partial model test and often performed to evaluate a system's intended rationality. A sector producing inaccurate results due to inaccurate input is superior to a model producing correct results from incorrect input.

Baseline OIMSA is converted to an open system, referred to as **Open Loop OIMSA**, by replacing all input variables defined as part of the system's major feedback loops with their respective reference parameters, thereby eliminating all model feedback. Tables 5.1 and 5.2 indicate the endogenously defined input variables replaced with their corresponding reference mode values in each individual sector to produce the **Open Loop OIMSA** output. The more accurate the sector output is to its corresponding reference mode parameter, the more accurate the sector is considered to be in producing the desired output. The ability of each **Open Loop OIMSA** sector to replicate its reference mode is an indication of the true performance of the sector.

Table 5.1: Variables replaced in the PRIMARY PRODUCTION sector to convert sector to an open system

Endogenous Input Variable	**Replacement**
Producer Leather Price per Ostrich in Rand	Reference Mode Producer Price of Leather per Ostrich
Producer Meat Price per Ostrich in Rand	Reference Mode Producer Price of Meat per Ostrich

Table 5.2: Variables replaced in the LEATHER INCOME and MEAT INCOME sectors to convert sector to an open system

Endogenous Input Variable	**Replacement**
Ostrich Slaughter Rate	Reference Mode Ostrich Slaughter Rate

Testing a sector as an open system can give an indication as to whether the difference between model results and reference mode is due to inaccuracies in model output being amplified by reinforcing effects of the model feedback, or structural flaws in the system design. It can also indicate whether a model structure was designed to explain the problem at hand, or simply to produce the desired model output. During the design phase of OIMSA, partial model testing for intended rationality of model parameters were regularly conducted in by running OIMSA as an open system as part of model validation (Sterman, 2000).

Sections 5.1.2, 5.1.3 and 5.1.4 compares the reference mode behaviour with both **Baseline OIMSA** and **Open Loop OIMSA** for the PRIMARY PRODUCTION, LEATHER INCOME and MEAT INCOME sectors respectively. The run specifications used for **Baseline OIMSA** and **Open Loop OIMSA** tabulated in Appendix A.1. Note that the only difference in run specifications between the tables are the run time.

Figures 5.1, 5.2 and 5.3 compares **Baseline OIMSA**, **Open Loop OIMSA** and the reference mode for the period t_0 (year 1993) through t_{21} (year 2014) after which **Baseline OIMSA** forecasts the behaviour of the ostrich industry of South Africa up until t_{27} (year 2020). Time path 1, in blue, shows **Baseline OIMSA**'s sector output variables while time path 2, in red, shows the corresponding reference mode. The third time path, shown in green shows the output generated from **Open Loop OIMSA**.

5.1.2 Primary Production sector

Figure 5.1 shows Ostrich Slaughter Rate, the key indicator of the Primary Production sector.

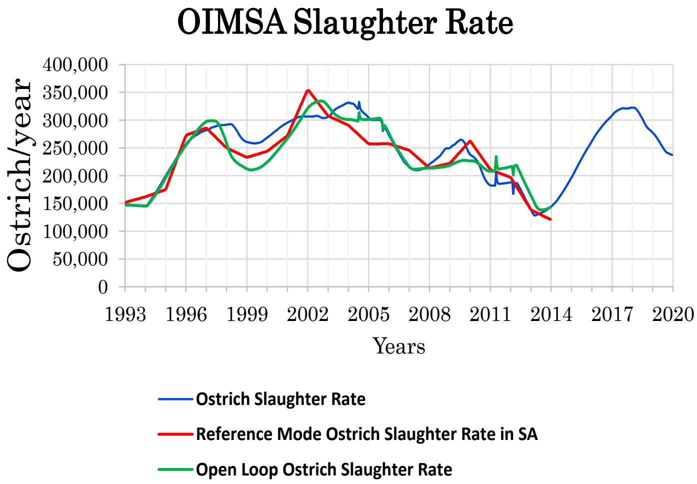


Figure 5.1: Comparison between slaughter rates

Both **Baseline OIMSA** and **Open Loop OIMSA** follow the same general shape as the historical data. **Baseline OIMSA** shows some delayed reaction during the early 2000's. This could be attributed to inaccuracies in parameter assumptions causing either over-responsiveness or a lack of responsiveness of the model feedback. The model results follow the same shape as the historical data but seem to be amplified during boom-periods.

Baseline OIMSA shows delayed and damped responsiveness of approximately two years from t_0 (year 1993) to approximately t_{12} (year 2005). For the same period **Open Loop OIMSA** does not show any lag but a slight undershoot from t_6 (year 1999) to t_{10} (year 2003). The slight variation indicates that the structure of the primary Production sector could potentially explain the ostrich industry structure for that period. **Baseline OIMSA**'s delay and dampening is therefore attributed to the reinforcing nature a system with feedback. For year t_{12} (year 2005) to t_{21} (year 2014) **Baseline OIMSA** replicates the shape of the reference mode fairly well but precedes the reference mode by approximately one year. Since **Open Loop OIMSA** does not replicate the reference mode well for this time period. **Baseline OIMSA** could be replicating the reference mode due to a structural error in the design of OIMSA.

The preceding Section 5.1.4 considers the constant delay between the Meat Income sector's **Baseline OIMSA** output and the reference mode (also the input of **Open Loop OIMSA**'s Primary Production sector) during the period of poor OSR output of **Open Loop OIMSA** and suggests the possibility of a delay in the reference mode likely attributed to a delay in reporting. If there is a delay in the Meat Income sector reference mode data, **Baseline OIMSA** could be displaying an acceptable output due to an acceptable model structure. In this instance, the fact that **Open Loop OIMSA** does not replicate the reference mode with lagged input values is considered affirmation that the structure could represent that of the South African ostrich industry: **Open Loop OIMSA** would be producing the wrong output for the correct reason.

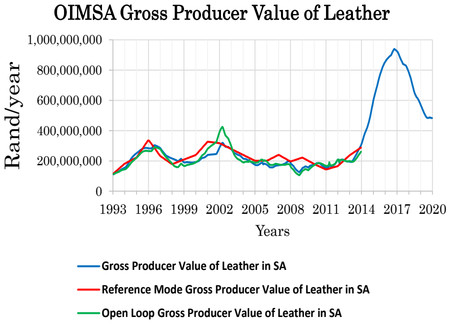
Note that the disturbance in both **Baseline OIMSA** and **Open Loop OIMSA** around year t_{12} (year 2005) and again at t_{18} (year 2011) and t_{19} (year 2012) is caused by OIMSA's reaction to the presence of bird flu and not because of the model DT being larger than the smallest adjustment time.

Baseline OIMSA continues running from t_{21} (year 2014) to t_{27} (year 2020) and shows a steep increase from t_{21} (year 2014) to t_{25} (year 2018). The increase, through large, is not uncontrolled as OIMSA appears to be balancing itself. Considering the stark increase in recent earnings for both income sectors, **Baseline OIMSA**'s reaction is deemed reasonable and intuitive.

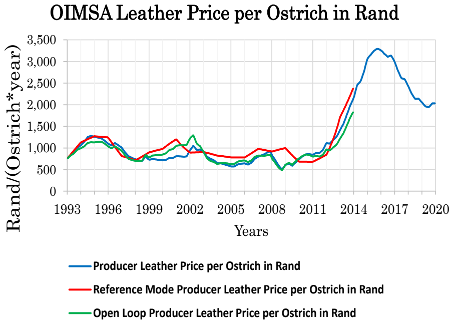
5.1.3 Leather Income sector

Income from ostrich leather currently accounts for 50% to 70% of the total income per bird (National Agricultural Marketing Council, 2003). Since the only endogenous variable influencing production is the gross profit margin is assumed to be income from ostrich products (see Section 4.1.2), the Leather Income sector is very influential to OIMSA's system feedback.

Figure 5.2 compares the Leather Income sector output generated by **Baseline OIMSA** and **Open Loop OIMSA** with the reference mode results. The results from both the Gross Producer Value of Leather in SA and Leather Price per Ostrich in Rand produces the same general behaviour as the historical data with some overshoot by **Open Loop OIMSA** during the boom-period of the cycle in the early 2000's. The overshoot could likely be attributed to the model's over-sensitivity to the Rand vs. Dollar exchange rate or inaccuracies in the data collected. The similarity in behaviour affirms that the proposed general model structure could resemble reality, but still needs to be refined using the validation techniques categorised as either direct structure tests or structure-oriented behaviour tests. The similarity between **Baseline OIMSA** and **Open Loop OIMSA** indicate that the Leather Income sector is fairly robust towards small discrepancies in input variables.



(a) Comparison between Gross Producer Value of Leather in SA outputs



(b) Comparison between Producer Leather Price per Ostrich in Rand outputs

Figure 5.2: **Baseline OIMSA** and **Open Loop OIMSA** compared to model reference mode

After t_{21} (year 2014) **Baseline OIMSA** forecasts the future earnings from the LEATHER INCOME sector. The Leather Price per Ostrich in Rand behaves intuitively to the steep increase in income between t_{19} (year 2012) and t_{21} (year 2014). **Baseline OIMSA** increases by a factor of less than a factor of one between t_{21} (year 2014) to t_{23} (year 2016) before declining, in a controlled fashion, to a reasonable level.

The Gross Producer Value of Leather in SA increases with a factor of more than two before seemingly stabilizing. When evaluating this output in isolation the forecast seems unreasonable but considering that Gross Producer Value of Leather in SA is the product of Leather Price per Ostrich in Rand and Ostrich Slaughter Rate and does not influence the dynamics of OIMSA, the behaviour is feasible.

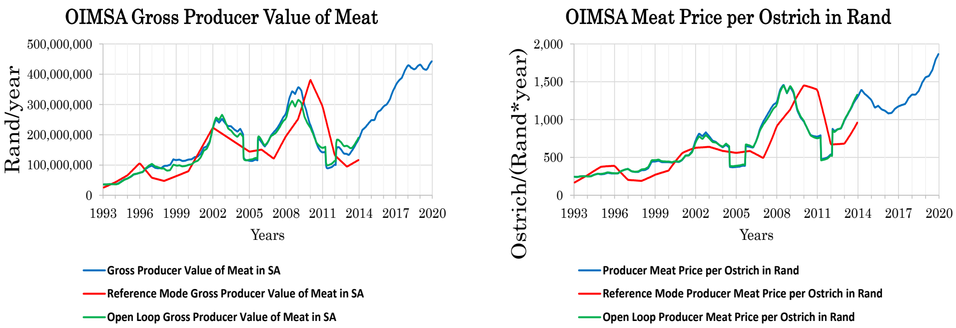
Since the Gross Producer Value of Leather in SA, forecasted to increase with a factor of more than two in the next three years, is the key indicator used by the ostrich industry, it is anticipated that the forecast will be met with reservations and scepticism.

5.1.4 MEAT INCOME sector

Income from ostrich meat is accountable for the majority of the rest of the income received. Since the only endogenous variable influencing production is the income received per ostrich (see Section 4.1.2), the MEAT INCOME sector is the only sector other than the LEATHER INCOME sector containing endogenously defined variables with major influence on OIMSA's system feedback.

Baseline OIMSA and **Open Loop OIMSA** follow each other very closely, indicating that the system feedback (in the form of Ostrich Slaughter Rate) has limited influence over OIMSA (see Section 4.2.4). Between t_0 (year 1993) and t_7 (year 2000), **Baseline OIMSA** and **Open Loop OIMSA**

did not replicate the overall behaviour of the reference mode. Instead the output seems to be an indicator of the overall trend of the reference mode. Since the ostrich meat export industry started at t_0 (year 1993) (National Agricultural Marketing Council, 2003; ECIAfrica (Pty) Ltd, 2010), it is assumed that structural changes are at play during the transitional time in the ostrich meat industry (shift from local to export sales). Since it is highly unlikely for OIMSA to undergo the reverse structural change of focussing on the local market, it is not considered priority to include the before mentioned shift in OIMSA.



(a) Comparison between Gross Producer Value of Meat in SA outputs

(b) Comparison between Producer Meat Price per Ostrich in Rand outputs

Figure 5.3: **Baseline OIMSA** and **Open Loop OIMSA** compared to model reference mode

The reference mode constitutes of one source for t_0 (year 1993) to t_9 (year 2002) and a different source for t_{12} (year 2005) to t_{21} (year 2014) with data extrapolated between 2002 and 2005 (see Section 4.3.2). From Figure 5.3 it is considered that the second data source, Lareman (2015), is potentially reporting figures on meat income a year after the fact. The reference mode lags behind **Baseline OIMSA** and **Open Loop OIMSA** at a constant time period of approximately one year. The delay is prescribed to the time it takes authorities to collect, analyse and distribute data regarding the MEAT INCOME sector of the ostrich industry of South Africa. Apart from the lag, **Baseline OIMSA** and **Open Loop OIMSA** replicate the reference mode fairly accurately from t_7 (year 2000) to t_{21} (year 2014).

Baseline OIMSA continues running from t_{21} (year 2014) to t_{27} (year 2020). Since the MEAT INCOME sector has limited dependence on the PRIMARY PRODUCTION sector (see Section 4.1.2), the Meat Price per Ostrich in Rand is most dependent on the forecasted Rand vs Euro Exchange Rate from Quantec EasyData (2015*a*).

5.2 Validation and verification [2]

Model verification and validation is a principal step of the modelling process and should be done before interpreting model behaviour or performing policy analysis Pruyt (2013). Model verification is the process of checking if the model has been coded or simulated correctly. The model was iteratively verified using the method prescribed by Pruyt (2013) throughout the development process. Pruyt (2013) entails checking and testing for:

- dimensional consistency,
- appropriateness of combination of numeric integration method and step size, and
- all equations and inputs for errors.

Additionally, the twelve points in Lai and Wahba (2001)'s System Dynamics Model Correctness Checklist were evaluated as part of the model verification process. OIMSA adheres to all points except for point number 10, stating that table functions should be used rather than logic statements. In reality, there are certain discontinuities in the behaviour of the ostrich production industry of South Africa and would therefore be inaccurate and cumbersome to model with graphical functions or table functions.

Model validation is the process of assessing whether or not a model meets the objectives of the modelling study (Barlas, 1996; Pruyt, 2013). Pruyt (2013) categorizes validation tests described in Sterman (2000) as:

- direct structure tests,
- structure-oriented behaviour tests, or
- behaviour reproduction tests.

Sterman's chapter on model validation is based on the article: Tests for building confidence in system dynamics models (Forrester and Senge, 1980). The method, and therefore extent, of which each test is applied to OIMSA is listed in Table 5.3 below.

[2]Section 5.2 is based on work that was presented at the 33rd International Conference of the System Dynamics Society, 19-23 July, 2015, Cambridge, Massachusetts, USA. See Appendix D.1 for details.

Table 5.3: Model validation tests performed on OIMSA

Tests	Methods and degree of implementation
Boundary adequacy	Judgement methods
Structural assessment	Judgement methods
Dimensional consistency	Judgement methods
	iThink® software "check units" function
Parameter assessment	Judgement methods
	Partial model testing (open loop tests)
Extreme conditions	Direct model inspection and equations
	Simulation
Integration error	DT-error test
	Comparison between different integration methods
Behaviour reproduction	Qualitative comparison between model output and behaviour
Behaviour Anomaly	Loop knockout analysis
Family member	Judgement methods
Surprise behaviour	Qualitative analysis
Sensitivity analysis	Numerical sensitivity analysis
	Behavior mode sensitivity analysis
	Policy sensitivity analysis
System Improvement	Judgement methods

See Sterman for in-depth explaination of each test as well as the potential methods available for testing (Sterman, 2000, p.859–889).

5.3 OIMSA applications, limitations and challenges

OIMSA simulates the ostrich production industry of South Africa from a producer's perspective. It is specific to the South African ostrich industry and cannot be universally applied to ostrich production in different countries, or different livestock industries in South Africa. This is firstly because South Africa supplies the overwhelming majority of the global market with ostrich products, implying that the global market conditions are considered endogenous for South Africa, but exogenous for economies with a fractional market share. Secondly, the ostrich production sector is in the unique situation where the majority of income from ostrich production is from leather exports to the USA and meat export to the EU, meaning two different markets, exported to two different continents, are built into the model.

The availability and reliability of data regarding ostrich production is one of the main limitations of the study. Another limitation is the ostrich industry's limited willingness to engage in the study via email or telephonic correspondence since geographical constraints prohibited the author from visiting ostrich industry players for the majority of the study's duration.

5.4 OIMSA equilibrium

This section confirms that OIMSA is inherently a stable, balancing system that is capable of equilibrating itself without intervention after experiencing a variety of different exogenous disturbances and evaluate the legitimacy of **Equilibrated OIMSA**'s ability to reproduce model behaviour. It also confirms that **Equilibrated OIMSA**, as defined out of first principles in Section 4.3.8, does in fact depict OIMSA in equilibrium.

The alternative way of determining model equilibrium is to run the model until it equilibrates naturally. The **Baseline OIMSA**, as introduced in the previous section, is ran from t_0 (year 1993) until it reaches equilibrium naturally to generate **Naturally Equilibrated Baseline OIMSA**. The **Naturally Equilibrated Baseline OIMSA** is compared with the OIMSA model equilibrated out of first principles in Section 4.3.8, referred to as **Equilibrated OIMSA**.

5.4.1 Initializing Equilibrated OIMSA

Section 4.3.8 introduces two new variables that does not act on **Baseline OIMSA**: Desired Production Rate and Leather Income Fraction. To initialize OIMSA in equilibrium, exogenous time-dependant variables acting on **Baseline OIMSA** are defined as constants equal to the time-series values of **Baseline OIMSA** at t_{21} (year 2014), as shown in Table A.5 of Appendix A.

Equilibrated OIMSA's Desired Production Rate is defined equal to **Baseline OIMSA**'s Baseline Leather Market Demand (see Section 4.3.8.3). The value for **Equilibrated OIMSA**'s Leather Income Fraction is estimated at 60% since the National Agricultural Marketing Council (2003) indicates the fraction to be between 50% to 70%. The run specifications for both **Naturally Equilibrated Baseline OIMSA** and **Equilibrated OIMSA** are shown in Appendix A.1. The **Equilibrated OIMSA**'s constant parameters are initialized with the values shown in Appendix A.5 - corresponding the time, t_{21}, or year 2014, values of the time-series exogenous inputs of the **Baseline OIMSA** model.

Figure A.1, in Appendix A.2, compare the results of each sector's key indicators. In all three figures, time path 1, in blue, shows the **Naturally Equilibrated Baseline OIMSA** reaching equilibrium over time while time path 3, in pink, shows **Equilibrated OIMSA** initialized as specified in Appendix A.2. The large discrepancies in equilibrium values of both the Leather Income and Meat Income sectors did not make a compelling argument in favour of legitimizing the use of **Equilibrated OIMSA**. As shown in Figure A.1b a misconception regarding the fraction of total income attributed to leather is responsible for the discrepancy rather than a structural misconception in OIMSA. **Equilibrated OIMSA**'s Leather Income Fraction is adjusted from 0,6 to the observed equilibrium value of Fraction of Income Contributed by Leather, shown by time path 1, in blue, as approximately 0,75. Time path 2, in red, shows **Equilibrated OIMSA** with an updated Leather Income Fraction of 0,75. The similarity in the equilibrium value of **Naturally Equilibrated Baseline OIMSA** and the updated **Equilibrated OIMSA** legitimizes the ability of **Equilibrated OIMSA** to show OIMSA in equilibrium.

In Figure A.1, time path 1 and 2 of every sector are very similar. Slight differences are attributed to the slight difference between the Fraction of Income Contributed by Leather that **Naturally Equilibrated Baseline OIMSA** equilibrates at in time path 1 compared to the Leather Income Fraction chosen for **Equilibrated OIMSA** in run 2. The difference is due to the fact that the Leather Income Fraction was chosen equal to Fraction of Income Contributed by Leather, rounded off to two decimal places.

5.5 Scenario testing and policy analysis

Baseline OIMSA is a result of multiple varying exogenous parameters acting upon the model throughout the simulation time. It would be unfounded to attribute any model behaviour to a disturbance, however major, to a single parameter. The true extent to which a disturbance in any individual parameter influences OIMSA, especially in the long term, cannot be deduced from the **Baseline OIMSA** results.

This section tests a single scenario per simulation run, with implementation of the disturbance starting at t_2, or year 1995. For a fair evaluation of the effect of any disturbance in a model parameter, **Equilibrated OIMSA** is initialized as in Section 5.4 with a Leather Income Fraction of 0,6. The fraction is chosen as 0,6 since the mental model of ostrich producers seems to be most comfortable with this fraction; scenario tests focuses on the system reaction, rather than actual system output values. Client engagement therefore outweighs numerical accuracy during scenario testing and policy analysis. During scenario testing, the nature of the system reaction of importance rather than actual values. The same run specifications are used throughout this section and can be found in Appendix A.1.

5.5.1 Comparison between disturbances

Section 5.5 evaluates the effect of possible scenarios and potential policies, each of which uniquely influences OIMSA. Before each individual scenario is discussed, the short and long term influences of each sensitivity analysis test is ranked to indicate the relative significance of each scenario or potential policy on OIMSA, assuming reasonable test parameters. The ranking gives no indication of whether the influence is detrimental or beneficial to the state of the system. The ranking is not rigid as the effect each test has on OIMSA depends on the values chosen during the sensitivity analysis and each colour-category is considered to have a similarly severe impact on OIMSA.

Table 5.4 ranks the short term effect of each test on OIMSA. The tests are ranked from the most to least severe effect on OIMSA, where there extent of each colour-categories' effect is visibly different from the other colour-categories. The categories are considered fixed while the order of the variables within each category is interchangeable.

Disturbances that have the greatest short term effect on OIMSA are most likely to be identified by the producers as the sole cause of tumultuous behaviour of the ostrich production industry. A rule of thumb is that severe destabilization of OIMSA results in severe system oscillations. System oscillations are detrimental to the general wellbeing of the industry. Therefore a disturbance in the parameters relating to the darkest colour-category is less favourable than the other two colour-categories. Since the bottom colour-category has minimal short term effects on OIMSA, the middle colour-category is considered the most effective way of changing the state of OIMSA. See figure in Appendix A.3 for the short term output of sensitivity analysis tests initialized, as stipulated in Appendix A.3.

The significance of the effect of all three factors in the bottom colour-category have been overstated by ECIAfrica (Pty) Ltd (2010), National Agricultural Marketing Council (2003), South African Ostrich Business Chamber (2002), South African Ostrich Business Chamber (2006), Brand *et al.* (2011) and Duminy (2015). Note that one of the sources overstating the significance of the three factors is an earlier publication of the author of this thesis.

Table 5.4: Ranking of short term effects of tests

Test Presence of Worldwide Economic Recession
Test Bird Flu Epidemic
Test Change in Rand vs Dollar Exchange Rate
Test Change in Rand vs Euro Exchange Rate
Test Percentage Increase or Decrease in Producer Cost per Ostrich
Test Change in Baseline Leather Market Demand
Test Change in Baseline Producer Meat Price in Euro
Test Conversion to Small Camps
Test Baseline Meat Market Absorption Capacity
Test Presence of BSE and FMD in Europe

Table 5.5 ranks the long term effect that each test has on OIMSA. The tests are ranked from the most to least severe effect on OIMSA, where half of

the tests show no long term effect on OIMSA and therefor are not assigned a colour. The first and fourth colour-categories are distinct while the second and third categories are not as fixed. Note that the long term effect does not consider the extreme case where the ostrich leather market is irreparably saturated as the extreme case requires extreme parameter values (see Section 5.5.3 on leather market saturation).

Table 5.5: Ranking between long term effects of tests

Test Change in Baseline Leather Market Demand
Test Change in Rand vs Euro Exchange Rate
Test Change in Baseline Producer Meat Price in Euro
Test Percentage Increase or Decrease in Producer Cost per Ostrich
Test Conversion to Small Camps
Test Presence of Worldwide Economic Recession
Test Bird Flu Epedemic
Test Change in Rand vs Dollar Exchange Rate
Test Baseline Meat Market Absorption Capacity
Test Presence of BSE and FMD in Europe

Test Change in Baseline Leather Market Demand is the only test that has a long term effect on the Ostrich Slaughter Rate without putting OIMSA in an extreme condition (see Section 5.5.3). Furthermore, Test Conversion to Small Camps has a negligible long term effect on OIMSA relative to the other colour-categories. The second and third colour-categories have no long term effect on Ostrich Slaughter Rate, but have substantial effects on the LEATHER INCOME and/or MEAT INCOME sector indicators. See Appendix A for examples of long term effects on OIMSA.

5.5.2 Delayed reaction of Ostrich Slaughter Rate

The delayed reaction of the Ostrich Slaughter Rate is observed whenever a disturbance in OIMSA is simulated. The delayed reaction is therefore addressed before looking at any specific cause of system disturbances.

Whenever the Producer Gross Profit Margin per Ostrich is changed, the change in Desired Breeding Ostriches and subsequent process to balance the Breeding Ostriches with the Desired Breeding Ostriches is initialized instantaneously. A side-effect of the process to balance the Breeding Ostriches with the Desired Breeding Ostriches causes a relatively small reaction to the Ostrich Slaughter Rate, opposite to the desired change in Ostrich Slaughter Rate (see the *worse-before-better* production policy in Chapter 4.2.2). This phenomenon is termed the *immediate reaction* in this chapter.

The expected changes in Ostrich Slaughter Rate, similar to the change in Producer Gross Profit Margin per Ostrich, starts showing approximately 1 year after the initial disturbance and is referred to as OIMSA's initial reaction. This is because any change in Breeding Ostriches will be reflected in the Ostrich Slaughter Rate after a constant delay time of approximately one year - the time it takes an ostrich to reach slaughter-ready age from the time the egg is laid.

Another phenomenon often encountered is the fact that Ostrich Slaughter Rate always decreases at a faster rate than it increases. This is because the system is far more responsive to the action of decreasing Breeding Ostriches than it is to increasing Breeding Ostriches. Young Breeding Ostriches can be sent for slaughter almost instantaneously, decreasing the size of the Breeding Ostriches stock, while it takes approximately three years to raise a slaughter-ready ostrich to sexual maturity where it can be acquired by the Breeding Ostriches stock (see Equation 4.3.11 in Chapter 4.3.4.1).

After the initial reaction of the system, OIMSA's reaction where Ostrich Slaughter Rate initially decreases is visibly more dampened and controlled than when Ostrich Slaughter Rate initially increases. The reason being that if the Ostrich Slaughter Rate changes at a faster rate, OIMSA's balancing feedback can prevent Ostrich Slaughter Rate from further change with less system overshoot.

5.5.3 Ostrich leather market saturation

In the extreme case where OIMSA's state changes significantly enough that a sustainable profit margin occurs while the ostrich leather market is completely saturated, it would presumably be marketed and sold for its quality as one of the most durable leathers on earth rather than as a niche luxury fashion item. The Producer Leather Price per Ostrich in Dollar would therefore reach some Minimum Value of Leather for which it would contend with the prices of other durable leathers rather than reducing to a value of zero (or less than zero) by the Leather Demand vs Supply Ratio to stabilize the system as usual through loop **B1**(refer to Section 4.2).

The equilibrating forces preventing Producer Leather Price per Ostrich in Dollar from being decreased to zero by loop **B1** ultimately causes an increase in Producer Gross Profit Margin per Ostrich, causing Ostrich Slaughter Rate to equilibrate at a value higher than its initial equilibrium value of Baseline Leather Market Demand. The Producer Leather Price per Ostrich in Dollar would show a decreased equilibrium value, but not a big enough decrease to have OIMSA escape out of the extreme condition. The disturbance has no long term effect on the Producer Meat Price per Ostrich in Rand since the meat market is able to absorb an increase in supply in the long term. Disturbances with the ability to cause a permanent state-change of this nature is listed in no particular order in Table 5.6 below.

Table 5.6: List of disturbances with the potential to saturate the ostrich leather market in extreme conditions

Test Change in Rand vs Dollar Exchange Rate
Test Change in Rand vs Euro Exchange Rate
Test Change in Baseline Producer Meat Price in Euro
Test Percentage Increase or Decrease in Producer Cost per Ostrich

The metric most often used by industry when analysing the state of the South African ostrich industry, the Gross Producer Value of Leather in SA and the Gross Producer Value of Meat in SA, could be misleading as to the state of OIMSA. Since the variables are combinations of the respective commodity prices per ostrich and the Ostrich Slaughter Rate, both the Leather Income and Meat Income sectors appear to be performing better than they are if a more holistic overview of the system were to be made.

5.5.4 Disturbance in exchange rates

5.5.5 Change in exchange rates

Even though exchange rates are exogenous to the system, both the Rand vs Dollar Exchange Rate and the Rand vs Euro Exchange Rate have a significant effect on OIMSA. Refer to Appendix A.4 for examples of short and long term reactions to a variety of disturbances in exchange rates.

Initial reactions to a change in exchange rates

- The *immediate reaction* of the Ostrich Slaughter Rate is in accordance with Section 5.5.2.
- The system reaction-time, indicated by the wavelengths of the oscillations in key system variables, are uniform regardless of the magnitude or direction of disturbance, except in the extreme condition where the ostrich leather market is saturated.
- The exchange rate of the commodity explicitly defined by the Leather Income Fraction as being responsible for the majority fraction of income will have the greatest destabilizing effect on the system (indicated by the amplitude of the system oscillations). Since the Leather Income Fraction is defined as 0,6 (see Section 5.4), a change in Rand vs Dollar Exchange Rate destabilizes the system more than a change in Rand vs Euro Exchange Rate. As a rule, the system is not more affected by Rand vs Dollar

Exchange Rate than Rand vs Euro Exchange Rate, the Rand vs Dollar Exchange Rate simply has a greater affect on the Ostrich Slaughter Rate for the parameters chosen.

- An increase in either of the exchange rates destabilizes the system more than a decrease in exchange rates since there is a longer delay involved with increasing production than there is in decreasing production (see Section 5.5.2).
- The Meat Income sector is more stable to changes in Ostrich Slaughter Rate than the Leather Income sector in the short term.

Long term effect of a change in Rand vs Dollar Exchange Rate

The producer perceives no long term effect of a change in the Rand vs Dollar Exchange Rate. A step-change in the Rand vs Dollar Exchange Rate causes OIMSA to equilibrate at the initial Ostrich Slaughter Rate as well as income received by the producer from both leather and meat (for both the per unit price and the total income).

The change in income received by the primary producer, caused by a change in Rand vs Dollar Exchange Rate, is compensated for by an opposite change in Producer Leather Price per Ostrich in Dollar. Since the Producer Leather Price per Ostrich in Dollar is not one of the variables commonly used by producers to evaluate the health of the ostrich production industry, their perception is that both the Leather Income and Meat Income sectors equilibrate at their initial values. In reality, the state of the Leather Income sector would have changed.

Long term reaction of leather market saturation caused by the Rand vs Dollar Exchange Rate

The extreme case where the Rand vs Dollar Exchange Rate increases significantly enough for a sustainable profit margin to occur without having the major feedback loop that balances leather demand with supply by adjusting the price, Producer Leather Price per Ostrich in Dollar, is described in Section 5.5.3.

