Identifying the significance of a Foot and Mouth Disease outbreak on the South African beef industry

by

Paige Carmen Bowen

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Declaration

I, Paige Carmen Bowen, declare that the dissertation, which I hereby submit for the degree MSc Agricultural Economics at the University of Pretoria, is my own work and has not been submitted for a degree at this or any other tertiary institution.

______________________	November 2023
Signature	Date

Acknowledgements

Getting to this point in my studies has been a rollercoaster ride. There are so many moments that come to mind when I think back over the years I have spent proudly calling myself a student. As I write this, it’s crazy to think it’s all finally ending. Nobody ever tells you that one of the toughest things about finishing your masters is writing the acknowledgements section. Where should I start? There have been so many people who have helped me along the way, giving me guidance and support and encouraging me to keep pushing through – too many to name; I am truly grateful to each and every one of you.

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Degree: MSc Agric Agricultural Economics

Department: Agricultural Economics, Extension and Rural Development

Internal supervisor: Dr Danie Jordaan

External Supervisor: Dr Tracy Davids[1]

Abstract

Foot and Mouth Disease (FMD) is a highly contagious viral disease endemic to South Africa (SA). As accepted by the World Organisation for Animal Health (OIE), South African had an FMD-free zone where vaccination was not practised, until an outbreak in January 2019, leading to the shutdown of SA's beef exports. While bilateral agreements were made between certain of SA's trading partners, the outbreak of FMD was generally regarded by industry role players as having a considerable impact on the beef industry of South Africa; however, the extent of this impact was not quantified. This study aims to quantify the impact that an FMD outbreak has on the average beef carcass price in SA.

1 Dr Tracy Davids heads up the Commodity Markets and Foresight Division at the Bureau of Food and Agricultural Policy (BFAP) in South Africa.

By making use of SA's volume of beef exported as a proxy to indicate FMD (given that an FMD disease outbreak prevents the export of beef unless bilateral agreements are made between specific trading partners), ordinary least squares (OLS) regression indicated that exports do have a statistically significant impact on the average beef carcass price in SA. However, diagnostic testing on the results showed that the model contained defects and, therefore, was unsuitable for hypothesis testing.

On this basis, while the study supported the need to quantify the impact of FMD outbreaks on the South African beef industry, it is recommended that further research is needed, especially noting the structural shift created by the outbreak, as the country's FMD-free-zone status is yet to be reinstated at the time of writing this study.

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List of Acronyms

ADF	Augmented Dickey-Fuller
AR	Autoregressive
BFAP	Bureau for Food and Agricultural Policy
BSE	Bovine spongiform encephalopathy
COVID-19	Corona Virus Disease of 2019
DAFF	Department of Agriculture, Forestry and Fisheries
DAG	Directed Acyclic Graph
DALRRD	Department of Agriculture, Land Reform and Rural Development
ECM	Error Correction Model
FAO	Food and Agriculture Organization of the United Nations
FIFA	Federation Internationale de Football Association
FMD	Foot and mouth disease
GDP	Gross Domestic Product
GVA	Gross Value Added
HPAI	Highly Pathogenic Avian Influenza
IHS	Information Handling Services
LHS	Left hand side
NBCIS	National Beef Cattle Improvement Scheme
NDA	National Department of Agriculture
OIE	Office International des Epizooties [World Organisation for Animal Health]
OLS	Ordinary Least Squares
PP	Phillips Perron

RESET	Regression specification error test
RIC	Refinitiv Identification Code
RHS	Right hand side
RMAA	Red Meat Abattoirs Association
RMLA	Red Meat Levy Admin
RPO	Red Meat Producers’ Organisation
SA	South Africa
SAFEX	South African Futures Exchange
SARS	South African Revenue Services
US	United States
WHO	World Health Organization

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Chapter 1:
Introduction

1.1 Background

The agriculture industry is an important contributor to the growth of the South African economy, as is evident in the second-quarter Gross Domestic Product (GDP) statistics for 2023 (Stats SA, 2023). Agriculture, forestry and fisheries showed the highest quarter-on-quarter growth rate of 4.2%, contributing 0.1% to GDP growth that quarter. Within the agricultural industry, the gross value added (GVA) by animal products contributes, on average, 49% to the total value of agricultural production (Figure 1.1), while the slaughter of cattle contributes approximately 25% to the GVA of animal products (BFAP, 2020 and DAFF, 2022).

