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

Lize Duminy
Masters Student, Department of Industrial Engineering, Stellenbosch University
Private Bag X1, Matieland, 7602, South Africa
15805875@sun.ac.za

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.

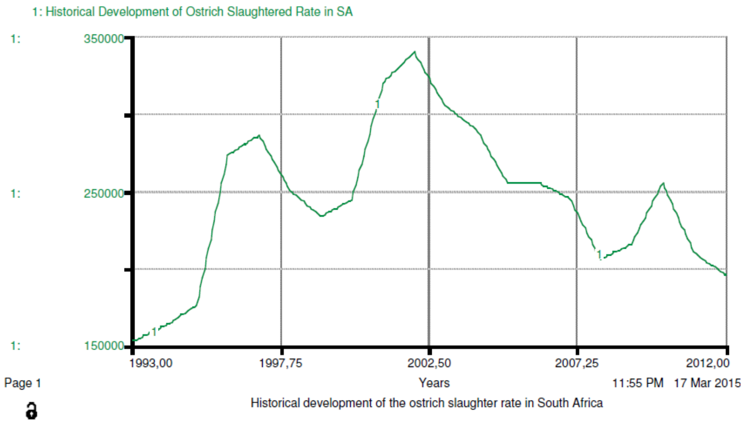

Figure 1: Historical development of ostrich slaughter rate in South Africa

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.

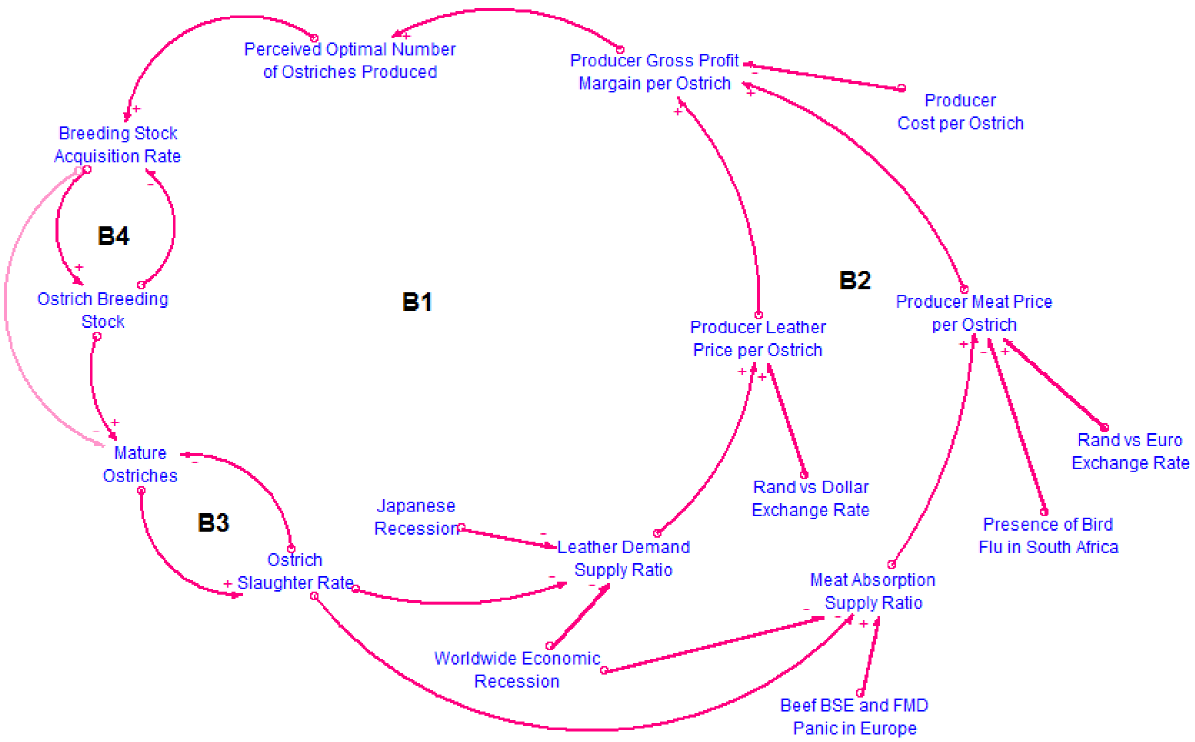

Figure 2: Aggregate causal loop diagram of system

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.

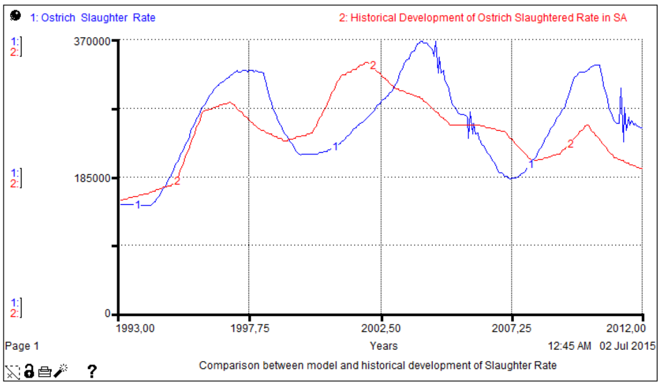

Figure 3: Simulated and historical data of the ostrich slaughter rate

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.

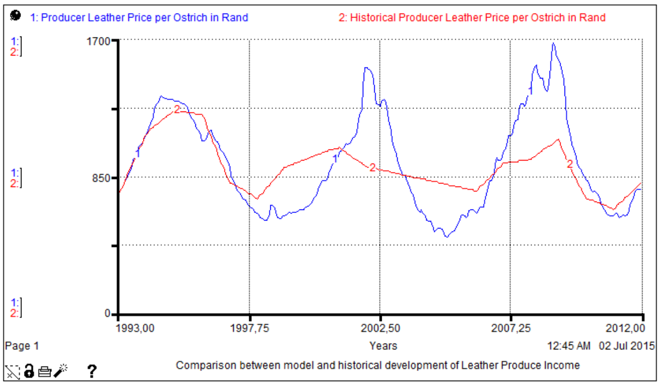

Figure 4: Simulated and historical data of the producer leather price

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.

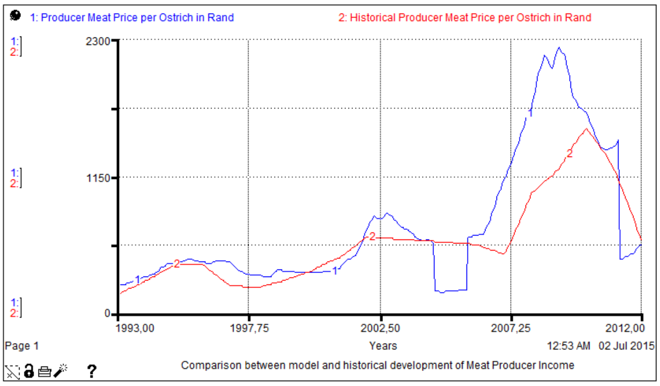

Figure 5: Simulated and historical data of the total producer meat price

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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