An extreme increase in the Rand vs Dollar Exchange Rate, causes both the Gross Producer Value of Leather in SA and Producer Leather Price per Ostrich in Dollar to equilibrate at an increased value despite the drastic reduction in the Producer Leather Price per Ostrich in Dollar. The increase is attributed to an increase in Rand vs Dollar Exchange Rate and the Ostrich Slaughter Rate. The industry therefore perceives a greater increase in the value of leather than there was in reality.

With regards to the MEAT INCOME sector, the extreme case has no long term effect of the Producer Meat Price per Ostrich in Rand since the meat market is able to absorb an increase in supply. The metric most often used by industry when analysing the ostrich meat industry, Gross Producer Value of Meat in SA, is increased because of an increase in Ostrich Slaughter Rate. The ostrich industry therefore perceives an increase in the value of meat.

Long term effect of a change in Rand vs Euro Exchange Rate

A disturbance in Rand vs Euro Exchange Rate would cause both the LEATHER INCOME and MEAT INCOME sectors to equilibrate at different values, even though the Ostrich Slaughter Rate equilibrated at its initial value, Baseline Leather Market Demand. Ostrich Slaughter Rate returns to its original value since the net income received by producers remain constant in the long term.

The Producer Meat Price per Ostrich in Euro equilibrates at its initial value since it is unaffected by the production rate in the long term however, Producer Meat Price per Ostrich in Rand as well as Gross Producer Value of Meat in SA are affected similarly by the change in Rand vs Euro Exchange Rate. The similar long term change in Producer Meat Price per Ostrich in Rand is balanced by an opposite change in Producer Leather Price per Ostrich in Dollar (and therefore Producer Leather Price per Ostrich in Rand) in order to have the Ostrich Slaughter Rate equilibrated back to the Baseline Leather Market Demand.

A change in the Rand vs Euro Exchange Rate could result in the ostrich industry perceiving that one sector is "consuming" the profits of the other sector. The producer may also argue that the system is at a better position (if Rand vs Euro Exchange Rate increased), or at a worse position (if Rand vs Euro Exchange Rate decreased) since the percentage change in income from meat is greater than the percentage change in income from leather, however, this is actually only a side-effect of the Leather Income Fraction of the system being chosen as 0,6 (see Section 5.4).

Long term reaction of leather market saturation caused by the Rand vs Euro Exchange Rate

In the extreme case where the Rand vs Euro Exchange Rate increases significantly enough for a sustainable profit margin to occur while the Producer Leather Price per Ostrich in Dollar is at its Minimum Value of Leather as described in Section 5.5.3, the Ostrich Slaughter Rate will equilibrate at a value higher than the Baseline Leather Market Demand (indicative of the saturation of the leather market).

An extreme favourable increase in Rand vs Euro Exchange Rate has the same affect on the MEAT INCOME sector as above. Since the Gross Producer Value of Leather in SA is a product of the Producer Leather Price per Ostrich in Rand that has approached its Minimum Value of Leather and the increased Ostrich Slaughter Rate, the ostrich industry could easily misperceive the reduction of income in such a circumstance.

5.5.6 Disturbances in market demands or product values

Refer to Appendix A.5 for examples of short and long term reactions to a variety of disturbances in market demands and product values.

5.5.6.1 Change in Baseline Leather Market Demand

This section discusses a change in the market demand of ostrich leather as a niche product that is influenced by a simple Leather Demand vs Supply Ratio. An example of an increase in Baseline Leather Market Demand would be if a new market for ostrich leather as interior of luxury cars were developed. An example of a decrease in Baseline Leather Market Demand would be if the handbag industry no-longer used any kind of leather in their luxury product ranges due to, for example, a radical campaign against using leather due to animal rights.

Initial reactions to a change in Baseline Leather Market Demand

- The *immediate reaction* of the Ostrich Slaughter Rate is in accordance with Section 5.5.2.
- The magnitude of the change in Baseline Leather Market Demand is similarly related to the degree, or size, of the disturbance (both amplitude and frequency of oscillations, as well as system transient time).
- The direction of the change in Baseline Leather Market Demand is another significant factor influencing the severity of a system disturbance: both amplitude and frequency of oscillations, as well as system transient time.
- An increase in Baseline Leather Market Demand results in larger system oscillations and longer transient times than that of a decrease since OIMSA's initial response is less responsive to increase the population than it is to decreasing it (see Section 5.5.2). The difference in responsiveness means that the change in Producer Leather Price per Ostrich in Dollar is more affected by an increase than it is to a decrease. This is because a highly inflated Producer Leather Price per Ostrich in Dollar that resulted from a long period of market undersupply required a corresponding period of oversupply (where Ostrich Slaughter Rate is greater than Baseline Leather Market Demand) before reaching a suitable profit margin relative to the size of production.

Long term reactions to a change in Baseline Leather Market Demand

A change in Baseline Leather Market Demand is the only way of causing a long term change in Ostrich Slaughter Rate without saturating the ostrich leather market, and is therefore considered the only sustainable method of causing a long term change in the size of the ostrich production industry of South Africa. Ostrich Slaughter Rate has a similar reaction to a change in Baseline Leather Market Demand in the long term.

Producer Leather Price per Ostrich in Dollar (and therefore the Producer Leather Price per Ostrich in Rand) has a similar initial reaction to a change in the Baseline Leather Market Demand. The long term reaction to a change in Baseline Leather Market Demand is also similar. Even though the severity of the systems' reaction is dependent on the direction of the change in the short term, the long term system reaction is not dependent on the direction of change, only the magnitude of the change. The Producer Meat Price per Ostrich in Euro and subsequent Producer Meat Price per Ostrich in Rand remains unchanged in the face of a change in the Baseline Leather Market Demand. Since the Producer Leather Price per Ostrich in Rand, Producer Meat Price per Ostrich in Rand and Ostrich Slaughter Rate is affected similarly, the primary producer could perceive the ostrich production industry of South Africa's behaviour from a change in Baseline Leather Market Demand more intensely than in reality due to the inflated values of the most used indicators: Gross Producer Value of Leather in SA and Gross Producer Value of Meat in SA.

5.5.6.2 Change in Baseline Producer Meat Price per Ostrich in Euro

This section simulates a change in the regular, long term selling price of ostrich meat. Ostrich meat is currently priced similar to that of high-quality beef in the European Union and is positioned as an every-day healthy alternative to red meat. An example of an increase in Baseline Producer Meat Price per Ostrich in Euro without market repositioning is if Baseline Producer Meat Price per Ostrich in Euro were to increase in response to an increase in high-quality beef. The increase in high-quality beef could be attributed to factors unrelated to the ostrich production industry of South Africa such as an additional carbon-related tax applied beef producers in the EU. An example of a decrease in Baseline Producer Meat Price per Ostrich in Euro is if ostrich meat were to be repositioned as an alternative to chicken rather than beef, and therefore priced to compete with chicken rather than beef.

Note that the market positioning of ostrich meat as an exclusive, exotic meat would result in structural change in OIMSA since Meat Income sector would be equally as dependant on a demand vs. supply ratio as the Leather Income sector. The before mentioned scenario is not considered in this study.

Initial reactions to a change in Baseline Producer Meat Price per Ostrich in Euro

- See Section 5.5.2 for explanation on the *immediate reaction* of the Ostrich Slaughter Rate.
- In the event of a disturbance in Baseline Producer Meat Price per Ostrich in Euro, the Ostrich Slaughter Rate's immediate reaction is in accordance to Section 5.5.2.
- The magnitude of the change in Baseline Producer Meat Price per Ostrich in Euro directly relates to the amplitude and transient time of the disturbance.
- The direction of the change in Baseline Producer Meat Price per Ostrich in Euro significantly influences the system responsiveness, or transient time, of the system: an increase in Baseline Producer Meat Price per Ostrich in Euro is damped more effectively than a decrease in Baseline Producer Meat Price per Ostrich in Euro. The improved response of the system in the event of an increase in Baseline Producer Meat Price per Ostrich in Euro is caused by the slower rate of initial change in the Ostrich Slaughter Rate that reduced the extent of over-adjustment to the leather price. The difference between this instance and a change in exchange rates where a negative change in the exchange rate causes a more effective dampening of the system in Section 5.5.5, is that the change in Baseline Producer Meat Price per Ostrich in Euro simulated as a gradual change while the exchange rates were simulated as step-changes.

Long term reactions to a change in Baseline Producer Meat Price per Ostrich in Euro

In the long term, the Producer Meat Price per Ostrich in Euro and subsequent indicators Producer Meat Price per Ostrich in Rand and Gross Producer Value of Meat in SA shows a fractional change exactly equal to the fractional change in Baseline Producer Meat Price per Ostrich in Euro.

The Producer Leather Price per Ostrich in Dollar adjusts to equilibrate Ostrich Slaughter Rate with Baseline Leather Market Demand. The change in Producer Leather Price per Ostrich in Dollar opposes the change in Baseline Producer Meat Price per Ostrich in Euro. A change in Producer Leather Price per Ostrich in Dollar causes a similar change in Producer Leather Price per Ostrich in Rand as well as Gross Producer Value of Leather in SA. Since the Ostrich Slaughter Rate equilibrates at its initial value, the percentage change in Producer Leather Price per Ostrich in Rand and Gross Producer Value of Leather in SA is equal.

Since the indicators most commonly used for industry analysis, Gross Producer Value of Leather in SA and Gross Producer Value of Meat in SA increase proportionally to their per unit equivalents, industry analysis of this phenomenon is not prone to misperceive the state of the system.

Leather market saturation caused by the Baseline Producer Meat Price per Ostrich in Euro

The only instance in which Ostrich Slaughter Rate equilibrates at a value other than Baseline Leather Market Demand is if the Producer Leather Price per Ostrich in Dollar (and therefore the Producer Leather Price per Ostrich in Rand) is balanced at its minimum value since the additional income from meat makes ostrich production sustainable. Such an extreme condition is explained in Section 5.5.3.

In such a case, the fractional decrease of Gross Producer Value of Leather in SA is less than that of the Producer Leather Price per Ostrich in Rand while the fractional increase of Gross Producer Value of Meat in SA is more than the Producer Leather Price per Ostrich in Rand. Both differences are caused by the increase in Ostrich Slaughter Rate explained in Section 5.5.3.

Industry analysts could wrongfully perceive that the Meat Industry is taking income away from the Leather Income sector as a result of the indicator they use. Such an interpretation would lead to the opinion that regain normal system conditions is in the best interest of the industry. When evaluating the state of OIMSA as a whole, the system is better off, and loose of production quantity constraints. The industry can therefore grow with no further long term implications on financial wellbeing.

5.5.6.3 Change in Baseline Meat Market Absorption Capacity

The meat market absorption capacity is considered to be the size of the market, in other words the amount of ostrich meat that people want to buy. An increase in supply forces market exploration, for example establishment of ties with more supermarket chains willing to stock ostrich meat. Additional market exploration results in an increase in Baseline Meat Market Absorption Capacity since more people are aware of ostrich meat and have the opportunity to purchase it (if a consumer product is not available, there is not market for it). An example of a change in Baseline Meat Market Absorption Capacity that is not dependant on product supply as a “pushing force” but rather customer demand as a “pulling force” is if a marketing campaign were to increase the awareness of ostrich meat to the European consumer through television commercials or billboards, or alternatively if ostrich meat were featured as a key element in a popular diet or cooking show. Note that popular diets could also potentially decrease the Baseline Meat Market Absorption Capacity if the diet condemns foods such as ostrich meat. An example of this scenario is the current popularity of "high-fat, low-carb" diets such as the "Tim Noaks diet" that favours meats that are high fat to lean meat such as ostrich or chicken.

Artificially changing the Baseline Meat Market Absorption Capacity through intervention such as a marketing campaign has effects that are temporary in nature with all elements in the system equilibrating in their respective initial equilibrium values.

Initial reactions to a change in Baseline Meat Market Absorption Capacity

- The disturbance in Baseline Meat Market Absorption Capacity's *immediate reaction* of the Ostrich Slaughter Rate is in accordance to Section 5.5.2.
- Intervention that causes a change in Baseline Meat Market Absorption Capacity has an initial similar reaction on income received from the MEAT INCOME sector.
- The additional income from the MEAT INCOME sector causes an initial similar reaction on Ostrich Slaughter Rate.
- The similar reaction in Ostrich Slaughter Rate is then counteracted by the Leather Demand vs Supply Ratio causing an opposite reaction in Producer Leather Price per Ostrich in Dollar. The counteracting affect is larger in both duration and amplitude for both Producer Leather Price per Ostrich in Dollar and Ostrich Slaughter Rate, meaning that any artificial change in the Baseline Meat Market Absorption Capacity has a backlash greater than the initial benefit.

5.5.7 Food safety concerns

As mention in Section 4.1.4, there are two food safety concerns that affect the ostrich production industry of South Africa namely the outbreak of bird flu in South Africa and concerns regarding BSE and FMD outbreaks in beef products produced in the EU. Both food safety concerns have a temporary affect on OIMSA, which returns to its initial equilibrium values in the long term. Refer to Appendix A.6 for examples of short and long term reactions to a variety of durations and severities of food safety concerns.

5.5.7.1 Presence of Meat Export Ban from Bird Flu

During a bird flu outbreak, ostrich producers lose a large portion of their income since raw ostrich meat exports to the European Union are banned. The ban applies to the entire country and not only to areas affected by the outbreak. Both the duration of the Presence of Meat Export Ban from Bird Flu (corresponding to the Equilibrium Duration of Bird Flu Epidemic) and the severity of the outbreak has implications for OIMSA. The severity of the outbreak is quantified as the percentage of the ostrich population to be culled, Equilibrium Percentage of Ostriches Culled in Bird Flu Epidemic. Another factor influencing the ostrich production industry is the Percentage of Income Lost due to Export Ban from having to sell ostrich meat either locally or export to countries other than the EU. The Percentage of Income Lost due to Export Ban has historically been a fixed value but since the export ban applies only to raw ostrich meat, the Percentage of Income Lost due to Export Ban could be reduced in future if the market for cooked ostrich meat products in the EU could be successfully developed.

Initial reactions to the Presence of Meat Export Ban from Bird Flu

- The *immediate reaction* of the system caused by the Presence of Meat Export Ban from Bird Flu is in accordance to Section 5.5.2.
- The Equilibrium Duration of Bird Flu Epidemic has a similar effect on the severity, or amplitude, of the disturbance as well as the system transient time.
- The Equilibrium Percentage of Ostriches Culled in Bird Flu Epidemic has a similar effect on the severity of the disturbance, but no significant influence on the transient time.
- Equilibrium Percentage of Ostriches Culled in Bird Flu Epidemic has a very severe short-term effect on the system however, the system recovers and stabilizes fairly quickly (short transient time). The Equilibrium Duration of Bird Flu Epidemic has a less severe short term effect on the system that is long lasting in nature (long transient time).
- The Percentage of Income Lost due to Export Ban only has a significant effect on the system for the duration of the export ban from the European Union. A decrease in the Percentage of Income Lost due to Export Ban results in a slightly greater amplitude and wavelength of the overall system disturbance since it reinforces the increase in contribution of the Meat Income sector at a time where the price of leather is inflated due to a sharp decrease in Ostrich Slaughter Rate.
- The Reluctance to Farm Ostriches due to Bird Flu Epidemic is responsible for a decrease in desirability relative to the duration of the presence of bird flu. Since there is no conceivable way of decreasing the risk related to bird flu that causes the Reluctance to Farm Ostriches due to Bird Flu Epidemic, it has not been indicated as a variable open for adjustment during sensitivity analysis.

- The spike increase in Ostrich Slaughter Rate, Gross Producer Value of Leather in SA and Gross Producer Value of Meat in SA (shown in Figure A.5) at the beginning of a period of bird flu as well as the spike decrease at the end of a period of bird flu is not a result of a DT that is larger than the smallest adjustment time in the system. It is a side-effect of adjusting the slaughtering strategy.

5.5.7.2 Presence of BSE and FMD in Europe

Concern over BSE and FMD has been cited as playing a significant role in decrease of the Fraction of Income Contributed by Leather, or the increase in the fractional income of meat, around 2001 (National Agricultural Marketing Council, 2003; ECIAfrica (Pty) Ltd, 2010; Brand *et al.*, 2011). However, since the scenario testing shows that OIMSA takes approximately one year for the European Market Development attributed to BSE and FMD Panic to have any impact on the Ostrich Slaughter Rate, the influence of this factor is considered to have very little impact in reality. The Presence of BSE and FMD in Europe has no long term impact on OIMSA.

Initial reactions to the Presence of BSE and FMD in Europe

- The *immediate reaction* of the Ostrich Slaughter Rate is in accordance with Section 5.5.2.
- The Equilibrium Duration of BSE and FMD in Europe has similar effect on transient time.
- The Equilibrium Duration of BSE and FMD in Europe has similar (very minor) effect on the severity of impact.

5.5.8 Production cost and economic climate

Both cost and economic climate are modelled as exogenous input variables to OIMSA since there is no feedback between OIMSA and either the price of feed, or the international economic climate (see Chapter 4.1). However, both these elements have significant impact on the endogenously determined Producer Gross Profit Margin per Ostrich - identified as the system driving force in Chapter 4.3.4.3. Refer to Appendix A.7 for examples of short and long term reactions to a variety of durations and severities of food safety concerns.

5.5.8.1 Change in Producer Cost per Ostrich

OIMSA estimates Producer Cost per Ostrich exogenously relative to the cost of feed. Changes in cost could come in the form of additional water tax levied on irrigated crops (increasing the price of feed), carbon tax levied per ostriches, or farming subsidies received (resulting in a decrease of cost).

Initial reactions to a change in Producer Cost per Ostrich

- The *immediate reaction* of the Ostrich Slaughter Rate is in accordance with Section 5.5.2.
- An increase in Producer Cost per Ostrich results in a greater transient time than the equivalent decrease in Producer Cost per Ostrich.
- An increase in Producer Cost per Ostrich results in a greater initial system reaction (amplitude of disturbance).
- A change in Producer Cost per Ostrich has a greater effect on the Leather Income sector than on the Meat Income sector.

Long term effect of a change in Producer Cost per Ostrich

A disturbance in the Producer Cost per Ostrich causes OIMSA no change in the equilibrium values of Ostrich Slaughter Rate or any of the Meat Income sector parameters since the Producer Leather Price per Ostrich in Dollar balances OIMSA. The change in the equilibrium value of Producer Leather Price per Ostrich in Dollar is similar to the change in Producer Cost per Ostrich. Ostrich producers are likely to have an accurate perception of the state of the ostrich industry since the fractional change in Producer Leather Price per Ostrich in Rand is equal to the fractional increase in the indicator Gross Producer Value of Leather in SA.

Long term reaction of leather market saturation caused by Producer Cost per Ostrich

In the extreme case where Producer Cost per Ostrich decreases significantly enough for a sustainable profit margin to occur while the Producer Leather Price per Ostrich in Dollar is at its Minimum Value of Leather, the Ostrich Slaughter Rate will equilibrate at a value higher than its initial equilibrium value, Baseline Leather Market Demand. All parameters in the Meat Income sector remains unchanged in the long term and equilibrates at its initial equilibrium values. In the more likely instance of an increase in cost, there is no extreme case that would change the equilibrium state of OIMSA.

5.5.8.2 Economic climate

The global economic climate is indicated by the presence of the Presence of the Worldwide Economic Recession as well as the Presence of Japanese Recession. Since Japan is no longer the majority consumer of ostrich leather as it had been in the 1990's (ECIAfrica (Pty) Ltd, 2010), only the Presence of the Worldwide Economic Recession was considered for sensitivity analysis.

- Section 5.5.2's explanation on the *immediate reaction* of the Ostrich Slaughter Rate is in line with OIMSA's reaction to the Presence of the Worldwide Economic Recession.
- A change in Equilibrium Duration of Worldwide Economic Recession results in a similar change in the severity (amplitude) of the system disturbance.
- A change in Equilibrium Duration of Worldwide Economic Recession results a similar change in the system transient time.
- The Producer Leather Price per Ostrich in Dollar and subsequent Producer Leather Price per Ostrich in Rand remains at a reduced value for the entire duration of the recession before oscillating on either side of the initial equilibrium value until the system is equilibrated at the initial equilibrium values.
- The Producer Meat Price per Ostrich in Euro and subsequent Producer Meat Price per Ostrich in Rand also remains at a reduced value for the duration of the economic recession but mostly oscillates underneath the initial equilibrium value rather than in-between until finally equilibrating at the initial equilibrium values.
- If the Equilibrium Duration of Worldwide Economic Recession is chosen between approximately 0,5 and 2,5 years, significant overshoot in Ostrich Slaughter Rate is produced during system recovery. The overshoot in Ostrich Slaughter Rate is a result of the overshoot in the LEATHER INCOME sector. This indicates that OIMSA would be resilient to worldwide economic hardship of between 0,5 and 2,5 years.
- If the Equilibrium Duration of Worldwide Economic Recession is set to a value greater than 2,5 years, the overshoot in the LEATHER INCOME sector does not happen since the Leather Demand vs Supply Ratio is damped by the prolonged period of a decreased Ostrich Slaughter Rate. The Ostrich Slaughter Rate, LEATHER INCOME sector and MEAT INCOME sector oscillates underneath the initial equilibrium value rather than in-between until finally equilibrating at the initial equilibrium values. This indicates that the Leather Income sector would not be resilient enough to rebound after more than 2,5 years of worldwide economic hardship unaffected. Rehabilitation of the Leather Income sector would happen gradually without

the income surpassing the equilibrium value for any significant amount of time.

A disturbance in the form of an economic downturn does not result in long term changes in OIMSA. OIMSA eventually equilibrates at its initial equilibrium values.

5.5.8.3 Conversion to small camps

Converting to small camp breeding to the current method of flock breeding is crucial to preserve and sustain the unique flora in the Klein Karoo region (Mugido, 2011). The difference between the two methods of production can be found in Appendix B. Since conversion requires financial investment, it is assumed that a regulatory authority would have mandate ostrich producers to convert from flock breeding to small camp breeding. It is assumed that policy would state a window-period in which the ostrich industry should convert. Different notice periods, defined as Equilibrium Time Allocated to Small Camps, are tested with the assumption that producers would spread the cost evenly throughout the time period.

- The disturbance in cost is dependent on the size of the Breeding Ostriches relative to the Equilibrium Time Allocated to Small Camps. In other words, fraction of Breeding Ostriches that is relocated to small camps per year is related the fractional increase in Producer Cost per Ostrich. The fractional increase in Producer Cost per Ostrich ultimately determines the severity of the system disturbance.
- Equilibrium Time Allocated to Small Camps does not have a significant effect on the transient time of OIMSA.
- To minimize system disturbance, a Equilibrium Time Allocated to Small Camps of ten years is recommended.
- If a Equilibrium Time Allocated to Small Camps of longer than ten years is chosen, OIMSA's ability to dampen system oscillations are diminished.
- If the Equilibrium Time Allocated to Small Camps is chosen as considerably less (five years or less), the initial severity of the system disturbance is too significant.

Long term effect of a change in Producer Cost per Ostrich

A policy to convert to the small camp breeding system will result in a long term increase in Producer Cost per Ostrich, attributed to maintaining the additional infrastructure. The long-term increase in Producer Cost per Ostrich is not dependant on the Equilibrium Time Allocated to Small Camps, but rather on the cost and frequency of infrastructure maintenance.

The Producer Leather Price per Ostrich in Rand and subsequent Producer Leather Price per Ostrich in Rand counteract the increase in Producer Cost per Ostrich. Therefore OIMSA will equilibrate at an increased Producer Leather Price per Ostrich in Rand. The fractional increase in Producer Leather Price per Ostrich in Rand will be equal to the fractional increase in Gross Producer Value of Leather in SA.

Since data and analysis of the annual Gross Producer Value of Leather in SA is readily available while producers are left to estimate their Producer Cost per Ostrich, producers may perceive an increase or decrease in Producer Gross Profit Margin per Ostrich.

5.6 Summary

This concludes the chapter regarding results from OIMSA. The preceding chapter, Chapter 4, proposed an aggregate CLD and SFD able to produce baseline, equilibrated, and open system model outputs, that is tested in this chapter.

First, **Baseline OIMSA** and **Open Loop OIMSA** is compared with the model reference mode in Section 5.1. **Baseline OIMSA** also shows a forecast into the future. All key indicators, namely Ostrich Slaughter Rate, Producer Leather Price per Ostrich in Rand, Producer Meat Price per Ostrich in Rand, Producer Leather Price per Ostrich in Rand and Producer Meat Price per Ostrich in Rand is deemed to have behaviour accurate enough to provide a qualitative explanation of the system. Next, Sections 5.2 and 5.3 discuss model validation and verification and OIMSA applications, limitations and challenges, respectively.

Section 5.4 then confirms that OIMSA is inherently a stable, balancing system that is capable of equilibrating. Equilibrated OIMSA is validated and calibrated for scenario testing and policy analysis. The first phase of the process of scenario testing and policy analysis was to rank the short and long term effects of each exogenous influence compared to all other influences to indicate the relative severity of each type of impact. In conclusion, disturbances in exchange rates, market demands, product values, food safety concerns, production costs, as well as economic climate is explored. The following section, Section 6, concludes the results of the study.

Chapter 6

Conclusion

The Ostrich Industry Model of South Africa (OIMSA) created a platform to include the ostrich production industry of South Africa into the Green Economy Transition movement through the design and development of OIMSA. The study also contributes to the limited amount of research available on ostrich products as commodities. OIMSA is the only dynamic model of the ostrich production industry that is able to test proposed policies that is known to the author. The dynamic model, OIMSA, consists of an original Causal Loop Diagram (CLD), as well as an original Stock and Flow Diagram (SFD). The mathematical formulation and the quantitative long and short term results of the SFD can be conveniently explained to ostrich industry stakeholders with no prior knowledge of system dynamics using OIMSA's aggregate CLD.

This study contributes an alternative system dynamics model of a livestock commodity cycle to Meadow's hog cycle. The livestock model contributed is set within a different socio-economic environment, as well as a different type of commodity market, to that of the hog cycle proposed by Meadows (1970). OIMSA therefore offers new insights into the agricultural sector of a developing country that exports niche and consumer items concurrently.

Additionally, the study contributes the only system-oriented analysis of the ostrich industry of South Africa known to the author. The study argues that presenting the ostrich production industry as a system with feedback could help mediate relations among ostrich producers, as well as between ostrich producers and upstream value-adding sectors. OIMSA's aggregate CLD could be a valuable tool to facilitate a collaborative long-term planning effort throughout the entire industry, ultimately creating a more stable production pattern that would benefit the greater ostrich industry of South Africa.

6.1 Research findings

The literature review of the ostrich industry revealed the lack of availability of studies using any kind of systems thinking tools to analyse the ostrich industry. South African ostrich leather and meat are both exported, implying that commodity prices are determined by the global market, and then heavily influence by the Rand vs. Dollar and Rand vs. Euro exchange rates rather than country-specific endogenous factors. Research on the topic of the price of ostrich leather as a commodity indicated that the strong dependence on previous global supply is common knowledge by the industry. Strong dependence on previous market supply levels is indicative of strong dependence on system feedback in the global ostrich industry. Since the South African ostrich industry accounts for approximately 70% of the global ostrich market (DAFF, 2013), the global market supply can be considered endogenous. Therefore a strong feedback exists between the ostrich production in South Africa and income received by ostrich producers for leather.

Research indicated that ostrich meat is considered a consumer item that is marketed as a heathy alternative to red meat. The international meat market price is therefore fixed to the, fairly stable, price of beef in the EU. In contrast to the ostrich leather market, the meat market has the capacity to undergo virtually endless market exploration.

OIMSA was created with the main purpose of investigating the boom-and-bust behaviour of ostrich production in South Africa in aid of the industry's green economy transition. Secondary purposes include potential policy analysis as well as investigating the most sustainable long term focus of the ostrich industry. OIMSA was constantly tested using a variety of verification and validation techniques including mainly judgement methods for direct structure tests, partial model testing for intended rationality (open loop tests), qualitative comparison between model output and behaviour, loop knockout tests as well as numerical, behavioural and policy sensitivity analysis.

Major limitations of the study include the availability and reliability of data as well as limited engagement with the ostrich industry of South Africa throughout the study. The study has limited broader research compatibility since OIMSA is specific to the South African ostrich industry. The model cannot be applied to the ostrich industry of a different country, nor to a different livestock production sector of South Africa. The model scope is constrained to the ostrich production industry. Income received by the ostrich producer from the value-adding sector is estimated while no inferences about the final selling price of commodities on international markets are made.

6.2 Results

A baseline simulation, intending to simulate the historical performance of the ostrich industry, was compared with its open system and reference mode counterparts. The baseline simulation also forecasts future behaviour of the ostrich industry. The most significant findings are listed below.

- The overall performance of the open system simulation deemed each individual sector of OIMSA acceptable. Deviation from the reference mode suggests that there is a degree of inaccuracies in the parameter assumptions of OIMSA. The inaccuracies are insignificant enough for the system structure to provide a holistic qualitative insight into the ostrich industry of South Africa. Failure of the open system PRIMARY PRODUCTION sector to accurately replicate the reference mode in later years are attributed to a delay in the reference mode data of the MEAT INCOME sector (the reference mode data of the MEAT INCOME sector is used as an input when simulating the PRIMARY PRODUCTION sector as an open loop system). The inaccuracy of the system output therefore serves as further validation of a system structure resembling reality. OIMSA does not produce the correct results with an incorrect input.

- The overall performance of the baseline simulation is close to that of the reference mode - more so in recent years than historically. The degree of accuracy is acceptable to convey a qualitative explanation of the industry structure. The baseline simulation MEAT INCOME sector corresponds closely to its open system counterpart, further validating the accuracy of the system structure. The forecasted behaviour is deemed plausible even though the indicators most commonly used by industry, the total gross income from each sector, seem extreme if one does not consider that the indicators are products of two endogenously defined system parameters, all within the bounds of reasonable operation.

6.2.1 Scenario analysis and policy testing

Scenario analysis and policy testing followed validation of the proposed equilibrated OIMSA model. Scenario analysis and policy testing is significant as it is the most accurate way of determining the true extent of influence that a single parameter has on the system as a whole. An overview of the findings are summarised below.

- Before studying each scenario and policy individually, the severity of each exogenous influence is measured relative to the other influences considered. Both long and short term effects were evaluated and ranked separately.

- The lasting, long term, effect that any exogenous influence has on OIMSA is considered to the most significant factor of the overall sustainability of the ostrich industry. The only influence that can cause a permanent increase in production is shown to be the ostrich leather demand. The ostrich leather demand is therefore identified to be the long term industry focus if sustainable industry growth is to be achieved.

- Other variables that have significant, long term, effects on individual ostrich industry sectors, while having no influence on overall production, are the change in Rand vs. Euro Exchange Rate, an increase in the selling price of ostrich meat in the EU, as well as the production cost. Converting to the small camp production system has an almost negligible long term effect on OIMSA. These influences are considered to have the ability to change the fractional income per sector, and therefore the significance of each sector, without having any influence over ostrich production. Changes in the fractional income per sector has no significance on the economical sustainability of ostrich producers while having potentially devastating effects on the up-stream value-adding ostrich industry of South Africa.