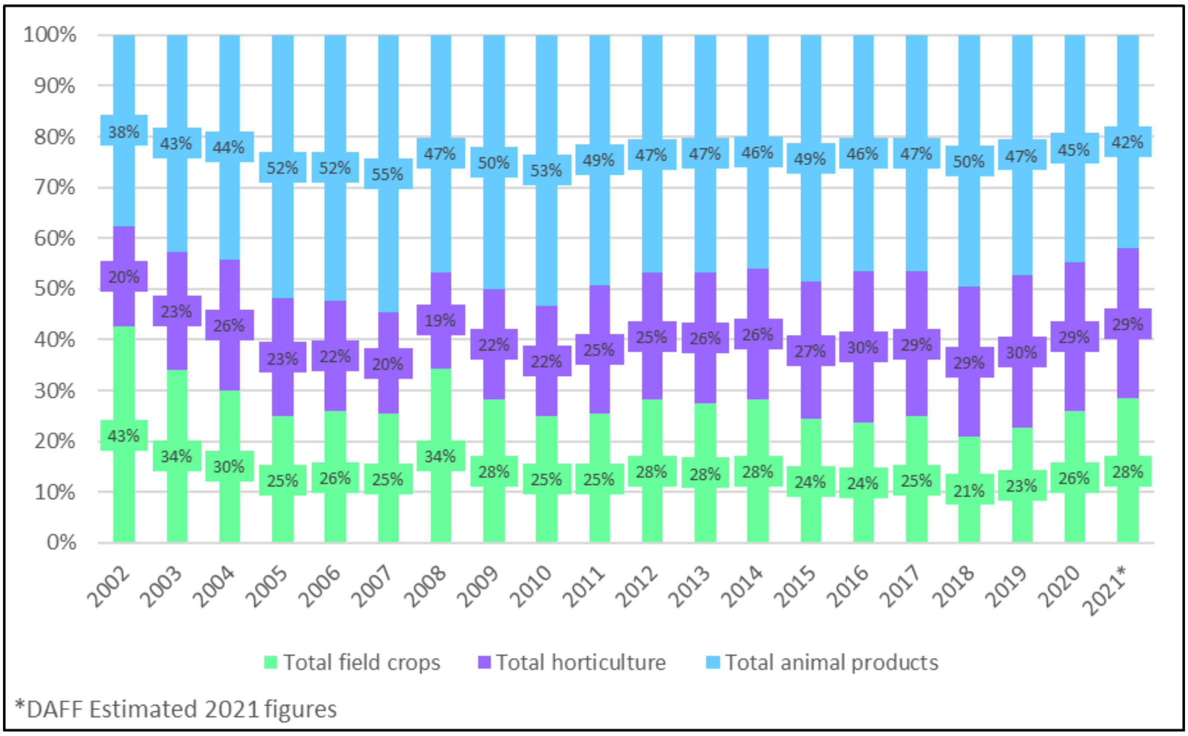

Figure 1.1 Gross value added per commodity type to the total value of agricultural production

Source: BFAP (2020) and DAFF (2022)

Meat is a large component of the diets of most South Africans (Claassens, 2017). Although poultry is the meat most consumed overall, beef is the most-consumed red meat, with its per capita consumption increasing from 12.69 kg/person/year in 2000 to 18.12 kg/person/year in 2020 (DALRRD, 2021: 58), with an expectation of further increases by 2029 (BFAP 2020). Over time, domestic production has increasingly fulfilled this higher domestic demand for beef as seen by the steady decline in imports of bovine meat (SARS, 2022). In the last fifteen years, there has been a rise in South Africa's meat exports, largely driven by the export of beef, which has made up an average of 45% of South Africa's total meat exports to the rest of the world since 2012 (Figure 1.2) (Easy Data by Quantec, 2021).