- The study shows that it is detrimental for the ostrich production industry as a whole to artificially increase demand of ostrich meat to be greater that its capacity to supply by, for example, a marketing campaign.

- Variables that have no permanent effects on OIMSA are the economic recession, bird flu epidemics, the Rand vs. Dollar exchange rate, the demand for ostrich meat in the EU, as well as the food safety concerns regarding beef produced in the European Union.

- Ostrich producers often wrongfully attribute the long term change brought on by an exogenous influence to some unrelated, recent, influence. A good example of this phenomenon is the attribution of an increase in the overall significance of the ostrich meat sector to panic over potential the existence of BSE and FMD in the European Union. This study proposes that the increase in income from ostrich meat was most likely caused solely by the increase in the Rand vs. Euro exchange rate since the other potential factor, a permanent change in the selling price of ostrich meat in the EU, was not reported during that period (see Section 5.5.6.2 and 5.5.6.3 for the difference between a permanent increase in the ostrich meat price and a temporary increase in demand for ostrich meat).

- OIMSA is significantly influenced by the presence of bird flu in the short term, while bird flu has no permanent impact on the long term wellbeing of the ostrich industry. It is therefore advisable for an agricultural speculator to acquire ostrich production farms during periods of bird flu, when ostrich farms have diminished desirability, and are likely to be sold below market value, since the ostrich industry is to recover fully regardless of the severity of the bird flu. Similarly, the fact that OIMSA is significantly influenced by the economic recession in the short term while the recession shows no long term impact argues that the ostrich industry of South Africa is worth governmental aid during economic hardship since the industry is a worthy investment that will recover fully once the economic recession has passed.

- The majority of ostrich industry dialogue over the effects of exchange rates are centred on the Rand vs. Dollar exchange rate. In OIMSA, the Rand vs. Dollar exchange rate is one of the most significant influences on in the short term, which is in stark contrast to the fact that the Rand vs. Dollar exchange rate has on long term influence over OIMSA. The Rand vs. Euro exchange rate has a moderate effect in the state of the system in both the short and long term. Even though ostrich producers are more aware of the effect of a change in the Rand vs. Dollar exchange rate, the industry should consider the anticipated movement of the Rand vs. Euro exchange rate, rather than the Rand vs. Dollar exchange rate, during long term planning.

- The extreme case where the OIMSA leather market is completely saturated, given the extreme condition causing saturation is sustainable, is the most ideal outcome for the system since income would no longer be constrained by market demand for ostrich leather as a niche product. This scenario would lead to virtually unlimited potential for ostrich production industry growth, promoting social and economic sustainability. Research indicates that the ostrich industry has an overall negative perception of such a scenario indicative of an overall risk-averse attitude. Influences identified as having the ability to cause leather market saturation are the Rand vs. Dollar and Rand vs. Euro exchange rates, a permanent change in producer selling price of ostrich meat, as well as a change in production cost.

6.3 Overall recommendations regarding transition to the green economy of South Africa

Long term focus of the ostrich industry of South Africa

- The long term focus of the ostrich industry should be on the development of additional luxury leather markets, for example, the use of ostrich leather as interior in luxury sports cars.

- Focussing on the ostrich meat market cannot result in a sustainable long term production increase, except in the unlikely scenario of total leather market saturation. The ostrich industry has no sustainable way of influencing the selling price of ostrich meat. The study proposes that ostrich meat is already optimally positioned as an every-day healthy alternative to red meat.

- Since a change in the selling price of ostrich meat results in significant influence on both the short and long term, coupled with the fact that a short term change in demand has an opposite overall effect on OIMSA, the optimal long term strategy for the ostrich meat industry is to ensure healthy, established, relationships with retail chains in the EU. The international demand, or the degree of establishment in the retail sector of South Africa, should equal or be slightly less than the ostrich industries' capacity to supply ostrich meat. The newly emerging market exploration and development of cooked ostrich meat products, having the advantage of not being banned from export to the EU during bird flu outbreaks in South Africa, should therefore replace products that are currently supplied rather than creating an additional demand to avoid negative side-effects, to the ostrich production industry as a whole.

Inclusion of new entrant black farmers

- Without the development of additional luxury leather demand, inexperienced new entrant black farmers are likely to fail in addition to causing permanent damage to the economic sustainability of the ostrich industry. One of the primary strategies proposed to achieve sustainable economic growth and social protection interdependently is to establish new black owned farms at a rate corresponding to the growth in luxury leather demand. If the two strategies are implemented concurrently, ostrich production will increase without a significant disturbance in the income received from leather per ostrich as the increase in supply is offset by a similar increase in demand. The stability of income received per ostrich is crucial to allow entrance of new black farmers - if the income increases noticeably, established farmers would simply increase their production, thereby forcing less established, inexperienced, farmers out of the industry.

Transitioning to small camp breeding system

- The implementation of a policy mandating ostrich producers to convert from the current production method of flock breeding to small camp breeding for the purpose of ensuring long term environmental sustainability of the Klein Karoo veld area has been a controversial topic between industry stakeholders since it requires ostrich producers to make an upfront, easily measurable, financial investment in farming infrastructure. However, the study shows that the mandatory conversion has an almost negligible short and long term effect on OIMSA compared to any other exogenous influence.

  Due to the anticipated resistance of ostrich producers to the proposed policy of having to spend money to out of hand, policy makers could potentially accumulate the capital for small camp infrastructure through means of taxation or levies on up-stream adding sectors over the same time-period that the mandated conversion would have taken place. The reduction in income of up-stream value adding sectors would inevitably be passed down-stream to a reduction in gross producer income equal to the cost of the infrastructure upgrade. Due to the very limited impact that the accumulation of funds is expected to have on ostrich production, the secondary contribution would likely go unnoticed by ostrich producers. Upon accumulation of enough capital, mandatory small camp infrastructure can then be installed industry wide without ostrich producers perceiving any personal cost.

Implementation of carbon tax per ostrich produced as well as water tax on irrigated crops

- The implementation of carbon tax per ostrich produced, as well as the implementaion of water tax on irrigated crops, translates to an increase in production cost in OIMSA. The former, a tax or levy applied directly to ostrich producers per ostrich, as well as the latter, a tax or levy applied to feed producers that ultimately causes an increase in feed price, influence OIMSA in identical ways.

  The short term, and therefore perceived affect by ostrich producers, of a change in cost, is relatively severe. This study advises against the considderation of implementing carbon and water tax simultaneously since the short term instability of the system will be twice as severe if both taxes are implemented at the same time. The study proposes a gradual implementation of any kind of additional tax or levy (both primary or secondary) as to minimize the short term, and therefore perceived affect, ostrich producers have on the change. The study also recommends that policy makers choose between either carbon tax on ostriches, or water tax on all irrigated crops, since there is no difference in ostrich industry reaction between the two policies: the one policy affects only the ostrich industry while the other affects the greater agricultural sector of South Africa.

6.4 Recommendations for future research

- Extend model boundary to include commodity markets.
- Quantitative model parameter estimation through econometric methods
- Potential final year industrial engineering project topic: "Development of a system dynamics simulation game for the ostrich industry stakeholders in South Africa". The learning objective of the game should be for industry stakeholders to become aware of the interdependencies to industry-wide decisions as well as the dynamic nature of the industry through experiential learning.

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Appendices

Appendix A

OIMSA run specifications and results

Appendix A contains OIMSA run specifications, exogenous parameter values and moedl output discussed in the Chapter 5.

A.1 Run specifications

Table A.1: **Baseline OIMSA** run specifications for comparison between **Baseline OIMSA**, **Open Loop OIMSA** and the reference mode in Section 5.1

Specification	Value
Start time	1993
End time	2020
DT	$\frac{1}{128}$
Unit of time	Years
Integration method	Euler's Method

Table A.2: **Open Loop OIMSA** run specifications for comparison between **Baseline OIMSA**, **Open Loop OIMSA** and the reference mode in Section 5.1

Specification	**Value**
Start time	1993
End time	2014
DT	$\frac{1}{128}$
Unit of time	Years
Integration method	Euler's Method

Table A.3: Run specifications for comparing **Naturally Equilibrated Baseline OIMSA** with **Equilibriated OIMSA** in Section 5.4

Specification	**Value**
Start time	1993
End time	2250
DT	$\frac{1}{64}$
Unit of time	Years
Integration method	Euler's Method

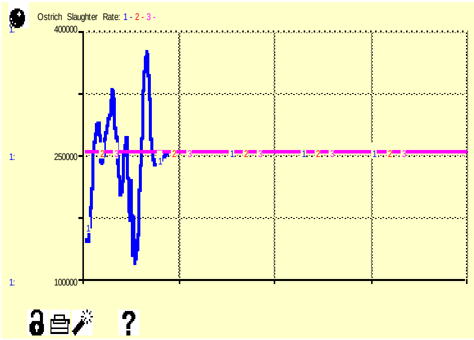
Table A.4: **Equilibriated OIMSA** run specifications used for sensitivity analysis in Section 5.5

Specification	**Value**
Start time	1993
End time	2250
DT	$\frac{1}{64}$
Unit of time	Years
Integration method	Euler's Method

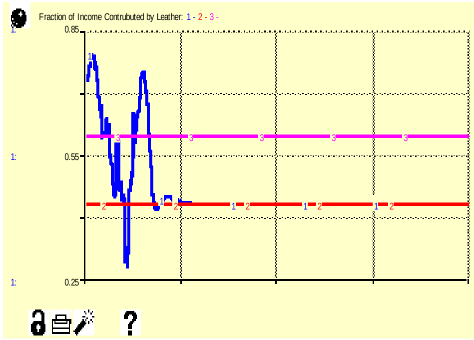
A.2 OIMSA equilibrium model validation

Table A.5: Defined values of **equilibriated OIMSA** parameters in Section 5.4

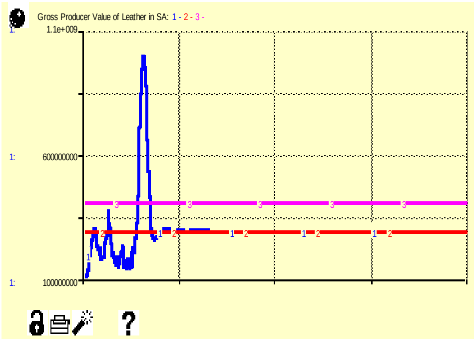
Parameter	Unit of Measure	Value
Desired Production Rate	ostrich/year	255 000
Leather Income Fraction	unitless	Run 2: 0,75; Run 3: 0,6
Cost of Lucerne per kg	R/kg	1,48
Cost of Maize per kg	R/kg	2,38
Cost of Sunflower Seeds per kg	R/kg	4,74
Presence of Japanese Recession	unitless	0
Minimum Value of Leather	Dollar	0
Rand Dollar Exchange Rate	R/Dollar	10,87
Presence of Worldwide Economic Recession	unitless	0
Rand Euro Exchange Rate	R/Euro	13,83
European HICP	unitless	0
Presence of BSE and FMD in Europe	unitless	0
Presence of the 2004 Bird Flu Epidemic	unitless	0
Presence of the 2011 Bird Flu Epidemic	unitless	0
Number of Ostriches Culled in the 2004 Bird Flu Epidemic	ostrich	0
Number of Ostriches Culled in the 2011 Bird Flu Epidemic	ostrich	0
Reluctance to Enter Market after Deregulation	unitless	1



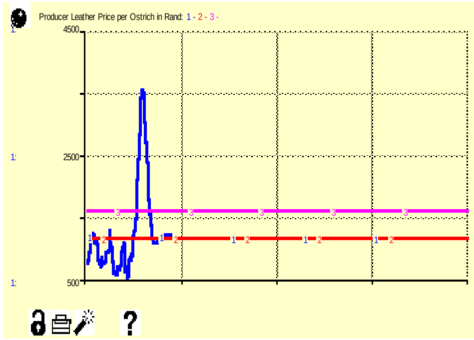
(a) Ostrich Slaughter Rate



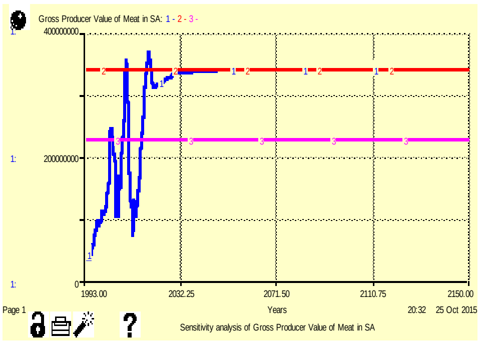
(b) Fraction of Income Contributed by Leather



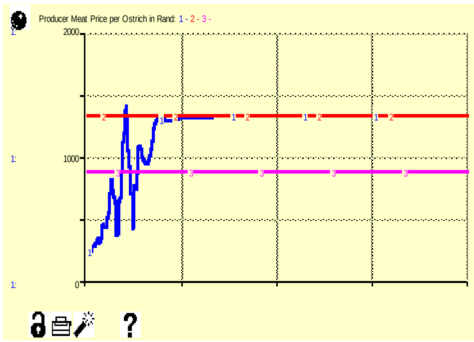
(c) Gross Producer Value of Leather in SA



(d) Producer Leather Price per Ostrich in Rand



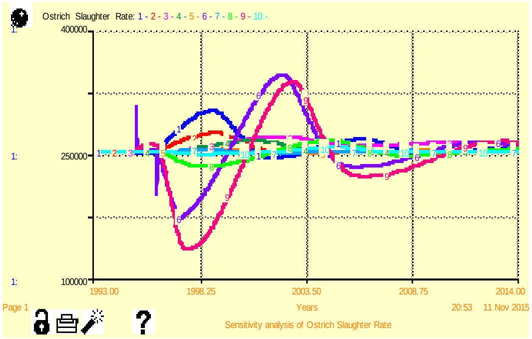
(e) Gross Producer Value of Meat in SA



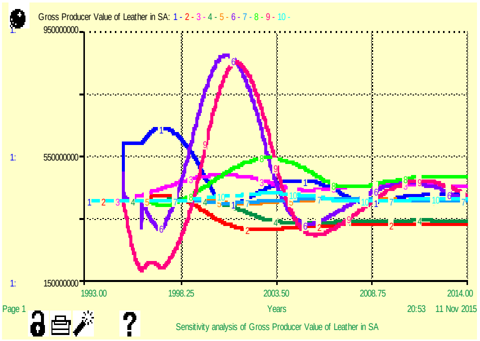
(f) Producer Meat Price per Ostrich in Rand

Figure A.1: **Baseline OIMSA** compared to **equilibriated OIMSA** in Section A.1

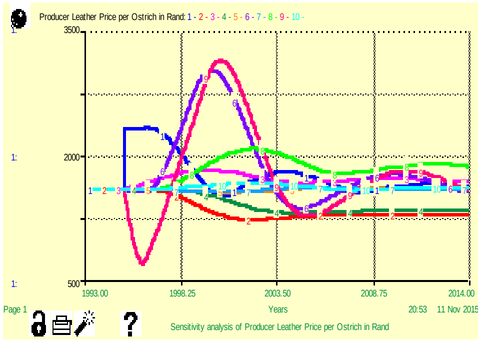
A.3 Comparison of disturbances



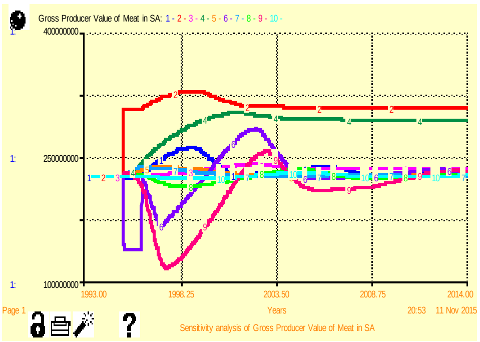
(a) Ostrich Slaughter Rate



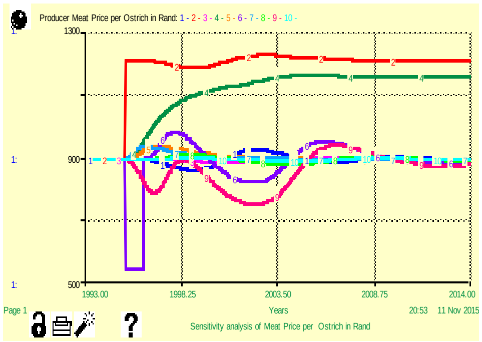
(b) Gross Producer Value of Leather in SA



(c) Producer Leather Price per Ostrich in Rand



(d) Gross Producer Value of Meat in SA



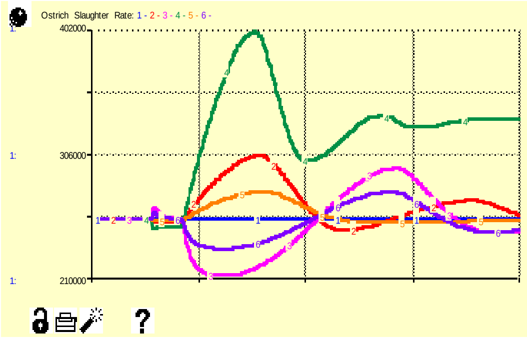
(e) Producer Meat Price per Ostrich in Rand

Figure A.2: Comparison of severity of disturbances in OIMSA in Section 5.5.1

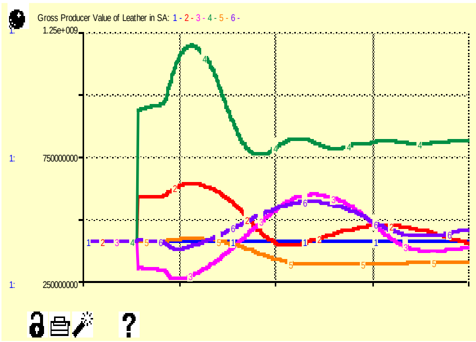
Table A.6: Initialization of disturbances compared in Section 5.5.1

	Scenario	Variable	Change in Value	Variable	Change in Value	Variable	Change in Value
Run 1	Test Change in Rand vs Dollar Exchange Rate	Step Increase of Decrease in Rand vs Dollar Exchange Rate	5				
Run 2	Test Change in Rand vs Euro Exchange Rate	Step Increase of Decrease in Rand vs Euro Exchange Rate	5				
Run 3	Test Change in Baseline Leather Market Demand	Step Increase or Decrease in Baseline Leather Market Demand	10000				
Run 4	Test Baseline Producer Meat Price Increase	Equilibrium Percentage Increase in Baseline Producer Meat Price	0.3				
Run 5	Test Baseline Meat Market Absorption Capacity	Equilibrium Increase in Meat Market Absorption Capacity	50000	Equilibrium Duration of Change in Meat Market Absorption Capacity	1		
Run 6	Test Bird Flu Epedemic	Equilibrium Duration of Bird Flu Epedemic	1	Equilibrium Percentage of Ostriches Culled in Bird Flu Epedemic	0.2	Equilibrium Percentage Loss of Income	0.4
Run 7	Test Presence of BSE and FMD in Europe	Equilibrium Duration of BSE and FMD in Europe	0.3				
Run 8	Test Percentage Increase or Decrease in Producer Cost per Ostrich	Equilibrium Percentage Change in Producer Cost per Ostrich	0.1				
Run 9	Test Presence of Worldwide Economic Recession	Equilibrium Duration of Worldwide Economic Recession	1				
Run 10	Test Conversion to Small Camps	Equilibrium Time Allocated to Convert to Small Camps	5				

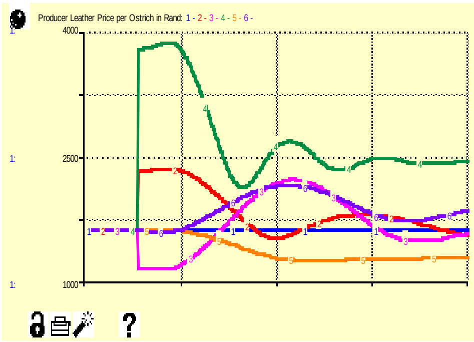
A.4 Disturbance in exchange rates



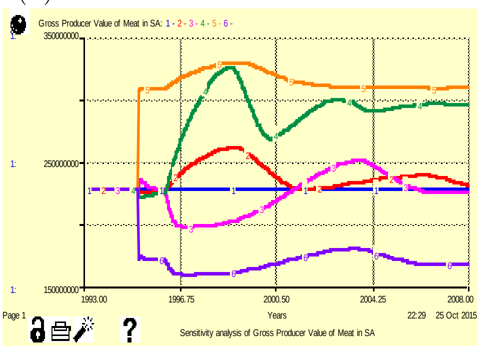
(a) Ostrich Slaughter Rate



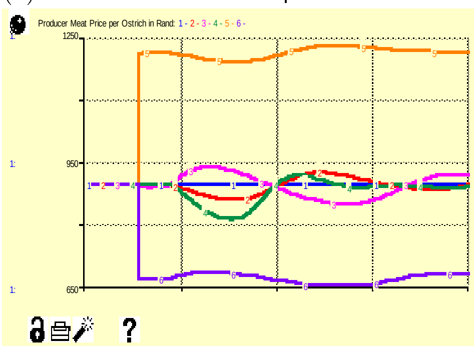
(b) Gross Producer Value of Leather in SA



(c) Producer Leather Price per Ostrich in Rand



(d) Gross Producer Value of Meat in SA



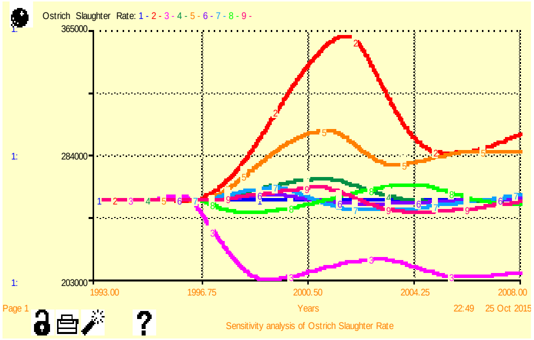
(e) Producer Meat Price per Ostrich in Rand

Figure A.3: Short term effect of a disturbance in exchange rates in Section 5.5.5

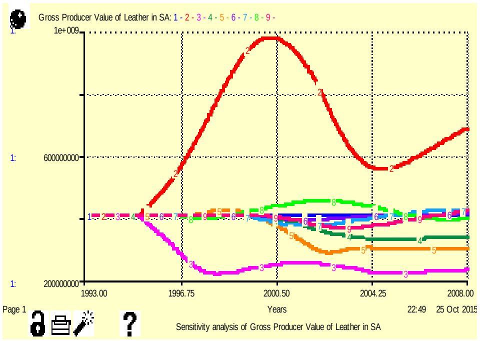
Table A.7: Long term effect of a disturbance in exchange rates in Section 5.5.5

	Run 1	**Run 2**	**Run 3**	**Run 4**	**Run 5**
Scenario	Test Change in Rand vs Dollar Exchange Rate	Test Change in Rand vs Dollar Exchange Rate	Test Change in Rand vs Dollar Exchange Rate	Test Change in Rand vs Euro Exchange Rate	Test Change in Rand vs Euro Exchange Rate
Variable	Step Increase of Decrease in Rand vs Dollar Exchange Rate	Step Increase of Decrease in Rand vs Dollar Exchange Rate	Step Increase of Decrease in Rand vs Dollar Exchange Rate	Step Increase of Decrease in Rand vs Euro Exchange Rate	Step Increase of Decrease in Rand vs Euro Exchange Rate
Change in Value	5	-3	15	5	-3.5
Ostrich Slaughter Rate	0.00%	0.00%	31.49%	0.00%	0.00%
Producer Leather Price per Ostrich in Rand	0.00%	0.00%	52.48%	-20.22%	14.15%
Producer Meat Price per Ostrich in Rand	0.00%	0.00%	0.00%	36.15%	-25.31%
Gross Producer Value of Leather in SA	0.00%	0.00%	100.48%	-20.22%	14.15%
Gross Producer Value of Meat in SA	0.00%	0.00%	31.49%	36.15%	-25.31%
Fraction of Income Contributed by Leather	0.00%	0.00%	16.67%	-20.00%	13.33%

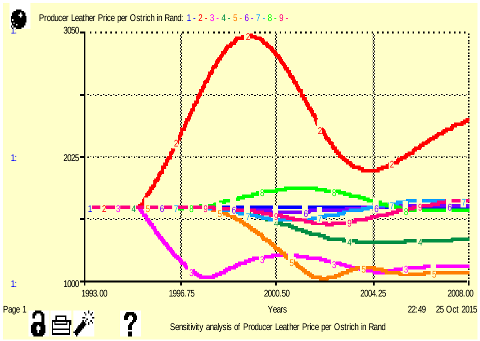
A.5 Disturbances in market demands or product values



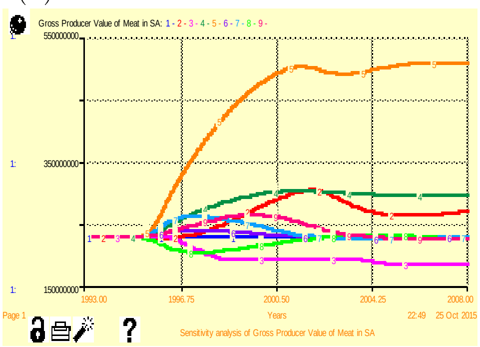
(a) Ostrich Slaughter Rate



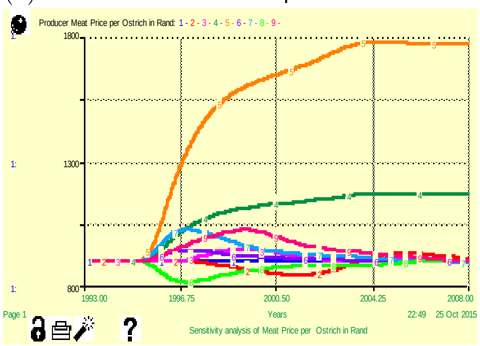
(b) Gross Producer Value of Leather in SA



(c) Producer Leather Price per Ostrich in Rand



(d) Gross Producer Value of Meat in SA



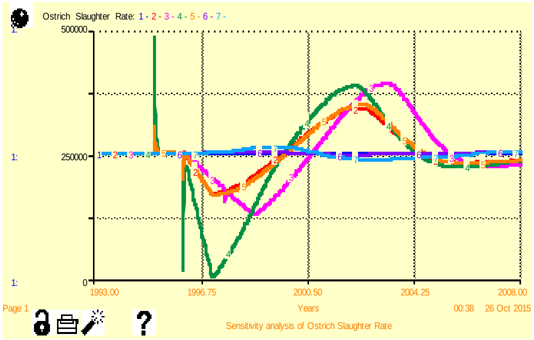
(e) Producer Meat Price per Ostrich in Rand

Figure A.4: Short term effect of a disturbances in market demands or product values in Section 5.5.6

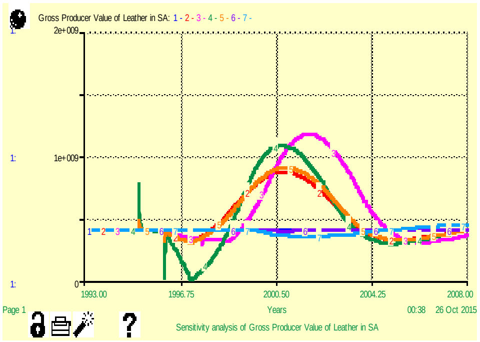
Table A.8: Long term effect of a disturbance in market demands or product values in Section 5.5.6

	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8
Scenario	Test Change in Baseline Leather Market Demand	Test Change in Baseline Leather Market Demand	Test Baseline Producer Meat Price Increase	Test Baseline Producer Meat Price Increase	Test Baseline Meat Market Absorption Capacity	Test Baseline Meat Market Absorption Capacity	Test Baseline Meat Market Absorption Capacity	Test Baseline Meat Market Absorption Capacity
Variable	Step Increase or Decrease in Baseline Leather Market Demand	Step Increase or Decrease in Baseline Leather Market Demand	Equilibrium Percentage Increase in Baseline Producer Meat Price	Equilibrium Percentage Increase in Baseline Producer Meat Price	Equilibrium Increase in Meat Market Absorption Capacity	Equilibrium Increase in Meat Market Absorption Capacity	Equilibrium Increase in Meat Market Absorption Capacity	Equilibrium Increase in Meat Market Absorption Capacity
Change in Value	50000	-50000	0.3	1	50000	150000	-100000	50000
Variable					Equilibrium Duration of Change in Meat Market Absorption Capacity	Equilibrium Duration of Change in Meat Market Absorption Capacity	Equilibrium Duration of Change in Meat Market Absorption Capacity	Equilibrium Duration of Change in Meat Market Absorption Capacity
Change in Value					1	1	1	4
Ostrich Slaughter Rate	19.61%	-19.29%	0.00%	13.15%	0.00%	0.00%	0.00%	0.00%
Producer Leather Price per Ostrich in Rand	32.68%	-32.16%	-16.78%	-34.01%	0.00%	0.00%	0.00%	0.00%
Producer Meat Price per Ostrich in Rand	0.00%	0.00%	30.00%	100.00%	0.00%	0.00%	0.00%	0.00%
Gross Producer Value of Leather in SA	58.70%	-45.25%	-16.78%	-25.33%	0.00%	0.00%	0.00%	0.00%
Gross Producer Value of Meat in SA	19.61%	-19.29%	30.00%	126.30%	0.00%	0.00%	0.00%	0.00%
Fraction of Income Contributed by Leather	11.67%	-16.67%	-16.67%	-41.67%	0.00%	0.00%	0.00%	0.00%

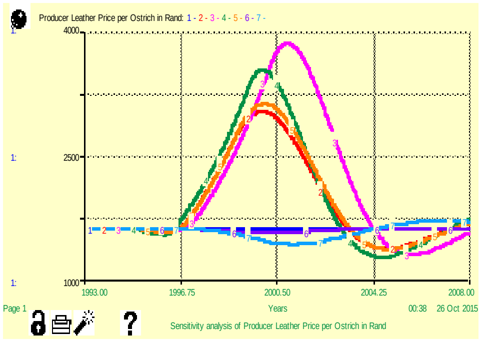
A.6 Food safety concerns



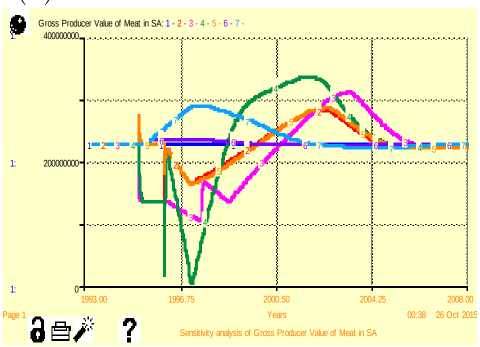
(a) Ostrich Slaughter Rate



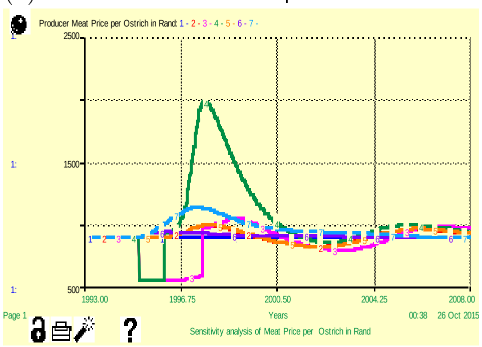
(b) Gross Producer Value of Leather in SA