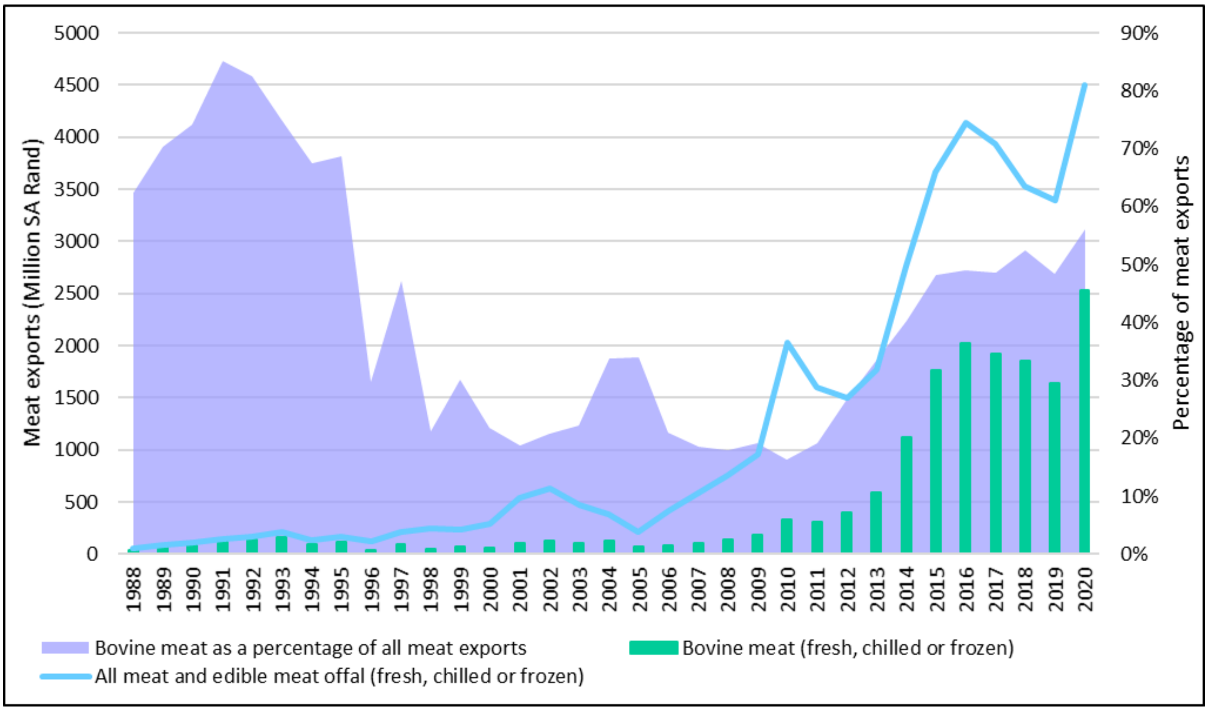

Figure 1.2 South African beef exports compared to total meat exports to the rest of the world (in a fresh chilled or frozen state)

Source: Easy Data by Quantec (2021)

The South African beef industry is dualistic in nature, with production systems ranging from a highly developed commercial sector to an emerging and subsistence sector (DAFF, 2019). A common farming method seen in developing countries such as South Africa and one of the world's oldest farming systems is communal livestock farming, generally practised by rural communities (Mmbengwa et al., 2015). While communal livestock farming is associated with improved household food security, communal farmers are at a higher risk of suffering harm from climatic conditions such as drought (Mmbengwa et al., 2015), as well as disease outbreaks attributable to the communal nature of the practice. Communal farmers may also sell their cattle at live auctions in order to earn an income – should these animals be infected, the disease could be spread to other farms including commercial farms.

One such disease is Foot and Mouth Disease (FMD), caused by the Aphthovirus, an organism of the family Picornaviridae (Brückner et al., 2003). The disease is highly contagious and affects cloven-hooved ruminants, such as cattle, sheep, goats and pigs, and can be spread through direct contact between animals and air-borne viral spores (OIE, 2021[a]; OIE, 2021[b]). In a diagnostic study conducted in north-western Tanzania, respondents noted that FMD spread in the area because of the "many cattle sharing communal grazing land and water points" as well as "the use of common routes by animals in search of water and pastures" (Rugalema and Mathieson, 2009). Characteristics of the disease include blister-like sores on the mouth, tongue, teats, and hooves; production losses such as weight loss, loss of appetite, drop in milk production and growth retardation; and death (OIE, 2021[a]). Considering the contagious nature of the disease and its impact on production, the Office International des Epizooties [World Organisation for Animal Health] (OIE) established an official recognition status that must be reported to the organisation. This status can be applied to a country as a whole or various zones within the country, as might be approved by the OIE, given that the country might prove it has the necessary controls and so maintain its FMD-free status.