(c) Producer Leather Price per Ostrich in Rand



(d) Gross Producer Value of Meat in SA



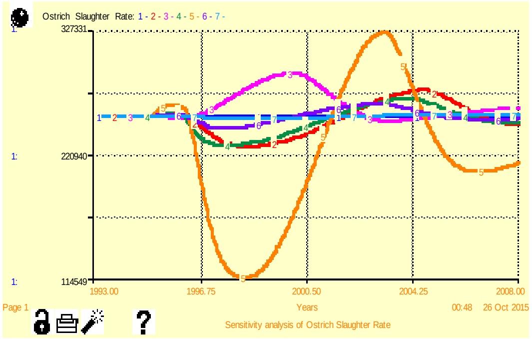
(e) Producer Meat Price per Ostrich in Rand

Figure A.5: Short term effect of a disturbance in food safety in Section 5.5.7

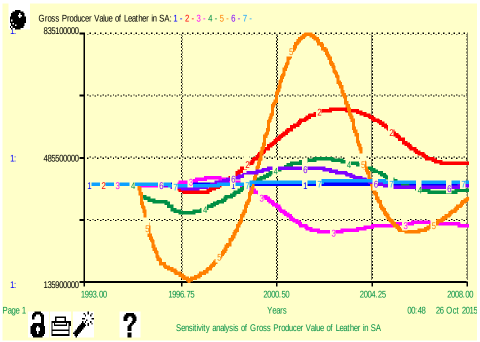
Table A.9: Long term effect of a disturbance in food safety in Section 5.5.7

	Run 1	**Run 2**	**Run 3**	**Run 4**	**Run 5**	**Run 6**
Scenario	Test Bird Flu Epedemic	Test Bird Flu Epedemic	Test Bird Flu Epedemic	Test Bird Flu Epedemic	Test Presence of BSE and FMD in Europe	Test Presence of BSE and FMD in Europe
Variable	Equilibrium Duration of Bird Flu Epedemic	Equilibrium Duration of Bird Flu Epedemic	Equilibrium Duration of Bird Flu Epedemic	Equilibrium Duration of Bird Flu Epedemic	Equilibrium Duration of BSE and FMD in Europe	Equilibrium Duration of BSE and FMD in Europe
Change in Variable	1	2.5	1	1	0.3	2
Variable	Equilibrium Percentage of Ostriches Culled in Bird Flu Epedemic	Equilibrium Percentage of Ostriches Culled in Bird Flu Epedemic	Equilibrium Percentage of Ostriches Culled in Bird Flu Epedemic	Equilibrium Percentage of Ostriches Culled in Bird Flu Epedemic		
Change in Variable	0.2	0.2	0.9	0.2		
Variable	Equilibrium Percentage Loss of Income	Equilibrium Percentage Loss of Income	Equilibrium Percentage Loss of Income	Equilibrium Percentage Loss of Income		
Change in Variable	0.4	0.4	0.4	0		
Ostrich Slaughter Rate	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Producer Leather Price per Ostrich in Rand	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Producer Meat Price per Ostrich in Rand	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Gross Producer Value of Leather in SA	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Gross Producer Value of Meat in SA	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Fraction of Income Contributed by Leather	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

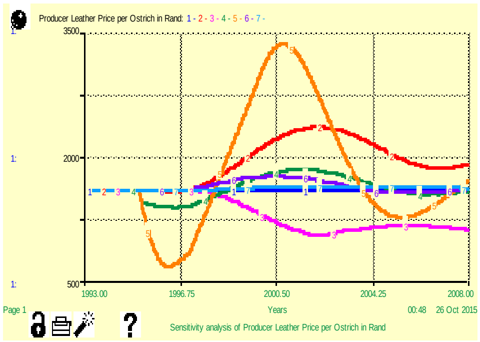
A.7 Production cost and economic climate



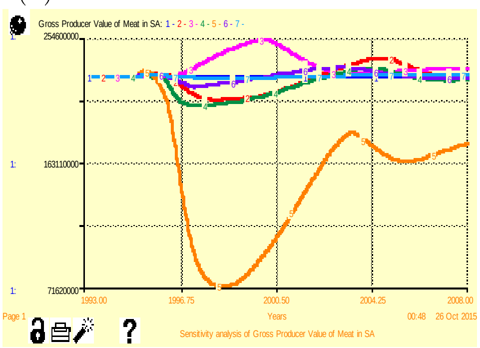
(a) Ostrich Slaughter Rate



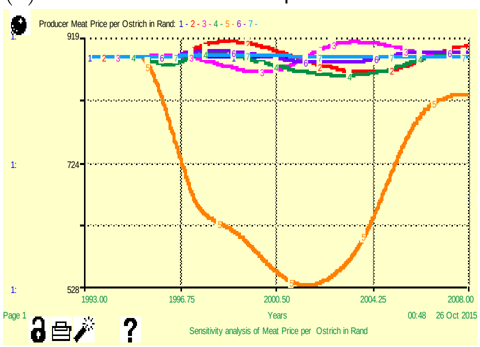
(b) Gross Producer Value of Leather in SA



(c) Producer Leather Price per Ostrich in Rand



(d) Gross Producer Value of Meat in SA



(e) Producer Meat Price per Ostrich in Rand

Figure A.6: Short term effect of a disturbance in production cost and economic climate in Section 5.5.8

Table A.10: Long term effect of a disturbance in production cost and economic climate in Section 5.5.8

	Run 1	**Run 2**	**Run 3**	**Run 4**	**Run 5**	**Run 6**
Scenario	Test Percentage Increase or Decrease in Producer Cost per Ostrich	Test Percentage Increase or Decrease in Producer Cost per Ostrich	Test Presence of Worldwide Economic Recession	Test Presence of Worldwide Economic Recession	Test Conversion to Small Camps	Test Conversion to Small Camps
Variable	Equilibrium Percentage Change in Producer Cost per Ostrich	Equilibrium Percentage Change in Producer Cost per Ostrich	Equilibrium Duration of Worldwide Economic Recession	Equilibrium Duration of Worldwide Economic Recession	Equilibrium Time Allocated to Convert to Small Camps	Equilibrium Time Allocated to Convert to Small Camps
Change in Variable	0.15	-0.2	0.1	2	1	10
Ostrich Slaughter Rate	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Producer Leather Price per Ostrich in Rand	23.39%	-31.18%	0.00%	0.00%	0.62%	0.62%
Producer Meat Price per Ostrich in Rand	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Gross Producer Value of Leather in SA	23.39%	-31.18%	0.00%	0.00%	0.62%	0.62%
Gross Producer Value of Meat in SA	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Fraction of Income Contributed by Leather	6.67%	-13.33%	0.00%	0.00%	0.00%	0.00%

Appendix B

Overview of the South African ostrich production industry

Appendix B contains a literature study of the South African ostrich industry, emphasizing primary production. Value adding activities are also discussed in aid of understanding the global ostrich-product markets ultimately influencing production; the primary markets are identified as the leather and meat markets and considered independent from one-another. Leather is mainly exported to the United States of America (USA) while the majority of meat is exported to the European Union (EU).

B.0.1 Product dominance shift

Even though ostriches were originally domesticated for their feathers, feathers currently account for less than 10% of the total income per ostrich. In the 1860's ostriches were domesticated in Southern Africa due to a high demand of ostrich feathers in the up-market European fashion industry. More than a century after the establishment of the ostrich industry, in the early 1970's, the majority income had shifted from exporting feathers to income from ostrich hides under the regulatory authority of the Klein Karoo Korporasie (Brand *et al.*, 2011). After the deregulation of the ostrich industry in 1993, industry participants built abattoirs that complied with the phyto-sanitary requirements for exporting meat to the EU. Ostrich meat steadily became more popular and a solid secondary source of revenue (ECIAfrica (Pty) Ltd, 2010). Van Zyl (2009) acknowledged that the EU ostrich meat market is grossly undersupplied and has the capacity to absorb meat from more than one million ostriches per year when ostrich meat were to be promoted as every-day red meat.

The industry-wide future targeted focus area is a highly contentious subject in the South African ostrich community since there is enormous potential for growth in the ostrich meat market while the leather income is highly dependent on the restriction of supply.

B.1 Overview of primary production

This section investigates the primary production sector of the South African ostrich industry. Ostrich production for commercial slaughter is split up into four sequential phases: breeding and hatching, chick rearing, grow-out and finishing, and slaughter. Each phase is explained in enough detail to not only create an accurate dynamic hypothesis in Chapter 4, but populate the model equations with the necessary exogenous variables.

B.1.1 Ostrich breeding and hatching

The most commonly known methods of ostrich breeding is small camp breeding and flock breeding. Both methods use feedlot system with zero grazing, meaning that enough food is artificially supplied that the ostriches do not graze from the veld at all (Mugido, 2011). An artificial food supply is crucial to production in the Klein Karoo region because of the limited carrying capacity (South African Ostrich Business Chamber, 2006).

Most farmers prefer flock breeding (Mugido, 2011). With flock breeding, flocks are kept in large numbers of between 50 and 100, in extensive free-range camps, where the male to female ratio is 6:10 (South African Ostrich Business Chamber, 2006). This type of breeding system poses a large threat to biodiversity in the Klein Karoo since larger birds have the ability to do extensive damage to the unique fynbos area if they are left to graze freely (Mugido, 2011). In contrast, with small-camp breeding, flocks are kept in small camps, in groups of 3 or 4, where the male to female ratio is 1:2 or 1:3 (South African Ostrich Business Chamber, 2006). The small-camp system takes up less space, allowing for veld rehabilitation, and makes it possible to keep accurate genetic records and selectively breed stock resulting in not only higher yields and lower chick mortality rates, but also genetically superior ostriches (Mugido, 2011). Even with the long-term incentives small-camp systems have, the higher initial capital investment in fencing that goes along with small-camp breeding compels most farmers to opt for flock breeding. For the purpose of the simulation, the assumption is made that all ostriches are bred with the flock breeding method, using the feedlotting system with zero grazing.

Unlike other poultry like chickens, ostrich eggs have a very low hatch-rate when hatched from an incubator. If the breeding ostriches are left to hatch their own eggs, the hatch-rate is greater but the overall number of eggs laid reduces drastically (South African Ostrich Business Chamber, 2006). Due to the considerable difference in yield, hatching of eggs by the parents in the nest is uncommon in modern day practice. For incubator hatching, where eggs are collected daily, each female lays between 50 and 60 eggs per breeding season (South African Ostrich Business Chamber, 2006). There is only one breeding season per year. Hatching time is exactly 42 days and the hatch-rate varies from 40-80% depending on a number of factors listed in Volstruishandleiding (South African Ostrich Business Chamber, 2006).

B.1.2 Chick rearing

The high-risk phase of primary production is rearing day-old chicks to juveniles of 3 to 4 months of age (ECIAfrica (Pty) Ltd, 2010). Ostriches are born without an immune system and are highly prone to airway infection during infancy, resulting a mortality rate of 15 to 30 percent. There is a lack of consensus as to the contributing factors to attaining a higher or lower mortality rates. General guidelines include good hygiene practices with regards to living arrangements as well as feed preparation (ECIAfrica (Pty) Ltd, 2010).

Chicks can be raised either extensively, therefore by breeding ostriches, or intensively, therefore hand reared in artificial housing. Both methods can be successful with intense management, however the best results have been found using breeding ostriches (South African Ostrich Business Chamber, 2006). Since there is a limited number of chicks each breeding ostrich can raise, producers are prone to make use of a combination of the two methods.

B.1.3 Bird grow-out and finishing

The grow-out and finishing phase of production is where juvenile birds of 3 to 4 months are grown until ready for slaughter (ECIAfrica (Pty) Ltd, 2010). The current commonly accepted slaughter age is 11 months. This is a highly debated subject ever since the ostrich leather price declined along with a product dominance shift from being solely dependent on ostrich skin for income to having a strong secondary income of both local and export meat.

The longer ostriches are grown out, the more feeding costs are incurred, and the bigger the leather and meat yield. Ostrich mass over time can be described as an S-shaped growth curve meaning that the older the ostrich gets, the slower the growth-rate of ostrich mass. Depending on the cost of feed relative to the combined income from leather, meat and feathers, an optimum age can be calculated. Prior to the development of the market for ostrich meat, the optimum slaughter age, producing the highest quality ostrich leather, would be between 8 and 9 months rather than the current widely accepted optimum of 11 months.

B.1.4 Production costs

Approximately 70% of the total primary production variable cost of a slaughter ready ostrich is attributed to ostrich feed (ECIAfrica (Pty) Ltd, 2010). The system used to rear birds has the most significant impact on the cost of ostrich feed since each system requires its own quantity and type of ostrich feed. Flock breeding using the feedlotting system with zero grazing requires ostrich feed to consist of 60% Lucerne, 30% grain and 10% oilseed ECIAfrica (Pty) Ltd (2010). Lucerne production is grown as an irrigated crop in the Klein Karoo. In a region with periodic droughts, Lucerne production is considered resource intensive and has a very inconsistent annual yield. During periods of drought in the Klein Karoo, Lucerne is sourced from elsewhere along with the grain and oilseed that are not produced in the area. The financial cost associated with transporting feed from other regions makes up a considerable fraction of the total cost of feed. The transportation cost is dependent on the region from which the feed is sourced. Feed purchased in other regions of the country contribute a large portion of the total carbon footprint of ostrich production.

B.1.5 Cost associated with increasing production capacity

The deregulation of the ostrich industry in 1993 resulted in an additional stream of income from the newly established export market to the EU. The additional stream of income, along with the devaluation of the South African Rand relative to the Dollar and Euro made ostrich farming and value adding activities seem very lucrative, attracting new local and foreign investment in infrastructure. South Africa has the capacity in to process more than the current annual throughput to the extent that some processing plants started processing other game or closed down altogether. The study assumes that there is no extra capital investment required to upgrade infrastructure for an increase in annual throughput.

B.2 Value adding activities

In the current free market system, value adding activities have been successfully developed to the extent that there is virtually no wastage throughout the entire process of primary production (ECIAfrica (Pty) Ltd, 2010). It is uncommon that ostrich producers sell the products that emerge from the value-added activities. Ostrich producers send their birds to slaughter and receive a predetermined price for each bird from participants who specialize in value adding activities. The dominant player in the value-adding industry, the Klein Karoo International Proprietary Limited, currently supplies 65% of all ostrich leather, meat and feathers found on the international market Klein Karoo International Proprietary Limited (2014). In addition to income form meat and leather, income is generated from industry by-products such as feathers, infertile eggs and wastage from carcasses.

B.2.1 Leather

Leather remains the primary income from ostrich production. Both the skin of the carcass and the leg skins are used. Thicker leather with more pronounced nodules is used for boots and upholstery while thinner leather with less pronounced nodules is more suitable for garment manufacturing (ECIAfrica (Pty) Ltd, 2010). Leg skin is very durable and has a very similar look to crocodile or snake skin. Leg skin is used for shoes and accessories.

B.2.2 Meat

Since deregulation of the market in 1993, ostrich meat has grown to become a solid secondary source of income through development of both an export and local market. Development of an export market in the EU is attributed to an outbreak of BSE Bovine Spongiform Encephalopathy (BSE), or mad cow disease, and Foot and Mouth Disease (FMD), in Europe at the end of 2000 that caused the European consumer to seek an alternative to traditional red meat. This caused a sudden surge in demand, resulting in an increase in price of nearly 40% between December 2000 and September 2001 (National Agricultural Marketing Council, 2003).

The meat yield from a 11 month old ostrich is, on average, 16kg prime cut meat and 15.5kg of other meat (ECIAfrica (Pty) Ltd, 2010). Under normal circumstances, therefore instances where there is no panic over BSE or FMD in the EU, the prime ostrich cuts are exported while the other cuts are used to make mince, sausages and patties for local consumption (ECIAfrica (Pty) Ltd, 2010). During periods of panic, demand increases and all ostrich products are exported (ECIAfrica (Pty) Ltd, 2010).

Raw ostrich meat exports to the EU is banned during periods of bird flu, reducing the income received from ostrich meat drastically (Mugido, 2011). To minimize losses during periods where raw ostrich meat exports to the EU are banned, product development and innovation led to the creation and development of an export market for cooked ostrich products - currently in its infancy phase (Mugido, 2011).

B.2.3 Feathers

The market for feathers in the fashion industry has completely stagnated. Most feathers are sold as decorative items or feather dusters.

B.2.4 Eggs

As a side-effect of the high infertility rate of ostrich eggs, a market was established for hollow eggshells as decoration. Craft and tourism markets sell the eggs in various innovative and artistic forms.

B.2.5 Pet food

After the outbreak of BSE in Britain, the British consumer not only became more conscious about the content and origin of their red meat, but also that of the food they feed their pets (ECIAfrica (Pty) Ltd, 2010). Ostrich tendons are processed as dog chews for the British market while the other intestines are used locally in pet food.

B.2.6 Fat

A market for ostrich fat has been established in the cosmetics industry as a medium that has the ability to extract fat (ECIAfrica (Pty) Ltd, 2010).

B.2.7 Agri tourism

There are multiple show farms in the Klein Karoo region attract a solid stream of both foreign and local visitors (National Agricultural Marketing Council, 2003).

B.3 Summary of Appendix B

Appendix B contains a literature study of the South African ostrich industry focussing on primary production in aid of developing an accurate dynamic hypothesis and model structure of the ostrich production industry of South Africa in Chapter 4.

An overview of the primary production sector of the ostrich industry is shown in Section B.1. Section B.1 divides primary production activities into four sequential phases: breeding and hatching, chick rearing, grow-out and finishing, and slaughter. Each phase is explained in enough detail in aid of not only creating an accurate dynamic hypothesis, but also to populate the model equations with the necessary exogenous variables in Chapter 4.

Finally, the value adding activities are discussed in aid of understanding the global ostrich-product markets ultimately influencing production in Section B.2.

Appendix C

Equations for system dynamics Ostrich Industry Model of South Africa (OIMSA)

☐ Baseline_Producer_Meat_Price_per_Ostrich_in_Euro(t) = Baseline_Producer_Meat_Price_per_Ostrich_in_Euro(t - dt) + (Change_in_Baseline_Producer__Meat_Price) * dt
INIT Baseline_Producer_Meat_Price_per_Ostrich_in_Euro = (1.5*Reference_Mode_Gross_Producer_Value_of_Meat_in_SA/(Reference_Mode_Ostrich_Slaughtered_Rate_in_SA*Rand_Euro_Exchange_Rate))*Switch_0Equilibrium_1Actual +(1-Switch_0Equilibrium_1Actual)*((Producer_Cost___per_Ostrich/Equilibrium_Rand_Euro_Exchange_Rate)* (Desired_Production_Rate*Average___Breeding__Period-0.1*Constant_Multiplication_Factor_for_Desirability*(Ostrich_Yield_per_Breeding_Ostrich_per_Year*Average___Breeding__Period-1))/((Ostrich_Yield_per_Breeding_Ostrich_per_Year*Average___Breeding__Period-1)*Constant_Multiplication_Factor_for_Desirability)-Producer_Leather_Price_per_Ostrich_in_Rand/Equilibrium_Rand_Euro_Exchange_Rate)

INFLOWS:

- Change_in_Baseline_Producer__Meat_Price = (Baseline_Producer_Meat_Price_per_Ostrich_in_Euro*(1+Switch_0Equilibrium_1Actual*European_HICP)-Baseline_Producer_Meat_Price_per_Ostrich_in_Euro)/Baseline_Meat_Price__Adjustment_Time+(1-Switch_0Equilibrium_1Actual)*Test_Change_in_Baseline_Producer_Meat_Price_in_Euro*(STEP(Equilibrium_Percentage_change_in_Baseline_Producer_Meat_Price*INIT(Baseline_Producer_Meat_Price_per_Ostrich_in_Euro),1995)-STEP(Equilibrium_Percentage_change_in_Baseline_Producer_Meat_Price*INIT(Baseline_Producer_Meat_Price_per_Ostrich_in_Euro),1995+Baseline_Meat_Price__Adjustment_Time))

☐ Breeding__Ostriches(t) = Breeding__Ostriches(t - dt) + (Breeding_Ostriches__Acquisition_Rate - Breeding_Ostriches__Slaughter_Rate) * dt
INIT Breeding__Ostriches = (Reference_Mode_Ostrich_Slaughtered_Rate_in_SA/Ostrich_Yield_per_Breeding_Ostrich_per_Year)*Switch_0Equilibrium_1Actual+(1-Switch_0Equilibrium_1Actual)* ((Desired_Production_Rate*Average___Breeding__Period)/(Ostrich_Yield_per_Breeding_Ostrich_per_Year*Average___Breeding__Period-1))

INFLOWS:

- Breeding_Ostriches__Acquisition_Rate = Desired_Breeding__Ostriches_Acquisition_Rate*(1-Presence_of_Meat_Export_Ban_from_Bird_Flu)

OUTFLOWS:

- Breeding_Ostriches__Slaughter_Rate = Breeding__Ostriches/Average___Breeding__Period {Culling}+ Culling_Rate/(Ostrich_Yield_per_Breeding_Ostrich_per_Year+1)

☐ Mature__Ostriches(t) = Mature__Ostriches(t - dt) + (Breeding__Rate - Ostrich__Slaughter__Rate - Breeding_Ostriches__Acquisition_Rate) * dt
INIT Mature__Ostriches = (Reference_Mode_Ostrich_Slaughtered_Rate_in_SA*Mature_Ostriches__Feeding_Period)*Switch_0Equilibrium_1Actual+(1-Switch_0Equilibrium_1Actual)* Breeding__Ostriches*Ostrich_Yield_per_Breeding_Ostrich_per_Year*Mature_Ostriches__Feeding_Period

INFLOWS:

- Breeding__Rate = DELAY(Rate_of_Eggs__Hatching, Maturation_Time) * (Net_Chick__Survival_Fraction)

OUTFLOWS:

Ostrich__Slaughter__Rate = IF (Breeding_Ostriches__Acquisition_Rate > 0)THEN (Mature__Ostriches/Mature_Ostriches__Feeding_Period-Breeding_Ostriches__Acquisition_Rate) ELSE (Mature__Ostriches/Mature_Ostriches__Feeding_Period){Culling}+ Culling_Rate*Ostrich_Yield_per_Breeding_Ostrich_per_Year/(Ostrich_Yield_per_Breeding_Ostrich_per_Year+1)

Breeding_Ostriches__Acquisition_Rate = Desired_Breeding__Ostriches_Acquisition_Rate*(1-Presence_of_Meat_Export_Ban_from_Bird_Flu)

Producer_Leather_Price_per_Ostrich_in_Dollar(t) = Producer_Leather_Price_per_Ostrich_in_Dollar(t - dt) + (Change_in_Producer_Leather_Price_per_Ostrich) * dt
INIT Producer_Leather_Price_per_Ostrich_in_Dollar = (Reference_Mode_Gross_Producer_Value_of_Leather_in_SA/(Reference_Mode_Ostrich_Slaughtered_Rate_in_SA*Rand_Dollar__Exchange_Rate))*Switch_0Equilibrium_1Actual +(1-Switch_0Equilibrium_1Actual)*((Producer_Cost___per_Ostrich*Leather_Income_Fraction/Equilibrium_Rand_Dollar_Exchange_Rate)* ((Desired_Production_Rate*Average___Breeding__Period-0.1*Constant_Multiplication_Factor_for_Desirability*(Ostrich_Yield_per_Breeding_Ostrich_per_Year*Average___Breeding__Period-1))/((Ostrich_Yield_per_Breeding_Ostrich_per_Year*Average___Breeding__Period-1)*Constant_Multiplication_Factor_for_Desirability)+0.1))

INFLOWS:

Change_in_Producer_Leather_Price_per_Ostrich = (Leather_Demand__vs_Supply_Ratio*Producer_Leather_Price_per_Ostrich_in_Dollar-Producer_Leather_Price_per_Ostrich_in_Dollar)/Leather_Price__Adjustment_Time+ Adjustment_Rate_to_Maintain_Reasonable_Skin_Value

Producer_Meat_Price_per_Ostrich_in_Euro(t) = Producer_Meat_Price_per_Ostrich_in_Euro(t - dt) + (Change_in_Producer_Meat_Price) * dt
INIT Producer_Meat_Price_per_Ostrich_in_Euro = Baseline_Producer_Meat_Price_per_Ostrich_in_Euro

INFLOWS:

Change_in_Producer_Meat_Price = (Baseline_Producer_Meat_Price_per_Ostrich_in_Euro*Meat_Absorption__vs_Supply_Ratio-Producer_Meat_Price_per_Ostrich_in_Euro)/Meat_Price_Adjustment_Time

Small_Camp_Capacity(t) = Small_Camp_Capacity(t - dt) + (Increase_in_Small_Camp_Capacity - Small_Camp_Degredation) * dt
INIT Small_Camp_Capacity = 0

INFLOWS:

Increase_in_Small_Camp_Capacity = (Goal_Capacity-Small_Camp_Capacity)/Small_Camp_Construction_Time+Small_Camp_Degredation

OUTFLOWS:

Small_Camp_Degredation = Small_Camp_Capacity/Small_Camp_Lifetime

Absorption_Capacity_Adjustment_Time = 1

Adjustment_Rate_to_Maintain_Reasonable_Skin_Value = DELAY1(MAX((Minimum_Value_of_Leather-Producer_Leather_Price_per_Ostrich_in_Dollar),Floor_Value_for_Leather_Price_Adjustment),1)/Minimum_Leather_Value_Adjustment_Time

Age_of_Sexual_Maturity = 3

Average___Breeding__Period = 7

- Baseline_Leather_Market_Demand = 255000*Switch_0Equilibrium_1Actual+(Desired_Production_Rate+Test_Change_in_Baseline_Leather_Market_Demand*STEP(Step_Increase_or_Decrease_in_Baseline_Leather_Market_Demand,1995))*(1-Switch_0Equilibrium_1Actual){Source:}

- Baseline_Meat_Market_Absorption_Capacity = DELAY1(Ostrich_Production_Rate+Establishment_and_Expansion_of_Meat_Consumers_and_Product_Ranges*Effect_of_Promotion_of_Meat_Product*Ostrich_Production_Rate,Absorption_Capacity_Adjustment_Time)*Switch_0Equilibrium_1Actual+ DELAY1(Ostrich_Production_Rate+STEP(Test_Baseline_Meat_Market_Absorption_Capacity*Equilibrium_Increase_in_Meat_Market_Absorption_Capacity,1995)-STEP(Test_Baseline_Meat_Market_Absorption_Capacity*Equilibrium_Increase_in_Meat_Market_Absorption_Capacity,1995+Equilibrium_Duration_of_Change_in_Meat_Market_Absorption_Capacity) ,Absorption_Capacity_Adjustment_Time)*(1-Switch_0Equilibrium_1Actual)

- Baseline_Meat_Price__Adjustment_Time = 1
- Breeding_Capacity = Breeding__Ostriches*Ostrich_Yield_per_Breeding_Ostrich_per_Year-Breeding__Ostriches-Breeding__Ostriches/Average___Breeding__Period
- Breeding_Seasons_per_Year = 1
- Breeding_Stock_Desirability = Producer_Gross__Profit_Margin_per_Ostrich*Industry_Desirability
- BSE_and_FMD_Panic__Time_Delay = 0.5
- Consolidated_Rand_Euro_Exchange_Rate = Rand_Euro_Exchange_Rate*Switch_0Equilibrium_1Actual+(1-Switch_0Equilibrium_1Actual)*(Equilibrium_Rand_Euro_Exchange_Rate+STEP(Step_Increase_or_Decrease_in_Rand_vs_Euro_Exchange_Rate*Test_Change_in_Rand_vs_Euro_Exchange_Rate,1995))

- Constant_Multiplication_Factor_for_Desirability = (30000-10000)/(3-1)*1.15
- Cost_of_Feed__per_kg = (0.6*Cost_of_Lucerne__per_kg+0.1*Cost_of_Sunflower__Seed_per_kg+0.3*Cost_of_Maize__per_kg)*Expected_Furure_Increase_During_Forecast*Switch_0Equilibrium_1Actual +(1-Switch_0Equilibrium_1Actual)* (0.6*Equilibrium_Cost_of_Lucerne_per_kg+0.1*Equilibrium_Cost_of_Sunflower_Seed_per_kg+0.3*Equilibrium_Cost__of_Maize_per_kg){Source of formula: The South African Ostrich Value Chain; Opportunities for black participation and Development of a programme to link Farmers to Markets.Submitted to:National Agricultural Marketing CouncilbyECIAfrica (Pty) Ltd.June 2010}

- Cost_of_Lucerne__per_kg = GRAPH(TIME{Source: Abstract of Agricultural Statistics 2013, Department of Agriculture, Forestry and Fisheries of South Africa, http://www.nda.agric.za/publications/publications.asp?category=Statistical+information}) (1993, 0.238), (1994, 0.315), (1995, 0.383), (1996, 0.31), (1997, 0.358), (1998, 0.418), (1999, 0.42), (2000, 0.433), (2001, 0.473), (2002, 0.873), (2003, 0.86), (2004, 0.639), (2005, 0.62), (2006, 0.67), (2007, 1.14), (2008, 1.32), (2009, 1.27), (2010, 1.19), (2011, 1.18), (2012, 1.54), (2013, 1.48), (2014, 1.48)

- Cost_of_Maize__per_kg = GRAPH(TIME{Source: Abstract of Agricultural Statistics 2013, Department of Agriculture, Forestry and Fisheries of South Africa, http://www.nda.agric.za/publications/publications.asp?category=Statistical+information}) (1993, 0.364), (1994, 0.335), (1995, 0.529), (1996, 0.65), (1997, 0.624), (1998, 0.743), (1999, 0.604), (2000, 0.963), (2001, 1.51), (2002, 1.03), (2003, 0.936), (2004, 0.687), (2005, 1.08), (2006, 1.65), (2007, 1.76), (2008, 1.51), (2009, 1.23), (2010, 1.83), (2011, 2.38), (2012, 2.38), (2013, 2.38), (2014, 2.38)