FMD is endemic to South Africa, as it is carried by African buffalo (*Syncerus caffer*). In 2014, South Africa was recognised by the OIE as having an FMD-free zone where vaccination was not practised. The various zones, as accepted by the OIE, are mapped out in Figure 1.3. In terms of the Animal Diseases Act (1984), the northern borders of South Africa, including the Kruger National Park (KNP) and its surrounds, are considered to be FMD-controlled areas, broken up into various sub-zones, according to OIE code (Table 1.1). Strict movement control is applied to animals and their products in the controlled area using veterinary permits, tests and quarantines. Vaccination for FMD is only allowed in the protection zone, and any animal that has received the vaccination for FMD is restricted from entering the FMD-free zone (National Department of Agriculture, n.d.).

Table 1.1 Description of FMD control zones in South Africa

Zone name	Zone area	Control method
Infected zone	Spanning approximately 350 km long and 60-80 km wide, this zone is located in the north-eastern part of South African including the KNP	Regular game inspections with reports of any suspected cases of FMD submitted to the state veterinarian
Protection zone	Approximately 350 km long and 10–20 km wide, the protection zone borders the western and southern boundaries of the KNP	All cattle are vaccinated every 6 months, with a weekly veterinary inspection
Surveillance zone	Located to the west of the protection zone, this area is 350 km long and 10 km wide	Inspection of cattle is performed every 14 days. Vaccination is not permitted in this area
Remainder of control zone	Running along the northern borders of SA, and approximately 10 km wide	Cattle are inspected every 28 days

Sources: NDA (n.d.) and Sirdar et al. (2016)