- Cost_of_Sunflower__Seed_per_kg = GRAPH(TIME{Source: Abstract of Agricultural Statistics 2013, Department of Agriculture, Forestry and Fisheries of South Africa, http://www.nda.agric.za/publications/publications.asp?category=Statistical+information})
(1993, 0.99), (1994, 1.08), (1995, 0.959), (1996, 1.11), (1997, 1.50), (1998, 1.39), (1999, 1.01), (2000, 1.43), (2001, 2.47), (2002, 2.18), (2003, 2.01), (2004, 1.74), (2005, 2.06), (2006, 2.81), (2007, 4.71), (2008 3.15), (2009, 3.26), (2010, 4.12), (2011, 4.85), (2012, 4.44), (2013, 4.44), (2014, 4.74)
- Cost_per_Small_Camp = 5100
- Culling_Rate = Presence_of_2004_Bird_Flu_Epidemic*Number_of_Ostriches_Culled_in_2004_Bird_Flu_Epidemic/Duration_of_2004_Bird_Flu_Epidemic+ Presence_of_2011_Bird_Flu_Epidemic*Number_of_Ostriches_Culled_in_2011_Bird_Flu_Epidemic/Duration_of_2011_Bird_Flu_Epidemic+ (1-Switch_0Equilibrium_1Actual)*Test_Bird_Flu_Epidemic*Presence_of_Test_Bird_Flu_Epidemic*Equilibrium_Number_of_Ostriches_Culled/Equilibrium_Duration_of_Bird_Flu_Epidemic
- Desired_Breeding_Ostriches = Breeding_Stock_Desirability*Constant_Multiplication_Factor_for_Desirability
- Desired_Breeding__Ostriches_Acquisition_Rate = IF ((Desired_Breeding_Ostriches - Breeding__Ostriches)<0) THEN ((Desired_Breeding_Ostriches - Breeding__Ostriches) /Minimum_Breeding_Ostrich_Reduction_Transfer_Time+ Breeding_Ostriches__Slaughter_Rate)ELSE ((Desired_Breeding_Ostriches - Breeding__Ostriches) /Minimum__Breeding_Ostrich__Acquisition_Transfer_Time+ Breeding_Ostriches__Slaughter_Rate)
- Desired_Production_Rate = 255000
- Duration_of_2004_Bird_Flu_Epidemic = (14/12)
- Duration_of_2011_Bird_Flu_Epidemic = (10/12)
- Effect_of_Bird_Flu_on_Meat_Price_per_Ostrich_in_Rand = Switch_0Equilibrium_1Actual* (1-Presence_of_Meat_Export_Ban_from_Bird_Flu*Percentage_of_Income_Lost_due_to_Export_Ban)+ (1-Switch_0Equilibrium_1Actual)*(1-Presence_of_Test_Bird_Flu_Epidemic*Equilibrium_Percentage_Loss_of_Income*Test_Bird_Flu_Epidemic)
- Effect_of_Japanese_Recession_on_Leather_Demand = 1-0.3*DELAY1(Presence_of__Japanese_Recession,1,1*Switch_0Equilibrium_1Actual)
- Effect_of_Promotion_of_Meat_Product = 1
- Effect_of_Worldwide_Economic_Recession_on_Leather_Demand = 1-MAX(DELAY1(1.5*Presence_of_Worldwide__Economic_Recession,5,0),Presence_of_Worldwide__Economic_Recession)
- Eggs_per_Hen_per__Breeding_Season = 55
- Equilibrium_Cost_of_Lucerne_per_kg = 1.48
- Equilibrium_Cost_of_Sunflower_Seed_per_kg = 4.74
- Equilibrium_Cost__of_Maize_per_kg = 2.38
- Equilibrium_Duration_of_Bird_Flu_Epidemic = 1
- Equilibrium_Duration_of_Change_in_Meat_Market_Absorption_Capacity = 1
- Equilibrium_Duration_of_Worldwide_Economic_Recession = 1
- Equilibrium_Duration_of__BSE_and_FMD_in_Europe = 0.3
- Equilibrium_Increase_in_Meat_Market_Absorption_Capacity = 50000
- Equilibrium_Number_of_Ostriches_Culled = (17839*(1+Ostrich_Yield_per_Breeding_Ostrich_per_Year))*Equilibrium_Percentage_of_Ostriches_Culled_in_Bird_Flu_Epidemic
- Equilibrium_Percentage_change_in_Baseline_Producer_Meat_Price = 0.3
- Equilibrium_Percentage_Change_in_Producer_Cost_per_Ostrich = 0.1
- Equilibrium_Percentage_Loss_of_Income = 0.4
- Equilibrium_Percentage_of_Ostriches_Culled_in_Bird_Flu_Epidemic = 0.2

Equilibrium_Rand_Dollar_Exchange_Rate = 10.872

Equilibrium_Rand_Euro_Exchange_Rate = 13.831

Equilibrium_Time_Allocated_to_Convert_to_Small_Camps = 5

Establishment_and_Expansion_of_Meat_Consumers_and_Product_Ranges = (Switch_0Equilibrium_1Actual)*(IF (TIME < 2006)THEN (0)ELSE (IF (TIME < 2007.5)THEN (1)ELSE (0))) {Source: Klein Karoo Annual Report 2006}

European_HICP = GRAPH(TIME)
(1993, 0.0169), (1994, 0.0169), (1995, 0.0169), (1996, 0.0169), (1997, 0.0169), (1998, 0.0122), (1999, 0.0117), (2000, 0.0218), (2001, 0.0243), (2002, 0.0227), (2003, 0.0212), (2004, 0.0219), (2005, 0.0219), (2006, 0.022), (2007, 0.021), (2008, 0.0332), (2009, 0.0031), (2010, 0.0161), (2011, 0.0272), (2012, 0.025), (2013, 0.0135), (2014, 0.0043), (2015, 0.00)

European_Market_Development_attributed_to_BSE_and_FMD_Panic = DELAY1(1+0.5*Presence_of__BSE_and_FMD_in_Europe,BSE_and_FMD_Panic__Time_Delay,1)

Expected_Furure_Increase_During_Forecast = GRAPH(TIME)
(1993, 1.00), (1994, 1.00), (1995, 1.00), (1996, 1.00), (1997, 1.00), (1998, 1.00), (1999, 1.00), (2000, 1.00) (2001, 1.00), (2002, 1.00), (2003, 1.00), (2004, 1.00), (2005, 1.00), (2006, 1.00), (2007, 1.00), (2008, 1.00) (2009, 1.00), (2010, 1.00), (2011, 1.00), (2012, 1.00), (2013, 1.00), (2014, 1.10), (2015, 1.21), (2016, 1.34) (2017, 1.47), (2018, 1.62), (2019, 1.78), (2020, 1.96)

Feed_Required__per_Mature_Ostrich_in_kg = 580{Source of value: The South African Ostrich Value Chain; Opportunities for black participation and Development of a programme to link Farmers to Markets. Submitted to:National Agricultural Marketing CouncilbyECIAfrica (Pty) Ltd.June 2010}

Fertility_per_Female_in_Small_Camp = MIN(1,1-(Small_Camp_Capacity-DELAY1(Small_Camp_Capacity,5))/Small_Camp_Capacity)*(Small_Camp_Yield_per_Female-Flock_Breeding_Yield_per_Female)+Flock_Breeding_Yield_per_Female

Flock_Breeding_Yield_per_Female = 23

Floor_Value_for_Leather_Price_Adjustment = 0

Fraction_of_Females_in_Breeding_Stock = 10/16

Fraction_of_Income_Contrubuted_by_Leather = Producer_Leather_Price_per_Ostrich_in_Rand/Total_Producer__Income_per_Ostrich

Goal_Capacity = (Breeding__Ostriches*((STEP(TIME-1995,1995)-STEP(TIME-1995-Equilibrium_Time_Allocated_to_Convert_to_Small_Camps,1995+Equilibrium_Time_Allocated_to_Convert_to_Small_Camps))/Equilibrium_Time_Allocated_to_Convert_to_Small_Camps))*(1-Switch_0Equilibrium_1Actual)*Test_Conversion_to_Small_Camps

Gross_Producer_Value_of_Leather_in_SA = Producer_Leather_Price_per_Ostrich_in_Rand*Ostrich__Slaughter__Rate

Gross_Producer_Value_of_Meat_in_SA = Producer_Meat_Price_per_Ostrich_in_Rand*Ostrich__Slaughter__Rate

Hatch__Fraction = 0.6

Historical_Producer_Leather_Price_per_Ostrich_in_Dollar = Reference_Mode_Leather_Price_per_Ostrich/Rand_Dollar__Exchange_Rate

Industry_Desirability = (1*(1-Switch_0Equilibrium_1Actual)+Reluctance_to_Enter_Market_after_Deregulation)*Reluctance_to_Farm_Ostriches_due_to_Bird_Flu_Epidemic *Reluctance_to_Farm_due_to_Economic_Recession

Leather_Demand__vs_Supply_Ratio = IF (Ostrich_Production_Rate = 0) THEN (1)ELSE (MIN(Proposed_Leather_Market_Demand/DELAY1(Ostrich_Production_Rate,0.25),1.25))

Leather_Income_Fraction = 0.6

Leather_Price__Adjustment_Time = 1

Maturation_Time = 11/12

- Mature_Ostriches__Feeding_Period = 14/365
- Maximum_Meat_Absorption__vs_Supply_Ratio = 5
- Meat_Absorption__vs_Supply_Ratio = IF (Ostrich_Production_Rate = 0) THEN (1)ELSE (MIN(Meat__Market_Development/Ostrich_Production_Rate,Maximum_Meat_Absorption__vs_Supply_Ratio))
- Meat_Market_Development_due_to_Economic_Recession = 1-DELAY1(Presence_of_Worldwide__Economic_Recession,2.5)
- Meat_Price_Adjustment_Time = 2
- Meat__Market_Development = Baseline_Meat_Market_Absorption_Capacity*Meat_Market_Development_due_to_Economic_Recession*European_Market_Development_attributed_to_BSE_and_FMD_Panic
- Minimum_Breeding_Ostrich_Reduction_Transfer_Time = 3/12
- Minimum_Leather_Value_Adjustment_Time = 0.25
- Minimum_Value_of_Leather = 100
- Minimum__Breeding_Ostrich__Acquisition_Transfer_Time = Age_of_Sexual_Maturity - Maturation_Time

- Net_Chick__Survival_Fraction = 0.7
- No_Policy_being_Tested = 1
- Number_of_Ostriches_Culled_in_2004_Bird_Flu_Epidemic = Switch_0Equilibrium_1Actual*30000 {Source: BBC(2004)}
- Number_of_Ostriches_Culled_in_2011_Bird_Flu_Epidemic = Switch_0Equilibrium_1Actual*41000 {Source: Curnow and Kermeloitis (2012)}
- Number_of_Small_Camps = Small_Camp_Capacity/Ostriches_per_Small_Camp
- Open_Loop_Gross_Producer_Value_of_Leather_in_SA = GRAPH(TIME)
(1993, 1.1e+008), (1994, 1.4e+008), (1995, 2.1e+008), (1996, 2.6e+008), (1997, 2.7e+008), (1998, 1.8e+008), (1999, 1.6e+008), (2000, 1.7e+008), (2001, 2.5e+008), (2002, 3.9e+008), (2003, 2.4e+008), (2004, 1.8e+008), (2005, 1.8e+008), (2006, 1.7e+008), (2007, 1.7e+008), (2008, 1.6e+008), (2009, 1.3e+008), (2010, 1.7e+008), (2011, 1.7e+008), (2012, 2.1e+008), (2013, 2e+008), (2014, 2.8e+008)
- Open_Loop_Gross_Producer_Value_of_Meat_in_SA = GRAPH(TIME)
(1993, 3.6e+007), (1994, 3.6e+007), (1995, 5.5e+007), (1996, 7.5e+007), (1997, 1e+008), (1998, 8.7e+007), (1999, 9.3e+007), (2000, 9.4e+007), (2001, 1.2e+008), (2002, 2.1e+008), (2003, 2.3e+008), (2004, 1.8e+008), (2005, 1.1e+008), (2006, 1.7e+008), (2007, 1.9e+008), (2008, 2.5e+008), (2009, 3.1e+008), (2010, 2.1e+008), (2011, 1.4e+008), (2012, 9.9e+007), (2013, 1.4e+008), (2014, 1.6e+008)
- Open_Loop_Ostrich_Slaughter_Rate = GRAPH(TIME)
(1993, 147758), (1994, 145482), (1995, 196435), (1996, 255550), (1997, 299501), (1998, 254158), (1999, 200861), (2000, 209555), (2001, 245793), (2002, 293473), (2003, 298755), (2004, 281238), (2005, 284935), (2006, 260211), (2007, 208008), (2008, 208349), (2009, 214256), (2010, 223564), (2011, 206566), (2012, 215264), (2013, 162839), (2014, 143301)
- Open_Loop_Producer_Leather_Price_per_Ostrich = GRAPH(TIME)
(1993, 749), (1994, 968), (1995, 1088), (1996, 999), (1997, 906), (1998, 699), (1999, 776), (2000, 817), (2001, 1034), (2002, 1345), (2003, 797), (2004, 654), (2005, 619), (2006, 664), (2007, 805), (2008, 780), (2009, 612), (2010, 757), (2011, 801), (2012, 962), (2013, 1231), (2014, 1984)
- Open_Loop_Producer_Meat_Price_per_Ostrich = GRAPH(TIME)
(1993, 245), (1994, 250), (1995, 282), (1996, 292), (1997, 349), (1998, 342), (1999, 463), (2000, 447), (2001, 470), (2002, 704), (2003, 754), (2004, 641), (2005, 390), (2006, 658), (2007, 935), (2008, 1184), (2009, 1440), (2010, 950), (2011, 687), (2012, 462), (2013, 846), (2014, 1133)
- Ostriches_per_Small_Camp = 3
- Ostrich_Production_Rate = (Ostrich__Slaughter__Rate*Switch_0CutLoops_1Actual+(1-Switch_0CutLoops_1Actual)*Reference_Mode_Ostrich_Slaughtered_Rate_in_SA)

- Ostrich_Yield_per_Breeding_Ostrich_per_Year = Eggs_per_Hen_per__Breeding_Season*Hatch__Fraction*Net_Chick__Survival_Fraction*Breeding_Seasons_per_Year*Fraction_of_Females_in_Breeding_Stock
- Perceived_Small_Camp_Cost_per_Ostrich = (Small_Camp_Cost/Breeding_Capacity)
- Percentage_of_Income_Lost_due_to_Export_Ban = 0.4
- Percentage_Primary_Production_Variable_Cost_Accounted_for_by_Feed = 0.7{Source of value: The South African Ostrich Value Chain; Opportunities for black participation and Development of a programme to link Farmers to Markets.Submitted to:National Agricultural Marketing CouncilbyECIAfrica (Pty) Ltd.June 2010}
- Presence_of_2004_Bird_Flu_Epidemic = Switch_0Equilibrium_1Actual*(IF (TIME < 2004+6/12)THEN (0) ELSE (IF (TIME < 2005+8/12)THEN (1)ELSE (0)))
- Presence_of_2011_Bird_Flu_Epidemic = Switch_0Equilibrium_1Actual*(IF (TIME < 2011+3/12)THEN (0) ELSE (IF (TIME < 2012+1/12)THEN (1)ELSE (0)))
- Presence_of_Meat_Export_Ban_from_Bird_Flu = Presence_of_2004_Bird_Flu_Epidemic+Presence_of_2011_Bird_Flu_Epidemic+Presence_of_Test_Bird_Flu_Epidemic
- Presence_of_Test_Bird_Flu_Epidemic = (1-Switch_0Equilibrium_1Actual)*Test_Bird_Flu_Epidemic*(IF (TIME < 1995)THEN (0)ELSE (IF (TIME < 1995+Equilibrium_Duration_of_Bird_Flu_Epidemic)THEN (1) ELSE (0)))
- Presence_of_Worldwide__Economic_Recession = Switch_0Equilibrium_1Actual*(IF (TIME < 2007+11/12) THEN (0)ELSE (IF (TIME < 2009+6/12)THEN (1)ELSE (0))) +(1-Switch_0Equilibrium_1Actual)*Test_Presence_of_Worldwide_Economic_Recession*(STEP(1,1995)-STEP(1,1995+Equilibrium_Duration_of_Worldwide_Economic_Recession)){Source: Public Information Office, National Bureau of Economic Research Inc., 1050 Massachusetts Avenue, Camebridge MA 02138 USA, www.nber.org/cycles.html}{Latex: \ref{NBER_RecessionDate}{IF (TIME < 2008)THEN (0)ELSE (IF (TIME < 2010)THEN (1)ELSE (0))}
- Presence_of__BSE_and_FMD_in_Europe = Switch_0Equilibrium_1Actual*(IF (TIME < (2000+9/12)) THEN (0)ELSE (IF (TIME < (2001+8/12))THEN (1)ELSE (0))) +(1-Switch_0Equilibrium_1Actual)*Test_Presence_of__BSE_and_FMD_in_Europe*(STEP(1,1995)-STEP (1,1995+Equilibrium_Duration_of__BSE_and_FMD_in_Europe)){Source: Impact Report: Deregulation of Ostrich Industry}
- Presence_of__Japanese_Recession = Switch_0Equilibrium_1Actual*(IF (TIME > 1997.5)THEN (0)ELSE (1))
- Producer_Cost___per_Ostrich = Producer_Feed__Cost_per_Mature_Ostrich/Percentage_Primary_Production_Variable_Cost_Accounted_for_by_Feed +(1-Switch_0Equilibrium_1Actual)*Test_Percentage_Increase_or_Decrease_in_Producer_Cost_per_Ostrich*STEP(Equilibrium_Percentage_Change_in_Producer_Cost_per_Ostrich *Producer_Feed__Cost_per_Mature_Ostrich/Percentage_Primary_Production_Variable_Cost_Accounted_for_by_Feed,1995)
- Producer_Feed__Cost_per_Mature_Ostrich = Cost_of_Feed__per_kg*Feed_Required__per_Mature_Ostrich_in_kg
- Producer_Gross__Profit_Margin_per_Ostrich = Total_Producer__Income_per_Ostrich/(DELAY1(Producer_Cost___per_Ostrich,1)+Perceived_Small_Camp_Cost_per_Ostrich)
- Producer_Leather_Price_per_Ostrich_in_Rand = Producer_Leather_Price_per_Ostrich_in_Dollar* Rand_Dollar__Exchange_Rate*Switch_0Equilibrium_1Actual+ Producer_Leather_Price_per_Ostrich_in_Dollar*(Equilibrium_Rand_Dollar_Exchange_Rate+STEP(Test_Change_in_Rand_vs_Dollar_Exchange_Rate*Step_Increase_or_Decrease_in_Rand_vs_Dollar_Exchange_Rate,1995))*(1-Switch_0Equilibrium_1Actual)

- Producer_Meat_Price_per_Ostrich_in_Rand = Producer_Meat_Price_per_Ostrich_in_Euro*Consolidated_Rand_Euro_Exchange_Rate*Effect_of_Bird_Flu_on_Meat_Price_per_Ostrich_in_Rand
- Producer_Price_of__Other_Products__per_Ostrich = 0.1*Producer_Cost___per_Ostrich{Assumption}
- Proposed_Leather_Market_Demand = Baseline_Leather_Market_Demand*(Effect_of_Japanese_Recession_on_Leather_Demand)*(Effect_of_Worldwide_Economic_Recession_on_Leather_Demand)
- Rand_Dollar__Exchange_Rate = GRAPH(TIME{Source: Quantec EasyData Quantec Quarterly Forecast - Exchange rate: ZAR/USD})
  (1993, 2.96), (1993, 3.12), (1994, 3.19), (1994, 3.37), (1994, 3.38), (1994, 3.44), (1995, 3.61), (1995, 3.61), (1995, 3.54), (1995, 3.57), (1996, 3.64), (1996, 3.65), (1996, 3.65), (1996, 3.77), (1997, 4.31), (1997, 4.47), (1997, 4.64), (1997, 4.51), (1998, 4.47), (1998, 4.64), (1998, 4.81), (1998, 4.95), (1999, 5.17), (1999, 6.23), (1999, 5.78), (1999, 6.10), (2000, 6.13), (2000, 6.10), (2000, 6.13), (2000, 6.30), (2001, 6.85), (2001, 7.00), (2001, 7.59), (2001, 7.82), (2002, 8.03), (2002, 8.38), (2002, 10.2), (2002, 11.5), (2003, 10.5), (2003, 10.4), (2003, 9.65), (2003, 8.34), (2004, 7.76), (2004, 7.42), (2004, 6.74), (2004, 6.77), (2005, 6.59), (2005, 6.38), (2005, 6.06), (2005, 6.00), (2006, 6.41), (2006, 6.51), (2006, 6.53)...
- Rand_Euro_Exchange_Rate = GRAPH(TIME{Source: Quantec EasyData Quantec Quarterly Forecast - Exchange rate: EUR/ZAR})
  (1993, 3.75), (1993, 3.72), (1994, 3.85), (1994, 3.88), (1994, 3.85), (1994, 3.87), (1995, 4.20), (1995, 4.42), (1995, 4.39), (1995, 4.54), (1996, 4.85), (1996, 4.78), (1996, 4.81), (1996, 4.85), (1997, 5.41), (1997, 5.69), (1997, 5.85), (1997, 5.31), (1998, 5.11), (1998, 5.07), (1998, 5.40), (1998, 5.38), (1999, 5.68), (1999, 6.95), (1999, 6.81), (1999, 6.85), (2000, 6.48), (2000, 6.39), (2000, 6.36), (2000, 6.22), (2001, 6.40), (2001, 6.32), (2001, 6.60), (2001, 7.22), (2002, 7.02), (2002, 7.47), (2002, 9.12), (2002, 10.1), (2003, 9.61), (2003, 10.3), (2003, 9.65), (2003, 8.96), (2004, 8.81), (2004, 8.35), (2004, 8.02), (2004, 8.47), (2005, 7.94), (2005, 7.80), (2005, 7.85), (2005, 7.86), (2006, 8.07), (2006, 7.94), (2006, 7.77)...
- Rate_of_Eggs__Hatching = DELAY(Rate_of_Egg__Production,Time_to__Hatch)*Hatch__Fraction
- Rate_of_Egg__Production = (Breeding__Ostriches *Fraction_of_Females_in_Breeding_Stock *Eggs_per_Hen_per__Breeding_Season *Breeding_Seasons_per_Year)
- Reference_Mode_Gross_Producer_Value_of_Leather_in_SA = GRAPH(TIME)
  (1993, 1.1e+008), (1994, 1.8e+008), (1995, 2.2e+008), (1996, 3.4e+008), (1997, 2.3e+008), (1998, 1.8e+008), (1999, 2.1e+008), (2000, 2.4e+008), (2001, 3.3e+008), (2002, 3.2e+008), (2003, 2.8e+008), (2004, 2.4e+008), (2005, 2e+008), (2006, 2e+008), (2007, 2.4e+008), (2008, 2e+008), (2009, 2.2e+008), (2010, 1.8e+008), (2011, 1.4e+008), (2012, 1.7e+008), (2013, 2.4e+008), (2014, 2.9e+008)
- Reference_Mode_Gross_Producer_Value_of_Meat_in_SA = GRAPH(TIME)
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- Reference_Mode_Leather_Price_per_Ostrich = Reference_Mode_Gross_Producer_Value_of_Leather_in_SA/Reference_Mode_Ostrich_Slaughtered_Rate_in_SA
- Reference_Mode_Meat_Price_per_Ostrich = Reference_Mode_Gross_Producer_Value_of_Meat_in_SA/Reference_Mode_Ostrich_Slaughtered_Rate_in_SA

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(1993, 152000), (1994, 162000), (1995, 175000), (1996, 273000), (1997, 286000), (1998, 250000), (1999, 233000), (2000, 244000), (2001, 272028), (2002, 355725), (2003, 307779), (2004, 291045), (2005, 257263), (2006, 257615), (2007, 245771), (2008, 213761), (2009, 222265), (2010, 262904), (2011, 210776), (2012, 196981), (2013, 138519), (2014, 120610)

Reluctance_to_Enter_Market_after_Deregulation = DELAYN(1,6,7,0.45)*Switch_0Equilibrium_1Actual

Reluctance_to_Farm_due_to_Economic_Recession = 1-0.3*DELAY3(Presence_of_Worldwide__Economic_Recession,1,0)

Reluctance_to_Farm_Ostriches_due_to_Bird_Flu_Epidemic = 1-DELAY3(Presence_of_Meat_Export_Ban_from_Bird_Flu*(1-Equilibrium_Percentage_Loss_of_Income*Test_Bird_Flu_Epidemic*(1-Switch_0Equilibrium_1Actual)),0.8,0)*0.3

Small_Camp_Construction_Time = 1

Small_Camp_Cost = Increase_in_Small_Camp_Capacity*Cost_per_Small_Camp/Ostriches_per_Small_Camp

Small_Camp_Lifetime = 20

Small_Camp_Ratio = MIN(1,Small_Camp_Capacity/Breeding__Ostriches)

Small_Camp_Yield_per_Female = 40

Step_Increase_or_Decrease_in_Baseline_Leather_Market_Demand = 10000

Step_Increase_or_Decrease_in_Rand_vs_Dollar_Exchange_Rate = 5

Step_Increase_or_Decrease_in_Rand_vs_Euro_Exchange_Rate = 5

Switch_0CutLoops_1Actual = 1

Switch_0Equilibrium_1Actual = 0

Test_Baseline_Meat_Market_Absorption_Capacity = 0

Test_Bird_Flu_Epidemic = IF (TIME < 2011+3/12)THEN (0)ELSE (IF (TIME < 2012+1/12)THEN (1)ELSE (0))

Test_Change_in_Baseline_Leather_Market_Demand = 0

Test_Change_in_Baseline_Producer_Meat_Price_in_Euro = 0

Test_Change_in_Rand_vs_Dollar_Exchange_Rate = 1

Test_Change_in_Rand_vs_Euro_Exchange_Rate = 0

Test_Conversion_to_Small_Camps = 0

Test_Percentage_Increase_or_Decrease_in_Producer_Cost_per_Ostrich = 0

Test_Presence_of_Worldwide_Economic_Recession = 1

Test_Presence_of__BSE_and_FMD_in_Europe = 0

Time_to__Hatch = 42/365

Total_Producer__Income_per_Ostrich = (Producer_Price_of__Other_Products__per_Ostrich+Producer_Leather_Price_per_Ostrich_in_Rand+Producer_Meat_Price_per_Ostrich_in_Rand)*Switch_0CutLoops_1Actual+(1-Switch_0CutLoops_1Actual)*(Reference_Mode_Gross_Producer_Value_of_Meat_in_SA+Reference_Mode_Gross_Producer_Value_of_Leather_in_SA)/Reference_Mode_Ostrich_Slaughtered_Rate_in_SA

Year_that_Policy_is_Implemented = 1995

Appendix D

Conference proceedings

D.1 Understanding the boom and bust cycles of ostrich production in South Africa using system dynamics (Duminy, 2015)

Understanding the Boom and Bust Cycles of Ostrich Production in South Africa using System Dynamics

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Abstract

Since the deregulation of the ostrich production industry in South Africa, primary production and value-adding activities have increased substantially. The industry has experienced dramatic production crashes without the environment or infrastructure reaching its carrying capacity. From a systems perspective, the boom and bust pattern of ostrich production is economically driven. This paper presents a dynamic commodity system built to explain the large fluctuation of ostrich production in South Africa. The model suggests that there are two major feedback loops competing for dominance in the pursuit of equilibrium. The major feedback loops are driven by ostrich leather and meat income respectively.

Introduction

South Africa is regarded as the undisputed world leader in ostrich production (NAMC, 2003). South Africa currently accounts for approximately 70% of the global ostrich market (Directorate Statistics and Economic Analysis, 2006). The majority market share means that strong feedback is bound to exist between South African ostrich production and the international commodity cycles of ostrich products, whereas other ostrich producing countries experience the ostrich product market as an exogenous influence. Ostriches in South Africa are produced for meat, leather and feathers. Ostrich meat is the largest meat export from South Africa in terms of both volume and value (Brand & Jordaan, 2001). The South African ostrich industry accounts for an average of 2% of the national total gross value added by animal production (Brand & Jordaan, 2001). The industry also adds significant value to the economy by making use of abattoirs, meat processors, tanneries, feather processors and even establishing ostrich agri-tourism.

Despite the prominent role ostrich production plays in the animal production sector, the ostrich farming industry has shown an extremely unstable pattern of development. Once the free-market system was implemented in 1993, the ostrich industry received a surge of capital investment and expanded rapidly only to suffer devastating production crashes, seeing many ostrich producers suffer big losses that resulted in them leaving the industry. The industry did not learn from the first collapse and the boom and bust cycles continues to repeat itself, implying that producers may not fully understand the market. The development does not seem to be associated with natural resource depletion. Examination of Figure 1 shows patterns of continuous boom and bust cycles in the historical development of the ostrich slaughter rate in South Africa.

This paper describes a system dynamics model developed in aid of examining and explaining the underlying causes of the boom and bust in the ostrich production industry. The development of the primary production section of model was based off of Meadows' hog cycle (Meadows, 1970). The generic commodity cycle proposed by Sterman (2000) was the main insight into the rest of the model.

This model is specific to the South African ostrich industry and could not be applied to ostrich production in a different country or a different livestock industry in South Africa. The next phase of the study, not discussed in this article is the policy design and implementation of carbon and water tax, as well as the transition from flock breeding to small camp breeding for environmental sustainability.

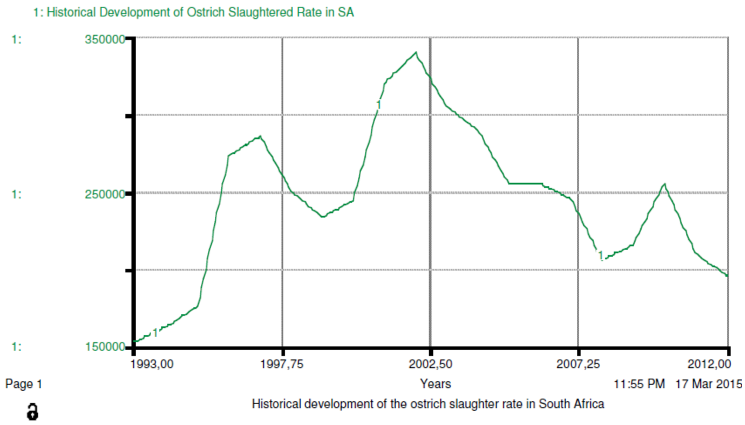

Figure 1: Historical development of ostrich slaughter rate in South Africa

Literature Review

Commodity cycles are a result of industry-wide market forces or feedbacks between supply and demand. Market forces can either attenuate or amplify shocks to a supply-chain, often resulting in cycles in production and prices, each with characteristic periods, amplitudes, and phases (Sterman, 2000). Commodity cycles, or oscillations, are most prevalent in industries with long time delays as well as relatively strong negative feedback forces, the most common of which is price seeking to equilibrate supply and demand (Sterman, 2000). Examples of industries with strong cyclical dynamics attributed to long construction or production delays are real estate, shipbuilding, paper and coffee.

An example of one of the first large-scale system dynamics models dealing with natural resource depletion is the Club of Rome's attempt to address The Limits to Growth problem (Meadows, et al., 1972). Shortly thereafter, Michigan State University developed a collection of large-scale and country-based agricultural sector models for various regions of the world (Harrison, et al., 1974), (Michigan State University Simulation Team, 1971).

The model proposed by Meadows (1969) serves as a significant building block for most system dynamics models of livestock commodity cycles published. It analyses the dynamic cycle theory of producing products, citing the cyclical fluctuations in the U.S. hog population prices (Meadows, 1969). Meadows (1969) uses the model simulation to define how commodity markets could be balanced. Ford (2015) later adapted the model to represent the modern livestock commodity cycle. The model adaptation is specifically produced for ease of understanding for educational purposes. Conrad (2004) included production and prices of dairies (milk production and demand) and grains (feed) in the cattle breeding-related model and considered the disruption caused by a foot-and-mouth (FMD) epidemic. McDermott, et al. (2005) made the distinction between dairy cattle and fattening cattle when modelling New Zealand's livestock industry and value chain. Ross, et al. (2011) modelled the entire beef production process in great detail to analyse the beef supply network in a bid to gain greater understanding in the livestock production process.

Meadows (1970) developed a system dynamics model of commodity cycles, applying the model to livestock production. The model was later refined by Sterman (2000). In Sterman's generic structure for commodity markets, he proposes three principle feedbacks to equilibrate supply and demand: B1, B2 and B3 (Sterman, 2000). B1 regulates the commodity selling price relative to its substitutes. B2

regulates the utilization of existing production capacity while B3 develops additional capacity if required (Sterman, 2000). Sterman (2000) also proposes changes to his generic structure of commodity markets for livestock applications. In the case of animal production, a decrease in immediate production will result in an increase in long-term production and vice-versa (Sterman, 2000).

Cloutier (2001) modelled the economic and production system of the maple sap production industry in Quebec using the structure introduced by Meadows (1970). The macrobehaviour of the industry was simulated using the microstructure of maple sap collection and syrup production as input.

Osorio & Aramburo (2009) used system dynamics modelling to examine the long term cyclical behaviour of the price of coffee. The model was based on the structures developed by Meadows (1970) and Deaton & Laroque (1996) (2003). The internal structure of the system proposed by Osorio & Aramburo (2009) includes price, investment, demand and capacity. Another example of a model based on the before mentioned structures, Bantz & Deaton (2006), evaluates the biodiesel industry of the United States of America. Bantz & Deaton (2006) used the supply-demand-price model, spread out through two sections, capacity and production inventory, to explain the feedback mechanisms and dynamics involved.

Applanaidu, et al. (2009) combines the system dynamics approach proposed by Meadows (1970) and Deaton & Laroque (1996) (2003) with econometric methods in modelling the Malaysian cocoa market. Haghighi (2009) also used the combination of econometric and system dynamics methods to determine the optimal employment and production policies in the agricultural sector of Iran.

Model Description

The system dynamics model presented attempts to recreate the boom and bust nature of ostrich production in South Africa. The model is divided up into four subsectors: Primary Production, Leather Income, Meat Income and Producer Cost.

Model Boundary

The proposed model simulates the ostrich production industry of South Africa from a producer's perspective. The process of breeding ostriches is simulated in detail along with the producers' decision-making process about number of ostriches produced. Since the primary producer receives his income upon slaughter (NAMC, 2003), the leather and meat income sectors are defined as the income the farmer (primary producer) receives from the ostrich value-adding sector upon slaughter, rather than the final selling price of the finished product in international markets.

Although both the before mentioned sectors are influenced by their respective market-related variables, the international ostrich leather and meat markets are not modelled in-depth. Instead, the meat and leather income sectors are a considered to be the price the value-adding sector, mainly consisting of meat and leather processors, is prepared to pay the primary producer upon slaughter. The value-adding sector only has their current and historical market performance to determine the price payed to primary producers, along with current exchange rates and economic welfare.

The model structure assumes that the only endogenous factor that influences ostrich producers' decision to increase or decrease production is the producers' current perceived profit margin per ostrich. The profit margin per ostrich is determined mostly by the income received from ostrich leather and meat, and the expense incurred from feed. The leather and meat sectors influence the profit margin per ostrich in addition to being part of the system's two major feedback loops. There is no

feedback between the ostrich production sector and the production cost sector; feed prices influence the system while the system has negligible effects on feed prices.

Primary Production Sector

The Primary Production sector involves all activities included in breeding, or producing, ostriches. Once producers decide to change their production rate, they do so by changing the breeding stock population to desired levels since "it takes hogs to make hogs" (Sterman, 2000). It is assumed that ostrich producers always follow a worse-before-better production plan, where a decrease in immediate production will result in an increase in long-term production (and vice-versa). An example of this assumption, in reference to Figure 2, is if the *Perceived Optimal Number of Ostriches Produced* is more than the current *Ostrich Slaughter Rate*, producers will withhold *Mature Ostriches* from slaughter in the current season to groom as future breeding stock, effectively widening the gap between the desired and actual slaughter rates in the short term. The *Ostrich Breeding Stock* eventually increases as the birds reach sexual maturity, increasing the *Ostrich Slaughter Rate* sustainably.

An example of the opposite, better-before-worse production plan, not implemented in the model, is if producers send *Mature Ostriches* to slaughter in the current season, effectively supplying the perceived optimal number of ostriches in the short term. This policy is unsustainable since the decrease in *Ostrich Breeding Stock* has decreased the production capacity in the long term, causing the producer to carry on slaughtering *Ostrich Breeding Stock* at an increasing rate until the stock is depleted.

The model is equilibrated through the two major balancing feedback loops regulating leather and meat income, B1 and B2 in Figure 2, respectively. Both balancing loops refer to the long-term reaction of the system.

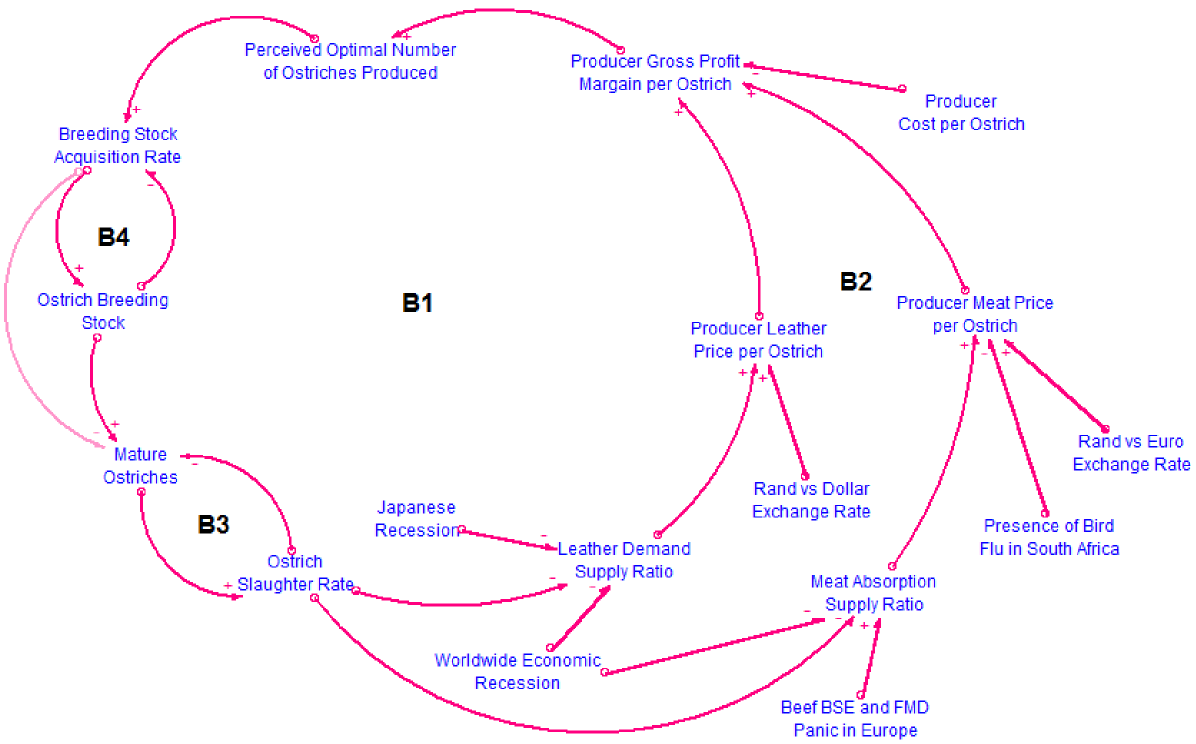

Figure 2: Aggregate causal loop diagram of system

Balancing Loop B1: Leather Income

Ostrich leather is sold in US Dollars. It is marketed as an exclusive product in the fashion and lifestyle industry. It accounts for 50% to 70% of the total income per bird (NAMC, 2003). The income per ostrich skin is relatively high, but since it is used predominantly in luxury products, the market is sensitive to economic welfare. As a niche product, the price of ostrich leather per square meter decreases endogenously as the perception of product availability increases. Exogenous influences on the leather price are the economic downturns of potential ostrich leather markets – identified as the *Japanese Recession* in the early 1990's as well as the *Worldwide Economic Recession* in 2009 in Figure 2.

The influence of exclusivity and economic hardship on the ostrich leather selling price - in Dollar - is modelled using a *Leather Demand Supply Ratio*. The presence of economic hardship, represented by the binary, exogenous variables, *Japanese Recession* and *Worldwide Economic Recession*, where 1 represents a period of recession, has an opposite effect on the *Producer Price of Leather per Ostrich*. Similarly, a disturbance in supply, shown as *Ostrich Slaughter Rate*, would also have an opposite effect on *Producer Price of Leather per Ostrich*.

The final exogenous variable acting upon the Ostrich Leather Market, *Rand vs Dollar Exchange Rate*, influences the income – in South African Rand - received by ostrich producers in South Africa per ostrich skin, *Producer Leather Price per Ostrich*, without having any influence on the selling price of ostrich skins in the international ostrich leather markets. The high volatility of the *Rand vs Dollar Exchange Rate* potentially misrepresents the state of the international ostrich leather market to ostrich producers in South Africa. Ostrich producers have historically flooded ostrich leather supply intentionally, anticipating that the ostrich leather price – in Dollar - would plummet, since their returns – in Rand – still had a very favourable profit margin during times where the South African Rand is very weak against the Dollar.

Balancing Loop B2: Meat Income

Ostrich meat is currently marketed as an exotic, healthy alternative to red meat and accounts for between 30% to 45% of the total income per ostrich (NAMC, 2003). Along with the deregulation of the ostrich industry in 1993 came the conception of an export meat market. This was made possible with the establishment of the first abattoir complying with the phyto-sanitary requirements, along with the implementation of a policy for meat to be traced to the source (ECIAfrica (Pty) Ltd, 2010). Unlike the Leather Income sector, the *Meat Producer Price per Ostrich* is robust towards fluctuations in market supply. Exogenous variables identified as influencing the Ostrich Meat Market is food-safety concerns (both in South Africa and in Europe), the exchange rate, as well as economic welfare.

The outbreak of BSE (Bovine Spongiform Encephalopathy or mad cow disease) and FMD (Foot and Mouth Disease) in Europe at the end of 2000 caused the European consumer to seek an alternative to traditional red meat and subsequently caused a surge in demand, resulting in an increase in price of nearly 40% between December 2000 and September 2001 (NAMC, 2003). The surge in *Producer Meat Price* is modelled using the exogenous, binary variable, *Panic from BSE and FMD*, and has a similar effect on the *Meat Absorption Supply Ratio* subsequently increasing the *Producer Meat Price per Ostrich.*

The most common reason for the loss of income in the ostrich meat sector through weakening the *Meat Absorption Supply Ratio*, is an EU import ban on raw ostrich meat from South Africa. An EU export ban is the result of the *Presence of Bird Flu in South Africa*, modelled as an exogenous, binary variable, in Figure 2. Such a ban can easily last for more than a year and results in big losses for the industry. Another exogenous binary variable negatively influencing Producer Meat Price per Ostrich is the presence of the *Worldwide Economic Recession*. The effect of the *Worldwide Economic Recession* on the Meat Income sector is less severe than on the Leather Income sector.

More than 90% of South Africa's total ostrich meat exported is to Europe, meaning the *Rand vs Euro Exchange Rate* has a dominant influence on the supplier income earned from export meat (NAMC, 2003). The exchange rate influences the income received from export meat – in Rand - even though it has no effect on the ostrich meat selling price in the EU, as is the case for the Leather Income sector.

Simulation

Definition and Classification of Variables

Key variables identified as influencing ostrich production in South Africa were categorised as endogenous or exogenous in nature. Even though the nature of the discipline of system dynamics modelling is to create system behaviour endogenously using feedback over time, exogenous parameters were identified as having great influence over the system. An example of variables having considerable influence over the model, that could not be recreated endogenously, is the exchange rate between the Rand and both the Euro and Dollar. A non-exhaustive list of key endogenous and exogenous variables are shown in Table 1. Parameters excluded from the model include production capacity constraints, environmental constraints and resource constraints.

Table 1: classification of key variables

Endogenous Variables	*Exogenous Variables*
Producer Leather Price per Ostrich in Dollar	Cost of Lucerne per kg
Mature Ostriches	Cost of Maize per kg
Producer Meat Price per Ostrich in Euro	Cost of Sunflower Seeds per kg
Ostrich Breeding Stock	Presence of Japanese Recession
Breeding Rate	Presence of Worldwide Economic Recession
Breeding Stock Acquisition Rate	Rand Dollar Exchange Rate
Breeding Stock Slaughter Rate	Rand Euro Exchange Rate
Change in Producer Leather Price per Ostrich	Presence of BSE and FMD in Europe
Change in Producer Meat Price per Ostrich	
Ostrich Slaughter Rate	
Desired Breeding Stock	
Producer Gross Profit Margin per Ostrich	
Leather Demand vs Supply Ratio	
Producer Leather Price per Ostrich in Rand	
Meat Absorption vs Supply Ratio	
Producer Meat Price per Ostrich in Rand	

Model Settings

The model was created and simulated using iThink® software. The model runtime is between 1993 and 2012, in years, with a timestep of 1/16 selected. Euler's method was selected for numerical integration purposes.

Model Verification and Validation

Model verification and validation is a principal step of the modelling process and should be done before interpreting model behaviour or performing policy analysis (Pruyt, 2013). Model verification is

the process of checking if the model has been coded or simulated correctly. The model was iteratively verified using the method prescribed by Pruyt (2013). Pruyt's method entails checking and testing for:

i. dimensional consistency,
ii. sub-models and structures,
iii. appropriateness of combination of numeric integration method and step size, and
iv. all equations and inputs for errors.

Model validation is the process of assessing whether or not a model meets the objectives of the modelling study (Barlas, 1996). Pruyt (2013) categorizes validation tests described in Sterman (2000) as:

i. direct structure tests,
ii. structure-oriented behaviour tests, or
iii. behaviour reproduction tests.

Model validation currently iterates through direct structure – and structure-orientated behaviour tests. The model will be subjected to behaviour reproduction tests before finalising the baseline results or undertaking scenario analysis in future.

Preliminary Baseline Results

For the purpose of this article, only the business as usual scenario is executed. The business as usual scenario is described as simulating what happened in reality in terms of regulations, outbreak of disease, global markets and feed cost between 1993 and 2012. The business as usual scenario results are compared to historical data as one method of model validation in terms of behaviour and accuracy, and represented graphically.

Future scenarios to be executed include prolonged instances of bird flu or drastic changes in the Rand-Dollar or Rand-Euro exchange rate on a model in equilibrium. The process of implementing a small-camp system for ostrich farming to allow for veld restoration is also considered along with the possibility of carbon tax on livestock and water tax on irrigated crops.

Ostrich Primary Production Sector

The ostrich slaughter rate is a key indicator of the Primary Production sector. Figure 3 compares the simulated behaviour to historical data for the period 1993 through 2012. Time path 1, in blue, shows the ostrich slaughter rate calculated by the proposed model, corresponding to the variable, *Ostrich Slaughter Rate,* in Figure 2, while time path 2, in red, shows historical data of the ostrich slaughter rate.

The results from the model follow the same general shape as the historical data with some delayed reaction during the early 2000's. This could possibly be attributed to either over-responsiveness or a lack of responsiveness of the model feedback. The model results follow the same shape as the historical data but seem to be amplified during boom-periods.

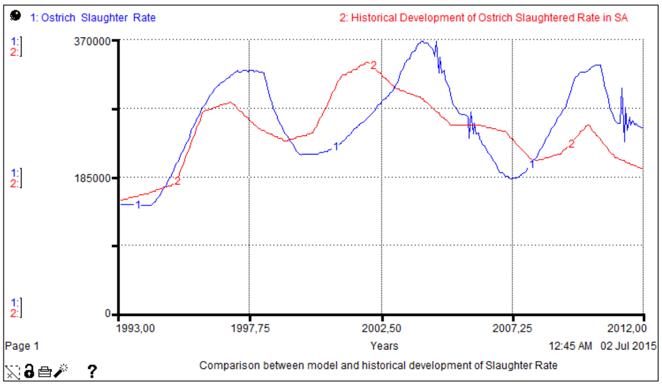

Figure 3: Simulated and historical data of the ostrich slaughter rate

The correspondence in the overall behaviour of the model slaughter rate with the historical data shows promise that the model structure resembles that of reality. The lag present in the early 2000's as well as the amplification is cause enough to continue the iterative processes of validation prescribed by Pruyt (2013).

Ostrich Leather Income Sector

The results produced from the ostrich leather market are very significant since the majority income per ostrich comes from ostrich leather. The leather sector of the model therefore weighs heavily during decisions regarding ostrich production.

The income ostrich producers receive from leather per ostrich is identified as the key indicator of the Leather Income sector. As seen in Figure 2, the leather sector forms part of the major feedback loop B1 that competes with B2 (relating to the meat sector) to balances the system.

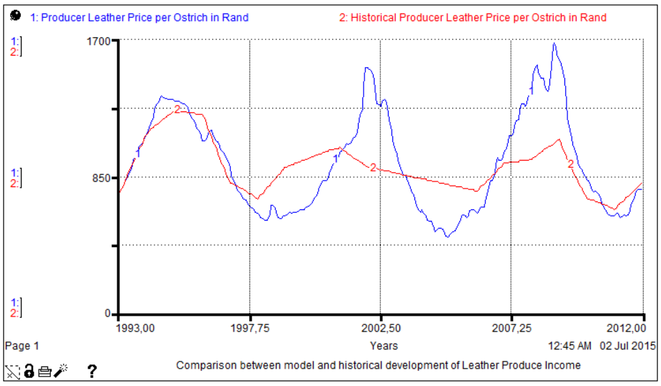

Figure 4: Simulated and historical data of the producer leather price

In Figure 4, time path 1, in blue, shows the total income received from leather calculated by the proposed model, shown as *Producer Leather Price per Ostrich* in Figure 2, while time path 2, in red, shows historical data of the total income received from ostrich leather per ostrich.

The results from the model produces the same general behaviour as the historical data with significant overshoot during the boom-period of the cycle. The overshoot could likely be attributed to the model's over-sensitivity to the Rand vs. Dollar exchange rate or inaccuracies in the data collected. The similarity in behaviour affirms that the proposed general model structure could resemble reality, but still needs to be refined using the validation techniques categorised as either direct structure tests or structure-oriented behaviour tests.

Ostrich Meat Sector

Income received from ostrich meat is traditionally a solid secondary source of income from ostrich production. As seen in Figure 2, the meat sector forms part of the major feedback loop B2 that competes with B1 (relating to the leather sector) to balances the system.

Figure 5 shows the total income received from the ostrich meat, as calculated by the model, as the blue time path 1. The historical data of the total income received from ostrich meat is shown as the red time path 2. The behaviour appears similar, with the model producing an over-shoot during the peak period.

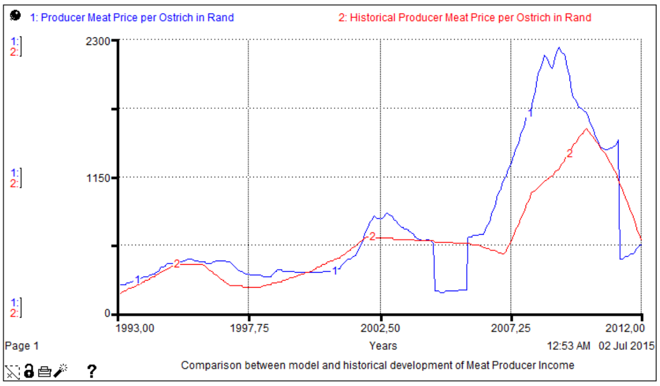

Figure 5: Simulated and historical data of the total producer meat price

Conclusion

The objective of this paper is to better understand the ostrich production industry of South Africa using system dynamics modelling. An aggregate causal loop diagram is introduced and key model sectors described. There are four model subsectors in total: Primary Production, Leather Income, Meat Income and Producer Cost. The model is found to be dominated through two competing major feedback loops influenced by the leather and meat income respectively. Validation of the proposed model is done by comparing the business as usual model results with historical data. The correspondence of the overall behaviour with historical data shows promise that the model structure resembles that of reality however, the model overshoot is still to be addressed in future. After further model validation and verification, scenario testing regarding policy testing and risk management is suggested.

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D.2 Commercial fishing and aquaculture implications of a green economy transition in the Western Cape (Duminy *et al.*, 2015)

COMMERCIAL FISHING AND AQUACULTURE IMPLICATIONS OF A GREEN ECONOMY TRANSITION IN THE WESTERN CAPE

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ABSTRACT

The Western Cape provincial government has prioritised shifting the Western Cape economy from its current carbon intensive and resource-wasteful nature to one that is smarter, greener and more economically sustainable. However, modern policy design often results in unintended outcomes or adverse secondary effects that were not considered by policy makers due to the complex and inter-related nature of the problem at hand. It is therefore anticipated that government intervention, as well as the gradual effect of climate change in the area, will influence fisheries and aquaculture in the Western Cape both directly and indirectly. Fisheries and aquaculture are identified as complex dynamic systems using systems thinking. Finally system dynamics modelling is introduced and proposed as a suitable tool for analysis and policy design of complex systems such as fisheries and aquaculture in the Western Cape. This article concludes that system dynamics modelling is an appropriate tool for determining the influence of both climate change and government intervention on fisheries and aquaculture in the Western Cape. It is then recommended to construct a system dynamics model with the overall modelling goal of evaluating proposed provincial governmental frameworks and action plans in terms of social, economic and environmental sustainability, taking into account the anticipated future climate change in the Province.

Key words: system dynamics, climate change, commercial fishing, aquaculture.

INTRODUCTION

Since the introduction of the term “green economy” in the Blueprint for a Green Economy (Pearce, et al., 1992), the interest and demand for the “green transition” is steadily increasing. At a visionary level, the United Nations Environment Programme (UNEP) defines a green economy as an economy where the action of significantly reducing the environmental risks and ecological scarcities directly benefits human well-being and social equity. At an operational level, the United Nations Environmental Programme defines a green economy as an economy that is driven by investments, including investments in human and social capital in the South African Green Economy Modelling Report (UNEP, 2013). The investments are sought to reduce carbon emissions and pollution, enhance energy and resource efficiency and prevent the loss of biodiversity and ecosystem services. Furthermore, the May 2010 Summit Report (DEA, 2010) states that South Africa defines a green economy as a development path that is sustainable in addition to addressing the interdependence between natural ecosystems, economic growth and social protection.

South Africa used the 2008 world financial and economic crisis as an opportunity to stimulate economic growth through activities relating to environmental and social development as part of an economic stimulus package by allocating US$800 million to environment related themes.

In November 2011, South Africa announced commitment to a Green Economy Accord; an agreement between government, industry, labour and trade unions, as well as the greater society. The Green Economy Accord aims to create 300000 new jobs by 2020. A priority area for green economy promotion in South Africa is the innovation of new technologies and behaviours, preparation for future flourishing green markets by expanding infrastructure as well as promotion of developing green industries (UNEP, 2013).

These initiatives prove that the South African government is committed to sustainably developing a green economy in the face of a global economic crisis, imminent depletion of natural resources and climate change.

In this article, a summary of national and provincial responses to climate change is followed by an overview of commercial fishing and aquaculture. Next, mathematical modelling and system dynamics modelling is introduced, followed by the article conclusion.

NATIONAL RESPONSE TO CLIMATE CHANGE

This section contains an overview of the three most relevant governmental reports used to develop the Western Cape Climate Change Response Strategy (DEA&DP, 2014). It is assumed that the reports used in such a prominent provincial document would be a fair overview of the national response on climate change as a whole. The three most relevant governmental reports are: the National Climate Change Response Policy (NCCRP), the National Development Plan (NDP) and the National Strategy for Sustainable Development and Action Plan (NSSD1). The Western Cape provincial response on climate change follows after this section.

The National Climate Change Response Policy

The NCCRP was released near the end of 2011 (RSA, 2011). The white paper formalised the South African Government's vision for an effective national response to climate change as well as a long-term transition to a low-carbon and climate-resilient economy. The report defines the two main objectives of South Africa's response to climate change. The first objective is to manage inevitable climate change impacts and the second objective is to make a fair contribution to the global efforts to stabilise greenhouse gas concentrations in the atmosphere (RSA, 2011). In addition to the two main objectives, the NCCRP identifies eight short-term Priority Flagship Programmes. The Priority Flagship Programmes identified are: Climate Change Response Public Works, Water Conservation, Renewable Energy, Energy Efficiency and Energy Demand, Transport, Waste Management, Carbon Capture and Sequestration and Adaptation Research. Finally, the NCCRP includes a Monitoring and Evaluation System developed to serve as a national tracking and reporting structure for South African climate change responses (RSA, 2011).

The National Development Plan

The NDP was developed by the National Planning Commission with the target of eliminating poverty and reducing inequality by 2030 (National Planning Commission of South Africa, 2012). The NDP acknowledges South Africa's role as a contributor to greenhouse gas emissions. The document also points out that South Africa is very vulnerable to the effects of climate change regarding health, livelihoods as well as water and food security. In addition, the report notes that the poor, especially women and children, are most exposed to the before mentioned risks. The topic of climate change is dealt with explicitly in Chapter 5 of the National Development Plan: Environmental Sustainability and Resilience. References to climate change can also be found in Chapter 3, 4, 6 and 8.

The National Strategy for Sustainable Development and Action Plan

The NSSD1 was approved by the Cabinet on 23 November 2011 and builds on the 2008 National Framework for Sustainable Development which laid out a plan of strategic interventions required to ensure South Africa's development path moves in an economic, social and environmentally sustainable direction (DEA, 2011). Five strategic objectives are identified in the NSSD1:

i. Enhancing systems for integrated planning and implementation;
ii. Sustaining our ecosystems and using natural resources more efficiently;
iii. Transitioning towards a green economy;
iv. Building sustainable communities; and
v. Responding effectively to climate change.

The common thread of the above mentioned documents, among other less significant documents and mandates, are used as the basis of the Western Cape Climate Change Response Strategy of 2014. This ensures consistency between the National Climate Change Response Strategy and the Western Cape Climate Change Response Strategy.

THE WESTERN CAPE STRATEGIC CLIMATE POLICY DOCUMENTS

This section contains an overview of the most prominent provincial climate change policies. Using national policies, strategies and plans as a basis for developing a provincial climate change response strategy ensures that the focus areas and priorities highlighted on a national level is enforced at an operational level in the Western Cape (DEA&DP, 2014).

The Western Cape Climate Change Response Strategy and Action Plan

The Western Cape Climate Change Response Strategy and Action Plan was released in 2008 by the Department of Environmental Affairs and Development Planning and introduced four prioritized programmes for the province (DEA&DP, 2008):

i. Integrating climate change and the relevant risk management into an joined water supply and infrastructure management programme;
ii. Establishing clear links between land stewardship, livelihoods and the economy and a whole;
iii. Establishing focused climate change research and weather information programmes; and
iv. Reducing the Western Cape's carbon footprint.

OneCape 2040

OneCape 2040 is an attempt to enable a transition of the Western Cape economy into something more inclusive and resilient. A highly skilled, innovation driven, connected, resource-efficient, high-opportunity and collaborative society is envisioned for the year 2040. The transformation plan is divided up into six different categories designed to work in tandem: Educating Cape, Working Cape, Green Cape, Connecting Cape, Living Cape, and Leading Cape (EDP, 2012). The aspect that each category directly influences is shown in **Error! Reference source not found.**.

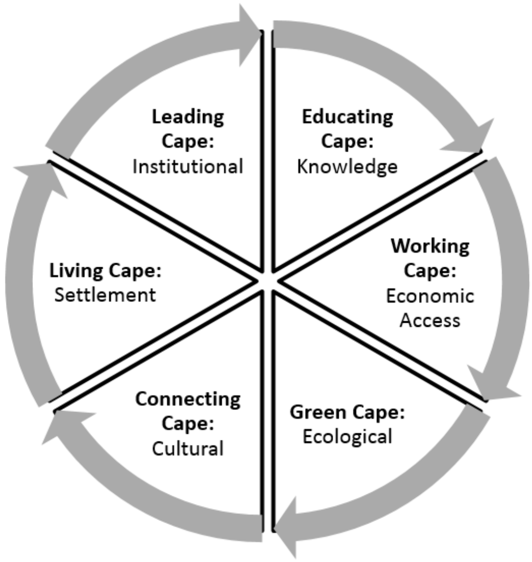

Figure 1: OneCape 2040 Transformation Plans

Green is Smart – Western Cape Green Economy Strategy Framework

Green is Smart's objective is to formalise a strategy to enable the Western Cape to become a global pioneer in the green economy, as well as to be recognised as the leading green economic hub of the African continent. The framework focuses on shifting the current carbon intensive and resource wasteful economy to one that is smarter, greener, more competitive and more equal and inclusive. The framework focuses on creating a province with a sustainable future that generates continuous and consistent economic growth. The five drivers for transition are identified as smart mobility, smart living & working, smart ecosystems, smart agri-processing and smart enterprise (WCG, 2013). Five enablers are explicitly recognised to aid the drivers in creating a region in which the mandate of a more sustainable economic, social and environmental future could become reality. The Five enablers are finance, rules & regulations, knowledge management, capabilities and infrastructure. Finally, Green is Smart identifies priorities that would position the Western Cape as an early adapter and pioneer of green economic activity (WCG, 2013).

Western Cape Draft Strategic Plan (2009 – 2014)

The Western Cape Draft Strategic Plan (2009 - 2014) outlines twelve Provincial Strategic Objectives (PSOs) of the Western Cape provincial government, each comprising of a number of working groups that include representation from most WCG departments as well as local and national stakeholders. Climate change is addressed as a priority focus area in PSO7: Mainstreaming Sustainability and

Optimising Resource-Use Efficiency (GWC, 2010). The working groups directly related to climate change are Energy, Climate Change Adaption, Sustainable Resource Management as well as Land-use Planning. PSO1: Increasing Opportunities for Growth and Jobs contains the Green Economy Work Group who focuses on promoting the Green Economy in the Western Cape. Clear links to climate change are also made in PSO11: Creating Opportunities for Growth and Development in Rural Areas, which deals with the development of the rural economy (GWC, 2010).

Provincial Spatial Development Framework

The Provincial Spatial Development Framework, currently being finalised by the Department of Environmental Affairs and Development Planning, sets out a framework of spatial governance, the sustainable use and management of the provinces assets, encouragement of participation in the Western Cape's space-economy as well as the development of integrated and sustainable human settlements (DEA&DP, 2013). The Provincial Spatial Development Framework supports the spatial priorities of the NDP.

Western Cape Sustainable Water Management Plan

The Western Cape Sustainable Water Management Plan was a collaborative effort between Western Cape Government's Provincial Departments and the Western Cape Regional Office of the National Department of Water affairs. The plan has three primary objectives: protecting water resources from environmental degradation, incorporating integrated planning processes, and promoting efficient water utilisation (WCG, 2012). A conclusive action-plan is proposed with the aim of achieving integrated and sustainable management of water in the Western Cape. The four strategic goals identified by the Western Cape sustainable Water Management Plan is to ensure the sustainability and integrity of socio-ecological systems, the sustainability of water resources for growth and development, effective co-operative governance and institutional planning for sustainable water management, and effective and appropriate information management and reporting of sustainable water management (WCG, 2012).