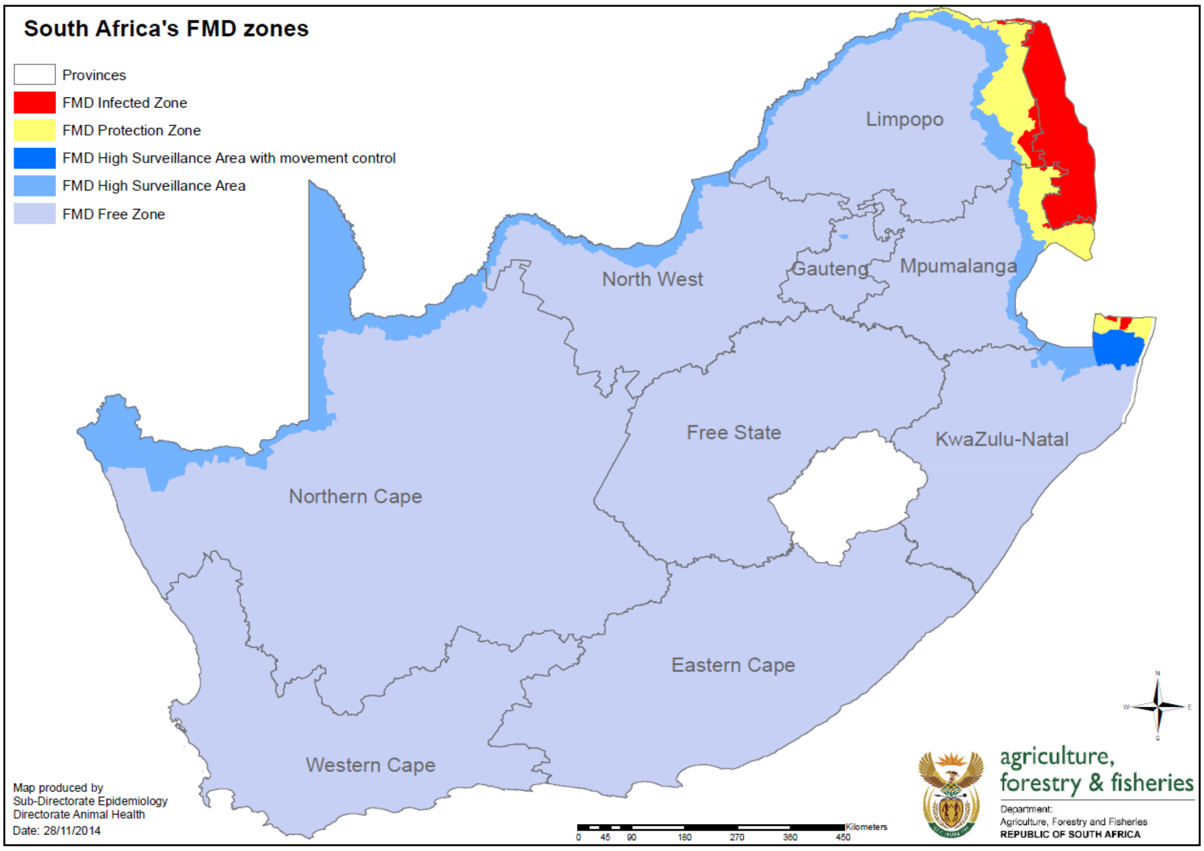

Figure 1.3 South Africa's FMD zones mapped

Source: DALRRD (2014)

On the 2nd of January 2019, it was confirmed that cattle in the Vhembe District of Limpopo were positive for FMD. As this area is within the zone classified as free from FMD, South Africa's FMD-free status was suspended by the OIE, which resulted in the shutdown of South Africa's beef exports. Over the next months, South Africa negotiated bilateral agreements with many trading partners, including Mozambique and China, to export safe meat and dairy commodities (Dairy Global, 2022). Furthermore, once an outbreak has occurred in a country that previously had FMD-free status, the costs involved in regaining that status might be enormous due to the costly control measures that need to be put in place and maintained (Knight-Jones and Rushton, 2013:161-173). By 2023, South Africa had not yet regained its FMD-free status.

1.2 Problem Statement

The immediate impact of the FMD outbreak was evident on domestic beef prices (Figure 1.4). In the week ending on Friday, 11 January 2019, the week during which the outbreak was confirmed, the live price for beef weaner calves plummeted by 15% compared with the prior week, while the carcass price for class A and class B grade beef both dropped by 2%. In the week following the outbreak announcement, the week ending Friday, 18 January 2019, class A and B grade beef carcass prices fell by a further 6% and 7%, respectively[2]. It took class A beef prices 29 weeks, while live prices of weaner calves took 43 weeks, to reach the same/similar price levels seen during the week prior to the outbreak announcement (Table 1.2).

Furthermore, Senzeni Zokwana, the South African Minister of Agriculture, Forestry and Fisheries, noted that the knock-on impact the outbreak had on trade was "devastating" within a week of losing the FMD-free zone accreditation (Mitchley, 2019). Role players in the South African beef industry have estimated the impact of the 2019 FMD outbreak to be as high as R10 billion with approximately 3000 tons/month of beef exports lost (Dean, 2019).

[2] Since 2000, the average price drop for weaner calves in the same week is 2%. While prices for class A and B beef drop on average 1-2% per week at the same time of year comparatively. This indicates that the price drop in 2019 is predominantly caused by the FMD outbreak.