Provincial Land Transport Framework

The Provincial Land Transport Framework informs all provincial decision-making bodies with respect to all transport and land-use related topics. The framework aims to transform the current transport system into one that is an efficient, accessible and integrated multi-modal public transport system managed by municipalities with both capacity and necessary infrastructure in addition to being well maintained, safe and sustainable to operate (Department of Transport and Public Works, 2012).

The Western Cape Infrastructure Framework

The Western Cape Infrastructure Framework has been developed by the Provincial Transport and Public Works Departments to align the planning, management and delivery of infrastructure. The framework envisions a future provincial infrastructure that satisfies current needs and backlogs, maintains the existing infrastructure, and plans proactively for a desired future outcome. Topics addressed in the Western Cape Infrastructure Framework that deal directly with climate change response are Energy, Water, Transport and Settlements (Department of Transport and Public Works, 2013).

From the summaries of the most relevant provincial strategic climate change policies below, a uniform theme, in line with the national response to climate change, can be observed throughout each provincial document. The next section gives and overview of the commercial fishing and aquaculture industry of South Africa as well as the Western Cape.

OVERVIEW OF THE COMMERCIAL FISHING AND AQUACULTURE INDUSTRY

This section deals with the commercial fishing and aquaculture industry of both South Africa, and the Western Cape, respectively. Aquaculture is the process of farming freshwater and saltwater populations under controlled conditions whereas commercial fishing describes the process of harvesting wild fish. According to the Status of World Fisheries and Aquaculture report, Africa contributed only around 1.5% of global aquaculture production in 2006 with South Africa responsible for less than 1% (Food and Agriculture Organization of the United Nations, 2008). With the current unsustainable rate of depletion of global wild fish stocks, promotion and growth of aquaculture is cardinal to curb global overexploitation of fish. The vast South African coastline stretching over more than 3200km is home to well-established fisheries considered to be fully used or overexploited, especially in the case of high-value fisheries such as abalone, linefish and prawns (WESGRO, 2012). The commercial fishery industry creates approximately 27000 jobs and has an annual turnover of about 2bn South African Rands (WESGRO, 2012). Vulnerabilities in South Africa's fishing industry are identified as pollution, poaching, inappropriate developments and over-use.

In contrast to fisheries, aquaculture is considered an underdeveloped sector in South Africa (DEA, 2010). The South African government thus identified aquaculture as an area to develop since historically, aquaculture focussed exclusively on a small number of high value species such as abalone, mussels and oysters. The WESGRO report of 2012 estimates that South Africa's aquaculture production has the potential to grow from 3453 tonnes (ZAR218m) to more than 90000 tonnes (ZAR2.4bn) over the next two decades (WESGRO, 2012).

The aquaculture industry of South Africa consists of both marine and fresh water aquaculture. Marine aquaculture exports consist mainly of abalone, oysters and mussels whereas oysters, mussels and salmon are imported and contributed to 0.02% of South Africa's Gross Domestic Product in 2011 (DAFF, 2012). Freshwater aquaculture is the oldest aquaculture sector in South Africa and is more developed in terms of both diversity of species cultured and the number of producers (DAFF, 2012). The major farmed fresh water species are rainbow trout, koi carp and ornamental species, tilapia and catfish. The Western Cape has been dominant in terms of total national production, accounting for approximately 85% of total fish exports. Frozen hake fillets have been the largest export from the Western Cape in 2012 (WESGRO, 2012). The demand for high-end fishery products, generally synonymous with high profit margins, is expected to increase at a steady rate for the next two decades, providing substantial opportunity for a sustainable increase in aquaculture production in the Western Cape.

Since aquaculture is less dependent on climate change than most other food production industries in the Western Cape, including fisheries, it is anticipated to become increasingly relevant for the food security and economic stability of the province. A medium-term need for aquaculture to be developed is identified to ensure social, economic and environmental sustainability of both the aquaculture and the commercial fishing industry. Such sustainable development requires a reliable, universal aquaculture framework based on sound analysis, planning and forecasting. Mathematical modelling is identified as a potential tool during the development of an aquaculture framework due to the combination of importance and complexity of commercial fishing and aquaculture in the Western Cape.

MATHEMATICAL MODELLING

Many of today's managerial problems in the public and private sector are too complex to solve without some form of optimization. Often management resorts to some form of modelling since the symptoms of a problem in a large system often seems unrelated to the actual problem and behave counter to human intuition. Furthermore, previous policy interventions may have unintended outcomes since the complexity and interconnectivity of the system was not properly addressed. This section introduces the discipline of mathematical modelling and compares analytical and numerical models.

Overview of Modelling

Modelling is often used to determine the outcome of a specific scenario without testing it in reality. Managerial or technical decisions are often based on the results of one or more different type of models in an array of disciplines. Eykhoff defined a model as: ``...a representation of the essential aspects of an existing system (or a system to be constructed) which presents knowledge of that system in a usable form'' (Eykhoff, 1974).

Models can be either physical or theoretical. Mathematical modelling is a common theoretical modelling method used to describe any system, defined as an integrated set of individual elements related through interaction or interdependence, with a fixed framework consisting of pre-defined rules and outlines using mathematical concepts and language. A mathematical model therefore returns numerical outputs that describe reality as accurately as required within given constraints (Gershenfeld, 1999).

Common forms of mathematical models include dynamic systems, statistical models, differential equations, or game theoretic models. Mathematical models very often integrate elements of several forms within different structures of the model to accurately describe the complex nature of most systems. Klamkin compares different description of mathematical modelling as well as the modelling process (Klamkin, 1980). The description of the modelling process is amplified from having three distanced stages to five or more.

Comparison between analytical and numerical models

Analytical models are models that can be clearly defined using mathematical analytic equations and are capable of delivering an explicit closed-form solution (Saff & Snider, 1993). Many problems are too large or complex to calculate a closed-form solution and therefore cannot be solved analytically.

Numerical models utilize a time-stepping procedure to determine the model output over time. Solutions can be tabulated or shown graphically (Saff & Snider, 1993). Numerical models may require several iterations to get to an acceptable output and is therefore very time and resource intensive. The equations describing numerical models are more intuitive and therefore easier to describe in terms of numerical equations. Most complex models are solved numerically rather than analytically.

SYSTEM DYNAMICS MODELLING

After a general overview of modelling, the system dynamics modelling is defined in order to create a feasibility checklist to determine whether a problem is suitable for system dynamic modelling.

System dynamics is one of many techniques that can be used to facilitate quantitative simulation modelling and analysis in complex systems (Wolstenholme, 1990). It is currently being applied in aid of policy analysis and design in both the public and private sector. The founder of system dynamics, Jay Forrester, defined the technique as: ``… the investigation of the information-feedback characteristics of [managed] systems and the use of models for the design of improved organizational form and guiding policy ʻʻ (Forrester, 1961).

Forrester's original description however, does not give any reference to time. Coyle proposes a thorough definition compiled by combining existing definitions from (Coyle, 1996), (Forrester, 1961) and (Wolstenholme, 1990): ``System dynamics deals with the time-dependent behaviour of managed systems with aim of describing the system and understanding, through qualitative and quantitative models, how information feedback governs its behaviour, and designing robust information feedback structures and control polices through simulation and optimization.ʼʼ

In the context of System Dynamics, a system is defined as individual parts being integrated to achieve a certain outcome (Coyle, 1996). It is noted that, in this definition of a system, a system can fail to achieve its required outcome due to any number of reasons, including: design flaws, problems with implementation, problems with integrating parts, inadequate policies or even an external force. Within the same context, a dynamic system is described as a system that changes behaviour as time passes. This description emphasises the idea that System Dynamics can be a useful tool when deciding on new policy to be implemented due to changes in the existing system over an extended period of time.

Coyle points out common features between dynamic feedback control systems and system dynamics models (Coyle, 1996):

i. Measuring or sensing the actual current state of the system
ii. Comparison of actual state to desired state
iii. Heavy dependence on information feedback to control the system
iv. Employment of policies to reconcile the actual state with the set desired state
v. Often involve time-delays before actions have any effect on the state of the system

A basic example of a dynamic feedback control system is a domestic storage water heater, or geyser, that keeps water continuously hot and ready for use by using electricity as an energy source. The required water temperature is specified on the geyser thermostat after which the geyser is expected to control itself over time where circumstances constantly change, for example, fluctuations in the outside temperature or change in the rate of water usage.

System Dynamics Modelling Feasibility

System dynamics modelling is one of many modelling and simulation tools available. A checklist is devised from the various descriptions in the previous section to ensure that the type of system at hand is suitable for system dynamics modelling (see Figure 2). This checklist could potentially avoid wasting resources using a modelling method unsuited to the problem at hand.

SYSTEM DYNAMICS MODELLING FEASIBILITY CHECKLIST

The *checklist requirements* are stated in italics underneath the heading of each sub-section of the checklist. Each sub-section's requirement is to be satisfied for system dynamics modelling to be a feasible modelling method. It can be noted that, even if all the requirements are met according to the checklist, the system at hand might still be better described using a different method of modelling.

Desired output from model:

At least one of the two boxes is to be checked

- ☐ Model describing the system output as accurately as required within given constraints
- ☐ Understanding of the functionality and control policies of the system

Characteristics of the system to be modelled:

Both boxes are to be checked

- ☐ Time dependent
- ☐ Managed system

Model behaviour governed by:

Box to be checked

- ☐ Information feedback

Type of model required:

At least one of the two boxes is to be checked

- ☐ Qualitative
- ☐ Quantitative

Desired solution approach:

At least one of the two boxesise to be checked

- ☐ Simulation and
- ☐ Optimization

Figure 2: System dynamics modelling feasibility checklist

Basic Components of a System Dynamics Model

This section introduces the basic components of a system dynamics model, focussing on the differences between stocks and flows. Stock accumulation and the rate of change of a system are discussed. After identifying all components of a model, the model's behaviour over time is discussed. Dynamic behaviour is attributed to the Principle of Accumulation that states that all dynamic behaviour occurs when flows accumulate in stocks (Radzicki & Taylor, 1997). In system dynamics modelling, both informational and physical entities can flow through the pipe and faucet assembly to accumulate in the stocks. A stock can have an unlimited amount of both inflows and outflows since the principal of accumulation holds regardless of the number of inflows or outflows.

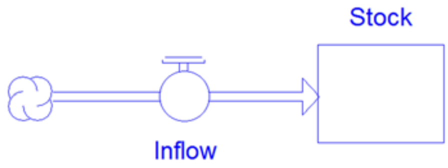

Figure 3: Simple Stock and Flow Structure

A graphic example of a simple stock and flow structure is shown in Figure . In this example, the system is only capable of stock inflow, indicated by a unidirectional arrow pointing in the direction of the stock. An example of a simple stock-flow structure with two flows, an inflow and outflow, is a water tank where the stock is represented by the water in the tank and the flow can be thought of as the valves, faucets and pipes that either fill or empty the tank. If the inflow is more than the outflow at a given point in time, the stock is increasing, whereas, if the outflow is less than the inflow, the stock is decreasing. The system is in a state of dynamic equilibrium if the inflow and the outflow are equal.

Identifying Stocks and Flows

A fundamental skill when building a system dynamics model, which beginners often find challenging, is correctly identifying each stock and flow in a particular system. A solid guideline is to distinguish between variables defining the state and the variables defining the changes in state. Variables responsible for defining the state are considered the system stocks whereas variables responsible for defining the changes in states are considered the system flows (Radzicki & Taylor, 1997). Differences between stocks and flows discussed by Coyle and Ford are listed in Table 1:

Table 1: Difference between stocks and flows (Coyle, 1996), (Ford, 1999).

Stocks	Flows
Represented by nouns, for example debt	Represented by verbs, for example deficit
If a hypothetical snapshot of a system were to be taken, stocks remain constant at the value observed in the instance of the snapshot.	If a hypothetical snapshot of a system were to be taken, all flows would be zero.
Serves as a source of information about the state to the rest of the system	Serves as a source of information about the state of the stock flow is flowing in/out.

Stocks

Radzicki and Taylor identified four individual stock characteristics that are responsible for the dynamic behaviour in systems (Radzicki & Taylor, 1997). The first characteristic is that stocks have memory. In the above example of the water tank, if both the inflow and outflow are shut off, the amount of stock stays as is until an inflow or outflow is re-introduced. The fallacy of shutting off an inflow to stop a population over-supply can be discredited using the characteristic of memory: shutting off inflow doesn't address the amount of entities currently in stock. A good example of the influence this characteristic can have on a system can be found in (Meadows, et al., 1992).

The second characteristic is that the nature of the flow is determined by the derivative of stock. Mathematically this means that flow rate at *t*, *q(t)*, is the derivative of the stock at *t*, *s(t)*, with respect to time. A thorough discussion of this characteristic can be found in (Forrester, 1968).

The third characteristic is that stocks "decouple" flows and allow disequilibrium behaviour at the stocks. Therefore, regardless of stock level, the inflow does not necessarily have to equal the outflow. This also means that the inflows and outflows can be controlled by different sources of information that do not necessarily relate to each other at all (Radzicki & Taylor, 1997).

The final characteristic of stocks is that they create delays in the system and therefore enable analysis over time. Identifying delays is an important step in the modelling process due to the significant impact on the system. It is not always easy to perceive a connection between cause and effect if there is a significant delay between the two.

Analysis over time

After identifying all components of a model, the next step is to identify key patterns of behaviour over time. The performance of crucial components, or system variables, over time is defined as the system variable's time path. Time paths can be described as being linear, exponential, goal-seeking, oscillating, or S-shaped in nature. Complex time paths can be described as exhibiting a combination of several traits where the traits can be combined concurrently. For example, a steady increase with small oscillations throughout evaluation, or sequentially, for example oscillating for 10 seconds before continuing linearly.

Linear time paths

Linear time paths are categorised as growing, declining, or in a state of equilibrium. Systems are seldom in a state of perfect balance. System equilibrium implies that all state variables are exhibiting equilibrium time paths simultaneously. System dynamics modelling method recognises that it is unlikely that a system would ever achieve equilibrium in reality, in contrast to much of modern economics and management science, that uses the assumption of equilibrium as a basis for their models. System dynamics models are only placed in an artificial state of equilibrium to study their behaviour to the implementation of policy changes.

Exponential Time Paths

Exponential time paths are categorised as either growing or decaying. Most systems have exponential time paths rather than linear time paths (Wagenaar & Sagaria, 1975), (Wagenaar & Timmeri, 1978), (Wagenaar & Timmeri, 1979). In practice, problems consisting exclusively of pure linear time paths usually contain no feedback and are likely not to conform to the definition of a system in the context of system dynamics. The problems are therefore most likely better described using a different method op applied mathematics or operations research.

Goal-seeking Time Paths

Goal-seeking time paths are paths that iteratively move as close as possible to a certain target-value over time. An exponential time path, where the exponent is negative, is an example of a path seeking a goal since the time path asymptotically moves closer to a certain goal y-value.

Oscillating Time Paths

Oscillating time paths can be sustained, damped, exploding or chaotic in nature (Radzicki, 1990). A period within an oscillating time path is defined as the number of peaks that occur before the oscillation cycle repeats. Sustained oscillations are characterized by having a period of one, therefore each oscillation is the exact replica of the previous oscillation. Damped oscillations decrease in amplitude with each oscillation until finally settling at a mean value whereas exploding oscillations increases in amplitude with each oscillation until the system either settles, therefore no longer characterised as exploding, or until the system falls apart. A chaotic time path has an infinite period since the irregular time path never repeats and is therefore considered random (Mosekilde, et al., 1988).

S-shaped Time Paths

Time paths that grow in an “S” shape over time have both exponential and goal-seeking attributes. The time path initially grows or declines exponentially before becoming goal-seeking when the system approaches its limit or carrying capacity.

Feedback

The final building block of dynamical systems is feedback. This section introduces the concept of model feedback with emphasis on closed system feedback. The concept of positive and negative feedback is also introduced. Feedback loops are often responsible for counter-intuitive behaviour in systems. A system can be classified as either ``open” or ``closed” (Ford, 1999).

Systems are classified as either open or closed. Closed systems have outputs that can both react to, and influence their respective inputs. Open systems have no influence upon their inputs. Open systems may only have outputs that respond to their respective inputs.

For a closed system a feedback path includes a stock, information about the stock, and a decision rule that is influences the flow strictly in the order that it is mentioned. Coyle uses an information/action/consequences paradigm schematic, coupled with a systematic procedure, to explain the basic principles of feedback in system dynamics modelling.

Feedback loops are considered to be either positive, or negative. Positive feedback loops, or reinforcing loops, reinforces the actions and results along loops resulting in a vicious or virtuous cycle. Positive feedback is responsible for growth or decline of systems, often up to the point of destabilization. Negative feedback loops work on bringing a system as close as possible to its desired state. Negative feedback either stabilizes the system, or causes oscillation.

CONCLUSION

Both the South African government and the Western Cape government are committed to the development of a green economy, even in the face of a global economic crisis, imminent depletion of natural resources and climate change. This article gives an overview of national and provincial responses to climate change that intentionally share the same common thread. An overview of commercial fishing and aquaculture follows, forecasting a growing demand in aquaculture to compensate for our current over-fished fish stock as well as other, more resource intensive, sources of protein. Commercial fishing and aquaculture are deemed fit to be modelled mathematically due to the combination of importance and complexity of the industries in relation to the green economy transition. Next, this article reviews the discipline of mathematical modelling with emphasis on system dynamics modelling. With a general introduction to the discipline of system dynamics, basic components of a system dynamics model are introduced. System dynamics model behaviour over time, as well as system feedback, is also explained in the before mentioned context.

The analysis and policy design of commercial fishing and aquaculture over time is of both high priority and high complexity. It is therefore concluded that system dynamics modelling is a suitable tool for commercial fishing and aquaculture policy makers on a provincial and national level. System dynamics modelling can be used to explore a variety of scenarios where the severity and effect of both climate change and government intervention is varied without much structural changes to the model created.

The recommended further action is to construct a system dynamics model, combining commercial fishing and aquaculture, with the overall modelling goal of evaluating proposed provincial governmental frameworks and action plans in terms of social, economic and environmental sustainability, taking into account the anticipated future climate change in the province.

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D.3 A system dynamics approach to understand the implications of a green economy transition in the Western Cape Province (Musango *et al.*, 2015)

A system dynamics approach to understand the implications of a green economy transition in the Western Cape Province of South Africa

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Abstract

Transitioning to a green economy presents opportunities and challenges for not only national governments, but also provincial and local governments. Within the South African context, a green economy transition is recognised as one of the key pathways towards achieving an environmentally sustainable, resource efficient, low-carbon economy, and a just society. For the Western Cape Province of South Africa, several sectors have been identified as capable of playing a key role in the government's effort to transition towards a green economy and becoming one of the leading green economic hubs of Africa. To achieve this transition, however, requires trans-disciplinary, integrated approaches to manage and plan the identified sectors. Using system dynamics, this paper developed a Western Cape Green Economy Model (WeCaGEM) to investigate the complexity involved in response to a green economy transition in the Western Cape Province. The model specifically focusses on green economy investment efforts in water, agriculture, transport infrastructure, renewable energies, energy production, carbon mitigation, and public services. The preliminary baseline results aim to validate simulated results with historical data. Future development of the model will involve validation with experts, establishing plausible or planned scenarios with experts and analysing green economy investment scenarios.

Keywords: *Green economy; Western Cape; South Africa; System Dynamics*

1 Introduction

Almost four decades after the World Commission on Environment and Development (WCED) defined sustainable development as "*development that meets the need of the present without compromising the ability of future generations to meet their own needs*" (WCED, 1987), the challenges, successes, failures and emerging problems concerning sustainable development are still at the forefront of international and national forums. The world today has unparalleled sophistication in the interventions, technologies and expertise available to address the many complex challenges that humanity face and to ensure intergenerational justice. However, numerous examples of shortfalls in terms of sustainable development are evident; the World Bank reports that carbon dioxide emissions continue to surge to unprecedented levels – global emissions in 2013 are estimated to be 36 billion tonnes, a 51 percent increase since 1990 (The World Bank, 2014). Another example sees that almost 27 percent of countries are "seriously off track" with their progress toward halving the proportion of people living without sustainable access to safe drinking water (The World Bank, 2014). In addition, phenomena like the global urban population growth outpacing the global rural population highlights the unremitting need to find innovative solutions to address and support sustainable development (UNEP, 2011b).

Aside from the vast number of methods and ways that have been developed to focus on the complex issues and 'wicked' problems concerning sustainable development, there are also developmental, scientific and economic improvement initiatives to address the multitude of crises that the world faces in terms of climate, biodiversity, fuel, food, water and global finances. One initiative that aims to bring forward a new economic paradigm in which "*material wealth is not delivered perforce at the expense of growing environmental risk, ecological scarcities and social disparities*" is the idea of a 'green economy' (UNEP, 2011a). Since Pearce et al. (1989) introduced the concept of a 'green economy" the notion, and the advantages and potential that it holds in terms of sustainable development, poverty eradication, and economic and social justification, has moved from specialist environmental discussions to the political mainstream (UNEP, 2011a). UNEP (2011b) defines a green economy as "*an economy that results in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities*". The United Nations Economic and Social Commission for Asia and the Pacific (ESCAP) further describes a green economy as one that emphasizes "*environmentally sustainable economic progress to foster low-carbon, socially inclusive development*". From these definitions it is evident that the relationship between the concept of a green economy and sustainable development lies in that a 'green economy' is a tool that can be utilized to assist and support sustainable development and poverty eradication efforts (UNECE & UNEP, 2011).

Since the introduction of the concept of a 'green economy', the demand for a 'green transition' is increasing. UNEP (2011b) and Musango et al. (2014a) demonstrate that the transition towards a green economy need not dampen economic activity and growth. UNEP (2011b) stresses three key enabling conditions that will support the transition towards a green economy: (i) deploying public and private investment in areas that are key towards transitioning to a green economy, (ii) sustainable forestry and ecological friendly farming, and (iii) providing guidance on policies to achieve the shift towards a green economy. The successful, sustainable transition towards a green economy thus demands a shift in socio-technical systems to arrive at a (not so distant) future state that allows for a sustainable approach to resource utilisation and ensures intergenerational justice (Markard et al., 2012).

Within South Africa, the government is increasingly recognizing the need to transition towards a green economy (DEA and UNEP, 2013; Musango et al., 2014a). Since the first Green Economy Summit that took place in South Africa in 2010[1], a number of initiatives relating to the green economy have emerged throughout the country at national, provincial and local governments. The drivers to a green economy transition include among others: (i) the need to move towards low carbon economies due to global climate change; (ii) increasing scarcity of material resources; (iii) rising awareness and threats of peak oil, food, water and financial crises; (iv) intergenerational justice; and (v) vulnerability of the economy to these factors (Lorek and Spangenberg, 2014).

An emerging literature is investigating various aspects of green economy transitioning. For instance, Law et al. (2015) developed a framework for assessing green economy transition in tourism destination, with specific focus in Bali, Indonesia. Doval and Negulescu (2014) utilized a survey to establish a model on the implications of green investments particularly for businesses in Romania. The key implications that they found were: (i) the formation of a new market; (ii) stability of small-medium enterprises; (iii) development of new polices targeting low carbon transition in order to maximise the value of green investments. The study by Musango et al. (2014a) is noteworthy in that it was the first in South Africa to develop an integrated system dynamics model to examine the transition to a green economy. They showed that green economy interventions could result in a low carbon transition, utilize resources efficiently and create additional jobs without necessarily slowing the economy. In addition, Musango et al. (2014b) specifically examined the green economy transition of the electricity sector in South Africa based on the South Africa green economy model. However, the limitation of the studies of Musango et al. (2014a; 2014b) is that the analyses were undertaken at a national level; yet, many of the green economy investment interventions are taking place at provincial and local government levels. Further, the provincial and local governments decision-makers are interested in understanding how much investments would be required to reach their planned targets, or whether their planned investments would achieve their planned targets, similar to the GETS scenario in Musango et al. (2014a).

This paper thus follows a similar conceptual framework utilized for the South Africa Green Economy Model (SAGEM) that was developed (Musango et al., 2014) to investigate the implications of green economy investments in the Western Cape Province of South Africa.

2 Description of the case study: Western Cape Province

The Western Cape Province is the fourth largest of the nine provinces in South Africa, both in terms of area and population. It covers an area of 129 370 km^2 and is home to approximately 6.1 million people (STATS SA, 2014).

The central emphasis of the transition to a Green Economy in the Western Cape Province primarily arises from the national policy response to the National Climate Change Response White Paper (DEA, 2011). The strategic priorities outlined in this document provide the direction of action and responsibility for the different levels of government. Section 10.2.6 of the National Climate Change Response states that: "*Each province will develop a climate response strategy, which evaluates provincial climate risks and impacts and seeks to give effect to the National Climate Change Response Policy at provincial level*" (DEA, 2011). In

[1] http://www.environment.gov.za/sites/default/files/docs/greene_conomy_summit.pdf.

response to this, the Provincial Government created the Western Cape Green Economy Strategy Framework with growth in green investments and market opportunities at the core of the strategic framework (Western Cape Government, 2013). According to the Strategy, the Western Cape Province aims at positioning itself as the lowest carbon province in South Africa and the leading green economic hub of the African continent. Five drivers that are identified for transitioning to a green economy are as follows (Western Cape Government, 2013):

- Smart living and working: Creating opportunities through less resource intensive living and working environments and consumption patterns.
- Smart mobility: Investment, job and enterprise opportunities created through reduced resource intensity of mobility and smarter mobility systems.
- Smart ecosystem: Enhanced water and biodiversity preservation, and expanded infrastructure, tourism, livelihood and job opportunities created through better managed ecosystems
- Smart agriproduction: Livelihood and market opportunities created through enhancing the competitiveness and resilience of our agricultural and food economies
- Smart enterprise: Investment, business and job opportunities created by establishing the Western Cape as a globally recognised centre of green living, working, creativity, business and investment.

Whilst the strategy is an attractive mode for transitioning, it remains the responsibility of the municipalities to plan and respond to climate change amidst the demanding challenges that they have to deal with. These challenges include, among others, limited skill development and capacity at a local level, persistent short-term needs diminishing already limited funds, and the inability to predict with any certitude the necessary adaptions for future conditions (South Africa LED Network, 2010). All of which form the setting of the emerging need to prepare municipalities towards a green economic transition, which is evidently a great challenge.

Informed by the strategy, this paper specifically focuses on water, agriculture, transport infrastructure, renewable energies, energy production, CO_2 emissions, and public services as a starting point for investigation.

3 Methodology

Most of the problems that are currently faced such as the depletion of natural resources and global climate change result from unintended consequences of past actions or interventions. Similarly, policies and strategies that are undertaken to solve these problems may fail of even pave the way of other problems. Effective decision-making thus requires a systems thinking approach that can be able to account the dynamic complexity of the problems been faced. The need for green economy transitioning is not an exception as it arises due to the recognition of a global polycrisis (Swilling and Annecke, 2012; Lorek and Spangenberg, 2014).

System dynamics is an integrated modelling approach that enables the understanding of complex real world problems over time in order to guide decision-making for achieving sustainable long-term solutions. Jay Forester developed system dynamics in the 1950's where he first applied it to analyze industrial business cycles (Forrester, 1961). Since then, it has been applied to address problems from various fields of studies relating to economy, society and environment. For instance, in his book, Ford (2010) illustrates cases for the application of system dynamics in modeling environmental issues. Forrester (1969) and Forrester (1971) applied it in analyzing socio-economic dynamics. Several authors have utilized it in sustainability issues including among others: water resource management (Winz et al., 2009), energy planning (Naill, 1992, Qudrat-Ullah, 2013); urban planning (Fong et al., 2009); and climate change mitigation (Bassi and Baer, 2009). It is also being utilised to investigate issues relating to a green economy transition (UNEP, 2011; Musango et al., 2014a; Musango et al., 2014b).

System dynamics makes use of four basic building blocks, namely: stocks, flows, auxiliaries and constants (Sterman, 2000; Musango et al., 2014b). Using these basic building blocks, it is possible to capture the dynamic complexity and represent different viewpoints. This is very relevant when it comes to green economy issues that require accounting for economy, society and environment sub-systems. Further, it is possible to develop scenarios in order to test the implications of green economy interventions.

4 Model description

This section outlines the structure of the model that was developed to examine the implications of a green economy transition in the Western Cape Province of South Africa. The integration of the concept of a green economy transition into a formal model calls for the amalgamation of economic and physical dimensions of the social, economic and environmental systems being analyzed. This analysis occurs across the different sectors of the province, following the dynamic nature of the green economy concept.

4.1 Model boundary

The key variables that were considered essential in catalysing the green economy transition in the Western Cape Province of South Africa were calculated endogenously in the model. An array of stocks, flows and variables, among which, are the variables of the prioritized areas of interest based on the research aim and problem definition. These include aspects such as: Water Conservation, Sustainable Agriculture, Sustainable and Efficient Transport Infrastructure, Renewable energies, Energy Production, CO_2 emissions, and Sustainable Public Services. Broadly these focus areas can be categorized into the three development spheres of sustainable development (see

Table 1), which aim to incorporate and define the model boundary in terms of where the sub-models fit within a green economy shift. The key variables in each sub-model were used as indicators for analyzing the model transition to a green economy within the Western Cape Province.

Table 1: Modules and development spheres for the Western Cape Green Economy

Society Sphere	Environment Sphere	Economy Sphere
Population 1. Population	**Land** 8. Provincial Land 9. Agricultural Land	**Production** 21. GDP 22. Agricultural yield 23. Agricultural Production
Education Sector 2. Education	**Water** 10. Water Demand	
Health Sector 3. Healthcare	**Emissions** 11. Emissions (Agriculture) 12. Emissions	
Employment 4. Employment	**Energy** 13. Fuel Demand 14. Electricity Demand 15. Nuclear Power 16. Pumped Storage Power 17. Solar PV power 18. Wind Power 19. Gas Power 20. Modal Energy Split	
Public infrastructure 5. Transport 6. Live Vehicles 7. Road Infrastructure		

4.2 Aggregate causal loop diagram

Figure 1 shows an aggregate causal loop diagram (CLD) to describe the relationship between the various aspects of a green economy that were investigated. The CLD gives a very brief overview of the model interactions, which were broken into a variety of specific and detailed sub-models.

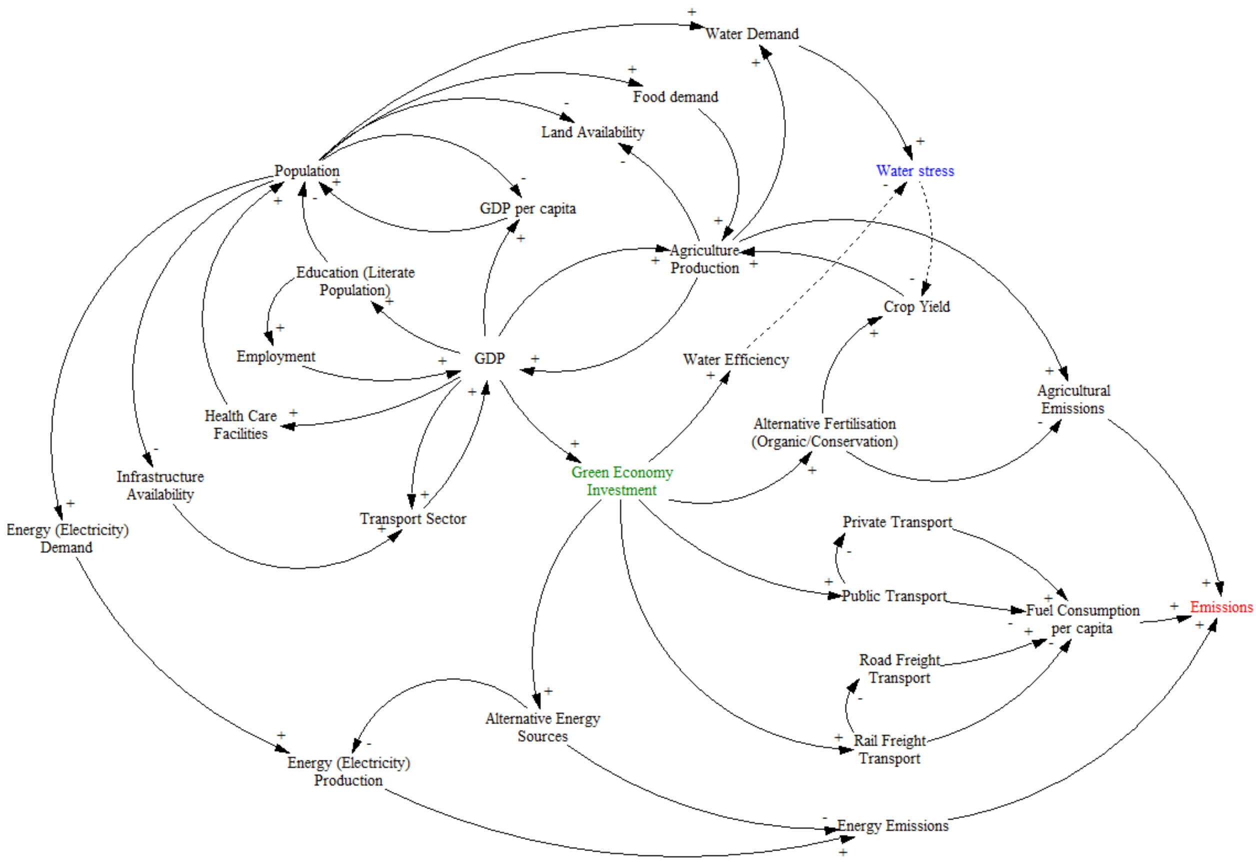


Figure 1: Aggregate causal loop diagram

In a broad sense the CLD indicates how an increase in population will increase water, food and electricity demand. An increase in population will also decrease land availability, GDP per capita, and infrastructure availability. The increase in water demand will increase the water stress indicator, which directly influences the agricultural crop yield and agricultural production. Food demand influences agricultural production, while an increase in agricultural production is likely to cause a decrease in land availability. Agricultural production will improve the GDP, which will in turn make more funds available to invest in education, contributing to better employment rates and once again influencing the GDP positively. A larger GDP will ensure that there is sufficient growth in the transport sector and health care facilities. A growing transport sector will positively contribute to the GDP while healthcare facilities will reduce mortality rates in the population.

Depending on the green economy (GE) investment strategy, a larger GDP is likely to lead to growth in the green economy investment scenario, which will increase water efficiency and lead to a reduction in the water stress indicator. The GE investment will also encourage the use of alternative fertilization techniques that can better the crop yield to increase agricultural production and lower the agricultural emissions. The GE investment will focus on shifting from road to rail freight and from private to public transport, which will decrease the fuel consumption per capita and lead to lower emissions in the transport sector. The use of alternative fuel and energy supplies will also be supported by GE investment and will decrease emissions from the energy sector.

4.3 *Model settings*

The model simulates a 40-year period, equating to a time horizon of 2001 to 2040. The model was simulated using the time unit of years. The Euler method was selected for numerical integration purposes: the level of data uncertainty, speed requirements and lack of specificity-requirements warranted selecting Euler over Runge-Kutta. The model was constructed and simulated using Vensim DSS (Ventana Systems, 2013).

4.4 *Sub-models*

This section describes the simulation model by introducing the sub-models that were developed. The model consists of 23 sub-models. These key sub-models are described in the sections that follows, surfacing the assumptions (and some of the limitations) associated with each part the sub-model.

4.4.1 Population sub-model

The population sub-model represents the population of the Western Cape Province. The population is categoris`d according to sex (male and female) and age groups. The sub model is used to estimate the population through the influence of dynamic factors such as fertility rate, net migration, and death rate. Fertility rate influences births, which increases population. Fertility rate is dependent on the effects of economic conditions and contraceptive prevalence (affected by literacy rate) in the province. Births are dependent on the total fertility rate, sexually active female population, and the childbearing age specific fertility rate. Childbearing age was defined as being between age 15 and 49. The population also increases through net migration, which is dependent on the Western Cape population itself and a migration rate. Deaths however decrease the Western Cape population. Deaths are influenced by the life expectancy of the residents of the province. Life expectancy is affected by income per capita and how that influences normal life expectancy.

Population itself also affects are factors in other sub-models. For example the age groups determine the amount of students in school and the adult literate population. If the population increases and access to education remains constant, then the average adult literacy rate of the population will decrease. This will result in a decrease in contraceptive use in the province and result in more births, which then in turn increases the population.

4.4.2 GDP sub-model

The GDP sub-model estimates and tracks the growth in the provincial GDP over time. Due to a lack in data and model outputs the GDP uses the baseline GDP of South Africa as determined in SAGEM and is factored down and calibrated to fit the existing GDP recordings. Whilst this may be considered a crude form of modeling, the variables used from this sub-model are predominantly exogenous, thus making the sub-model in its entirety somewhat exogenous as well. The major variables considered in this module are those of Relative Real GDP and the Relative Real GDP per capita, both used as growth factors in other sub-models.

4.4.3 Education sub-model

The education sub-model is based on the South African educational system, which stipulates that a pupil can be classified as literate after a minimum of seven years of education. The system further makes education compulsory up until grade 9, indicating that everyone will have a minimum of nine years General Education and Training (GET). As part of the GET and Adult Basic Education and Training (ABET) everyone should have basic reading and numeracy skills by the age of 15 and would then be considered literate. The reality is however that not all children in the school going age (generally considered to be 6 to 14 years of age) attend school, due to financial constraints and a lack of space in the school system capacity caused by under investment.

The education sub-model considers factors influencing the school entrance rate, like willingness to go to school, population in school going age and available school capacity. The model then simulates dropout rate and grade 9 completion rate based on historic data and average time taken to complete a grade and education expenditure. The model uses the population sub-model to determine the literate young adult population and literate initial adult population, which is used to simulate the average adult literacy rate of the Western Cape. The average adult literacy rate influences a number of factors in various other models, like the use of contraceptives to influence birth rates, the awareness of water conservation to decrease water usage per capita and employment rates.

4.4.4 Health sub-model

The health sub-model for Western Cape healthcare facilities aims at representing the access to basic health care based on government expenditure. This sub-model provides variables indicating the access to basic health and follows the number of healthcare facilities in working order as the stock. Health care facilities were broken into three subscript levels with public hospitals (including national central, provincial tertiary, regional, district and specialized hospitals), primary healthcare facilities (including clinics/community health centers, satellites, and mobiles) and private registered hospitals.

The one stock – Western Cape healthcare facilities – is increased by health center construction and decreased by health center disruption, which is influenced by the average lifespan of the facility. The factors influencing the construction of new health centers is the capital health expenditure allocated from the provincial government and the associated construction costs based on past and current projects. The total health expenditure from provincial government budgets was correlated to information gathered from National Treasury Budget reports. The proportion of total capital expenditure spent on the construction of new health centers was derived from the annual infrastructure payments from the health budget. The two main variables existing as performance indicators are the number of population per health center and the access to basic health care based on the area covered by the different health centers relative to total land.

4.4.5 Employment sub-model

Employment is a measure of the amount of people actively participating in the economy. Unemployed people do not create or add to the economy, nor do they support economic activity by paying for goods or services. The model differentiates between three different streams of employment, each represented by a stock: agriculture, usual industry and usual services. The stocks are each influenced by their respective net industry-hiring rate. The rate of hiring/firing in each respective industry is determined by the capital investment in each sector. Finally, the total employment in the Western Cape economy is estimated.

4.4.6 Road infrastructure sub-model

The road infrastructure sub-model aims to estimate the access to road infrastructure in terms of relative kilometers of functioning roads per hectare of land translating to the accessibility of road infrastructure. The sub-model consists of three stock; the first two being roads under construction and functioning roads, systematically illustrating the dynamics that exist in road infrastructure development. The major variable affecting the flow of starting to construct a road is the Budget attributed to road infrastructure and the average construction cost per kilometre of road. The third stock tracks the change in costs road maintenance per kilometre over time; this has a direct influence on road maintenance costs which then draws the required government expenditure on road infrastructure.

Starting construction increases the stock of roads under construction, once completed it moves to the stock of functioning roads where road depreciation and disruption occurs thus decreasing the stock over time. Road maintenance decreases the disruption to the roads by increase the average road life, however increases in heavy vehicle haulage over a certain amount decreases the average life. The relative kilometers of roads act as a measure of road access and are used in the greater transport sub-model.

4.4.7 Live vehicles sub-model

The live-vehicles sub-model aims at tracking the amount of live vehicles on the roads in the Western Cape each year. The total amount of live vehicles is sectioned into the subscripts: motorcars and motorcycles, mini-busses, busses, light duty vehicles and light load vehicles, trucks, and other vehicles. The sub-model consists of one stock, motor vehicles, which is increased by vehicles sales and decreased by vehicle disposal. Vehicle sales are derived from the desired vehicles relating to the population and desired vehicle ownership, which is influenced by GDP. On the other hand, the average vehicle life spans are different for the different vehicle sub-groups. The key variables utilized in the greater transport sub-model are the relative number of trucks on the road (relating to functioning road disruption), the total vehicle count for each year and the relative motor vehicles used as a growth factor.

4.4.8 Transport sub-model

The transport sub-model is used to estimate a number of variables ranging from the energy use for different transport sectors to the fuel demand and CO_2 emissions. The transport sub-model is categorized into three modes, namely: road, rail and air. These are further categorized based on whether the mode is dealing with the transportation of passengers or freight/goods/cargo commodities. The annual modal passenger travel distances are determined by the travel distances per vehicle type growing according to the relative kilometers of functioning roads and the relative real GDP. For private passenger trips and minibus taxis the live vehicle stock is used as the multiplying factor, yet for the other modes different population factors are used in conjunction with the average capacity of the vehicles to determine the passenger travel distances. The annual road freight haulage is determined in a similar manner, using the live vehicle stock for heavy vehicles and the average load for road freight haulers.

The rail sector for both passenger and freight modes are dependent mainly on the relative GDP and calibrated to fit collected annual data with the use of elasticity factors. The annual passengers carried by rail are also linked to the relative growth of the population and for the energy consumption was considered to be 100% electricity dependent as the majority of the cape Metrorail line is electrified. Similarly, air transport of both goods and passengers are determined by growing factors of relative population and GDP with elasticity factors to calibrate the output. The volumes of passengers and goods handled along with the distances they are transported are used to determine the energy use for the different transport modes as well as the resulting CO_2 emissions each year.

4.4.9 Land sub-model

The land sub-model represents the land use of the Western Cape Province. The model consists out of two models in total, namely provincial land and agricultural land. The provincial land model includes settlement land, invasive alien species land, livestock land, conservation land, agriculture land, and other land. Due to irrigation and rain restrictions only 19% of the Western Cape's total land is cultivatable; therefore agriculture land ("Land available for agricultural use") is limited to no more than 19% of total land for this model.

The agriculture land sub-model consist out of land used in the agricultural sector for; conventional, conservation, organic farming. It is assumed for this model that land for conservation and organic use can only be converted from conventional land. It is also assumed that conservation and organic land will never degrade back to conventional land once the decisions has been made to increase either one those two practices.

4.4.10 Water demand sub-model

The water sub-model is primarily used to estimate the water stress index, which has an influence on the production sectors. To estimate the water stress index the yearly available water supply and demand is required. The available water supply is calculated by taking precipitation, cross border inflows and water gains from restoration into account. In the case of the total water demand the domestic, municipal and production sectors are considered. The domestic and municipal water demand depends on per capita water demand, which in turn is affected by the education and wealth of the user. Production water demand is mainly dependent on the GDP of the Western Cape.

4.4.11 Energy sub-model

The energy sector looks exclusively at electricity and ignores other forms of energy that are not used for generating electricity. The electricity sector is categorized into electricity demand and electricity supply. Electricity supply consists of the different methods of generating electricity in the Western Cape Province namely, nuclear, pumped storage, natural gas, wind, and solar, and also electricity generation technology share. The aforementioned technologies are considered to be the most suitable for implementation in the province. Electricity generation from coal is not included, as no coal-fired power stations are in operation in the province and there are no future plans to add any coal-based power stations. Wind energy and solar energy are the only generation technologies seen as renewable energy technologies in this model. Electricity demand is calculated using the total provincial electricity consumption and the generation, transmission and distribution losses, giving a total electricity demand.

In reality, the electricity grids of the different South African provinces cannot be separated, as they are all part of one large national grid. Electricity produced by power stations in one province can be used by consumers in any other province, and the electricity demand in a province can be supplied by a combination of power stations in the other provinces. For the purpose of analyzing the Western Cape Province in isolation, the province is seen as having its own electricity grid. All the electricity that is generated by power stations within the province is assumed to supply only the demand of the province. If the province's electricity demand exceeds the supply, the needed electricity is imported from outside the province. This situation is normally the case, with the majority of South Africa's base load generating capacity situated outside the Western Cape.

The electricity generation technology share module estimates the proportion in which each technology contributes to the total electricity supply. Electricity demand is calculated by adjusting demand according to changes in GDP, population, green investment in energy efficiency, and electricity price. Electricity price is seen as an exogenous variable. This assumption is reasonable because the province has no control over the price of electricity. In South Africa, the electricity price is regulated by the National Energy Regulator of South Africa (NERSA).

4.4.12 Emissions sub-model

The air emissions module estimates CO_2 emissions from the different sectors. These sectors are categorized as emissions from electricity and non-electricity industry. The electricity sector includes emissions from coal, nuclear, pumped storage, hydropower and renewable resources. The non-electricity sector comprises of transport, agriculture, residential and industry CO_2 emissions. A Western Cape Scaling Factor is used where no data for the province has been collected previously. Therefore the South African data is scaled to fit the Western Cape profile. The annual CO_2 emission is endogenously determined in the modeling.

4.4.13 Agriculture yield sub-model

Agricultural yield is influenced by multiple factors such as agriculture capital and water stress levels in the province. The agriculture yield for each crop type is further affect by conventional, conservation, and organic farming practices. Organic farming has less CO_2 emissions per hectare than conventional farming, but yields also tend to be less than that of conventional farming.

4.4.14 Agriculture production sub-model

The agricultural production sub-model mainly focuses on food crops. The food crop considered were broken up in three main categories, namely: fruit, gain, and vegetables.

Table 2 lists the elements of each one of these three categories as well as the different farming practices that can be applied to each category. Conservation farming practices are not applicable to fruit farming, therefore any conservation land that is allocated to fruit will be regarded as conventional land and yield. Due to a lack of technology and significant capital investment, conservation farming is also not considered for vegetable farming.

Table 2: Food crop categories for agriculture production

Food crop category	Elements	Farming practises
Fruit	• Citrus • Apples • Wine and table grapes • Stone fruit • Pears • Other fruit	• Conventional • Organic
Grain	• Wheat • Canola • Other grains	• Conventional • Conservation • Organic
Vegetables	• Potatoes • Onions • Other vegetables	• Conventional • Organic

The land required of each type of food crop can be determined by using the average yield per hectare and population requirements of the Western Cape. For example, if the yield per hectare for apples increases and the population stays the same, then less area is required for apple production. Another example is when wheat yield per hectare decreases (due to water stress) then more area is required to provide wheat to the current population.

4.5 *Model verification and validation*

Model verification and validation is integral part of system dynamics modeling. Model verification entails checking and testing (i) dimensional consistency; (ii) sub-models and structures; (iii) appropriateness of combination of numeric integration method and step size; and (iv) all equations and inputs for errors (Pruyt, 2013). The developed model was verified using the System Dynamics Model Documentation and Assessment Tool (Martinez-Moyano, 2012).

On the other hand, validation corresponds to establishing confidence in the purpose and usability of the model (Barlas, 1996; Pruyt, 2013). There is no single test for validation and these can be categorized into: (i) direct structure tests; (ii) structure-oriented behavior tests; and (iii) behavior reproduction tests (Barlas, 1996; Pruyt, 2013). There is currently no historical data for the green economy intervention sectors that is available to properly utilize the behavior reproduction tests for most of the model variables. This was limited to some variables such as population and gross domestic production. Much of the validation done was mainly the direct structure tests and structure oriented behavior tests. It is expected that the model will be further subjected to expert opinion before undertaking scenario analyses.

5 Preliminary baseline results

For the purpose of this article only the business as usual (BAU) scenario is executed. The green economy investment (GEI) scenario analysis will only be executed once validation with experts has been undertaken and suggestions on plausible or planned scenarios and targets are established. The BAU scenario can be described as continuing with current practices and regulations until 2040.

BAU sets the baseline for the whole model and estimates how the Western Cape is functioning across all sectors until 2040. The estimated results can then be compared to historical data in order to validate the models behavior and accuracy. The BAU scenario can also be compared with the GEI scenario in the future. This allows green economy investments to be evaluated against current practices and can also be presented graphically.

Figure 2 illustrates the results that were obtained for the Western Cape's population. The population grows from 4.5 million in 2001 to 7.8 million in 2040. When the estimated population is compared with historical data, it is noted that the estimated graph follows the historical data within an acceptable level. The average life expectancy also increases from 53 years (in 2001) to 67 years (in 2040). With regards to education, total school students increases which is expected since the total population also increases over the same time period. The relative adult literacy rate increased and decreased back to 1 over the course of the simulation. This might be due to the population size increasing too fast for the education system as time progresses. This might also be due a lack of government investment to increases capacity for new students as population increases.

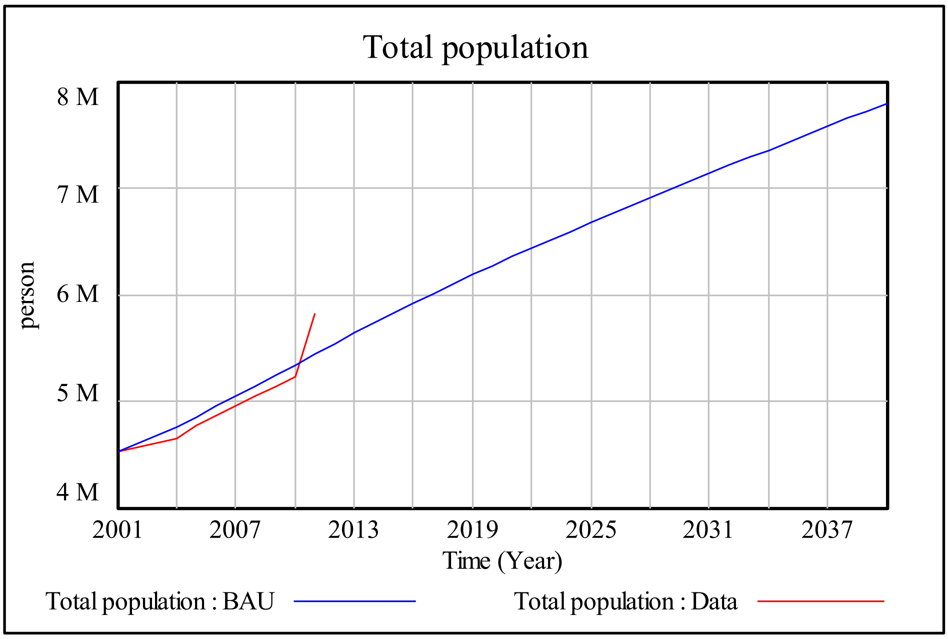


Figure 2: Population for BAU

The GDP per capita increases from R41 640.00 to R65 670.00 per person over the simulation period. The GDP for the Western Cape also increases over this period. The GDP growth is illustrated in Figure 3. It follows historical data accurately and fluctuate around 1.85% growth from 2019 onwards.

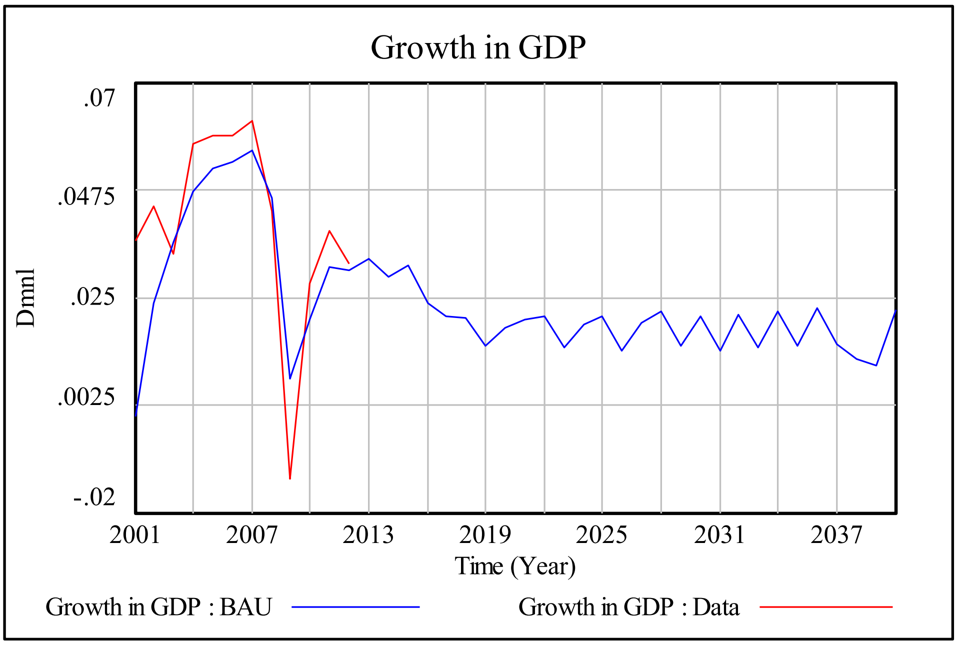
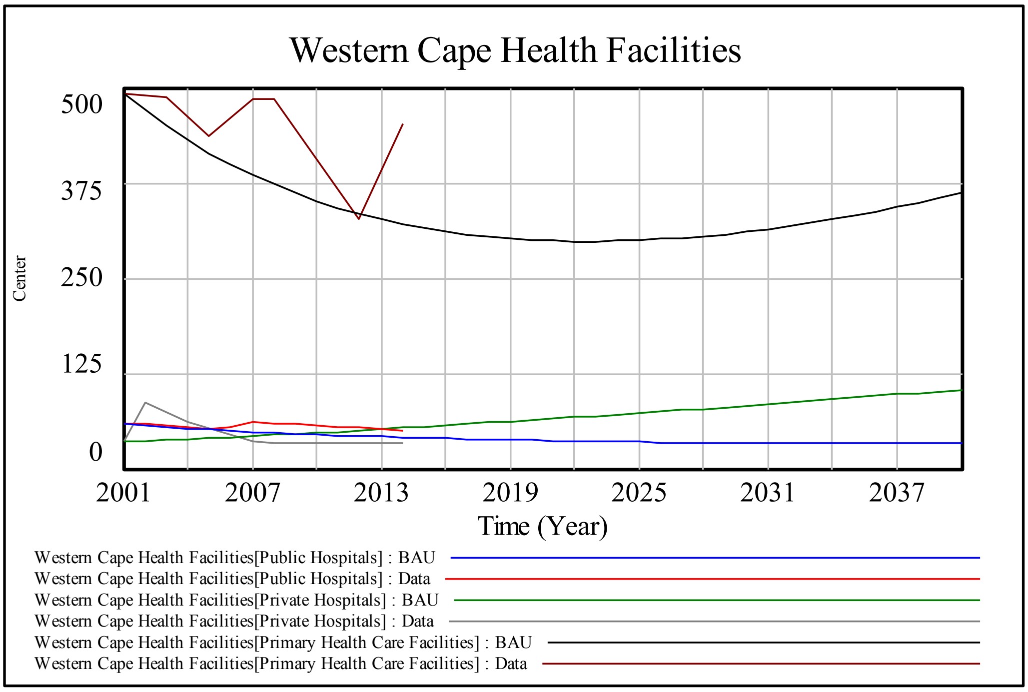
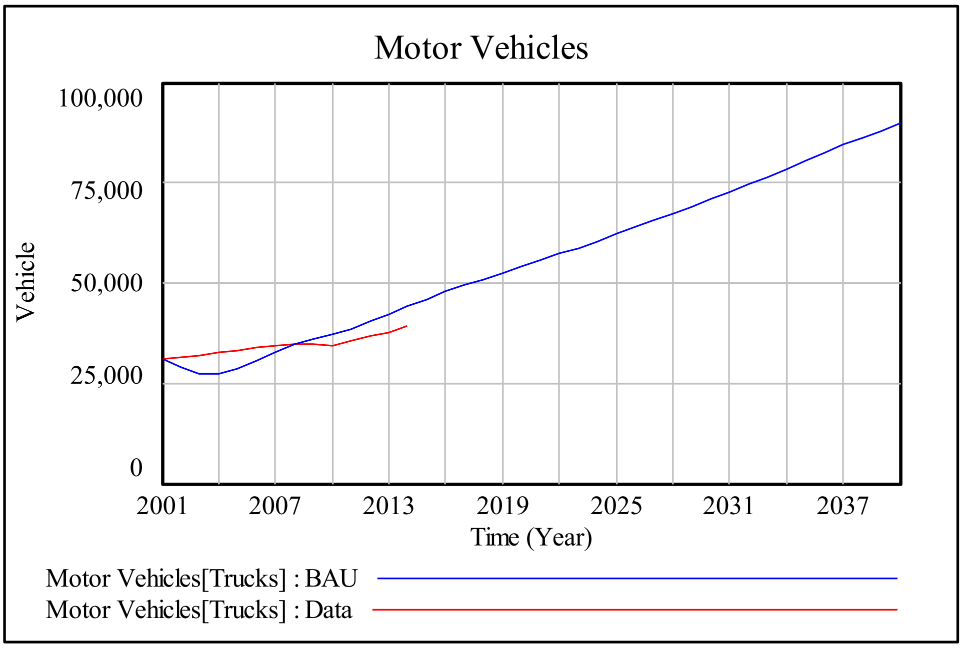


Figure 3: GDP growth for BAU

The results for the healthcare sector shows that the public health infrastructure (public hospitals, clinics, etc.) is decreasing over time. This is mostly due to the lack of government expenditure in the public healthcare sector. The private sector however shows an increase in private hospitals, which relates back to the increase in GDP and GDP per capita.



With regards to transport, road freight haulage increases sharply form 32.66 billion (in 2001) to 95.87 billion (in 2040) ton-km per year. This is a result of rail freight only growing by a slow rate over the same period, so more goods need to be transported by road for the growing population. The total kilometres of functioning roads decease due to an increase in road freight haulage (as noted above) and due to more passenger vehicles being on roads (due to increased population). The road freight haulage is linked to the number of live trucks on the roads that are recorded annually, the dynamics for the live truck population occur within the Live Vehicles sub-model and show an accurate correlation to historical data.



Water stress in the Province increases, which is a result of water sources remaining constant whilst the population increases. This creates a scenario of low supply and high demand of water in the province. Electricity demand for the Western Cape is met by local electricity supply throughout the duration of the simulated period. It should be noted that the supply/demand ratio decreases over time.

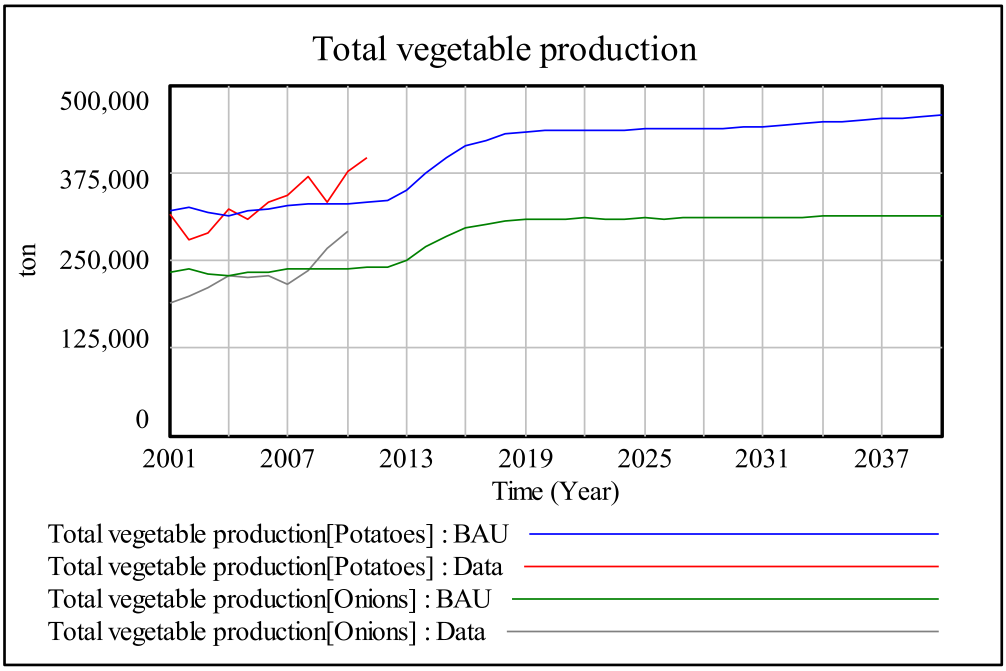


Figure 4: Vegetable production for BAU

Settlement land increases as population size increase, which is as expected. Agricultural land requirements however decrease for the food crops considered the simulation. This is result of an increase in yield per hectare over time due to more capital being invested into the agricultural sector. This increased capital investment also result in less labor employment in the agricultural sector. Food crop production is however not significantly affected and local and international demand is always met. Figure 4 illustrates the vegetable production form the BAU scenario as compared to historical data.

6 Conclusion

Globally, transitioning to a green economy is gaining relevance in both policy and academic domains. At the policy domain, green economy presents opportunity to not only the national government, but also to provincial and local governments. The Western Cape Province of South Africa identified smart living and working, smart mobility, smart ecosystem, smart agri-production and smart enterprise as the five key drivers for transitioning to green economy. In order to support and inform the implementation of these identified drivers, this paper developed a Western Cape Green Economy Model (WeCaGEM) to investigate the implications of green economy transition in the Western Cape Province of South Africa.

The model consists of 23 sub-models, with specific focus on Western Cape green economy efforts in water conservation, sustainable agriculture, sustainable and efficient transport infrastructure, renewable energies, energy production, CO_2 emissions, and sustainable public services. Preliminary business as usual scenario was executed with the aim of validating the simulated results with the historical data for some specific variables. Further validation with the experts will be undertaken, and plausible or planned scenarios will be established in order to analyze the green economy investment scenarios.

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