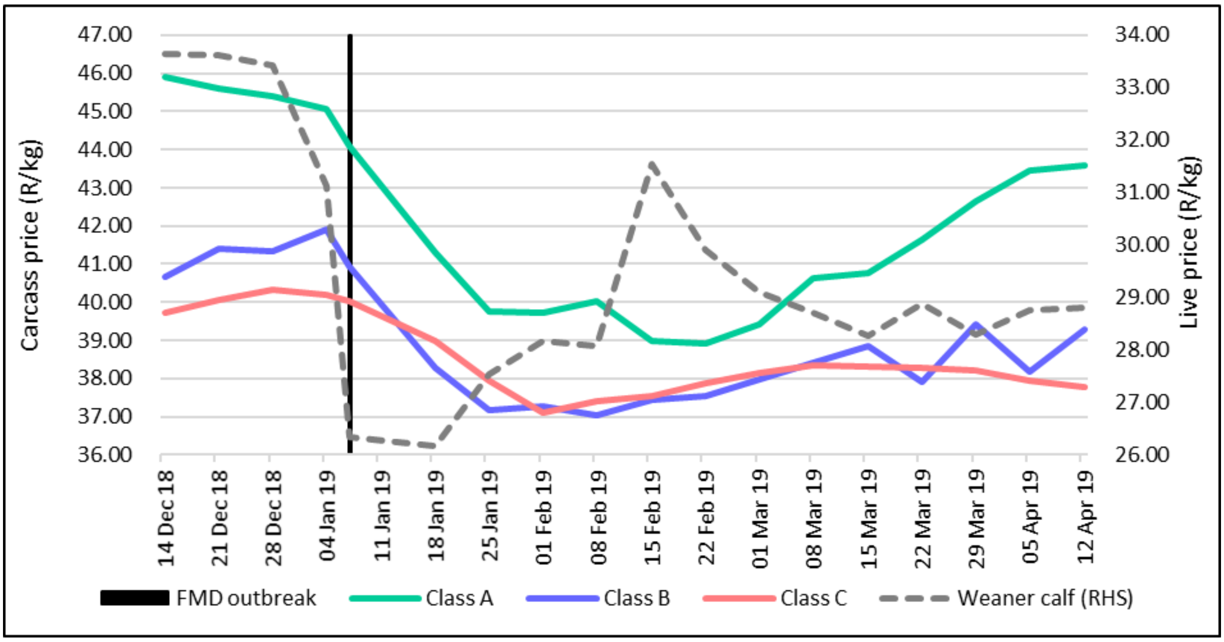

Figure 1.4 Weekly South African carcass price of beef grades (LHS) and live price of weaner calves (RHS)

Source: Absa Agribusiness (2022); RMAA (2022)

Table 1.2 Impact of South African FMD outbreak announcement on domestic beef carcass prices and live weaner calf prices

	Class A *Carcass Price (R/kg)*	**Class B** *Carcass Price (R/kg)*	**Class C** *Carcass Price (R/kg)*	**Weaner Calf** *Live Price (R/kg)*
Price week before outbreak announcement Week ending: 4 January 2019	45.08	41.91	40.19	31.13
FMD outbreak announcement (7 January 2019)				
Price week of outbreak announcement Week ending: 11 January 2019	44.08	40.93	40.04	26.34
Price week after outbreak announcement Week ending: 18 January 2019	41.31	38.27	38.97	26.17
Time taken for price to reach pre-outbreak levels				
Length of time (number of weeks)	29	47	58	43
Price reached	R45.08/kg Week ending: 26 July 2019	R41.17/kg Week ending: 22 November 2019	R40.19/kg Week ending: 7 February 2020	R30.02/kg Week ending: 25 October 2019

Source: Absa Agribusiness (2022); RMAA (2022)

The problem is that, although an outbreak of FMD is generally regarded as having a considerably negative impact on the South African beef industry by industry role players, the extent of this impact has not been quantified. The literature review of this study will show that, while many studies have been done to outline the control mechanisms of FMD in South Africa, such as quarantine and movement control of livestock, equipment and vehicles (OIE, 2021[a]), no studies have been conducted with the aim of quantifying the outbreak-specific impact on South African beef prices. Quantifying the impact would support the need for policy enhancements to control the spread of animal diseases.

1.3 Research Objectives

This study's main objective is to quantify the impact that an FMD outbreak would have on the average price of class A beef within the South African beef industry. To accomplish this overarching goal, the researcher outlined sub-goals that are more specific as part of the research approach:

1. To map the key activities in the beef value chain of South Africa;
2. To establish the extent and importance of exports in the South African beef industry;
3. To determine whether South Africa's beef export volumes have a statistically significant relationship to South Africa's average beef carcass prices, and could therefore be used as a proxy for an FMD outbreak; and
4. To quantify the impact of an FMD outbreak on the average beef carcass price within South Africa.

1.4 Hypotheses

As noted in Section 1.2, the general consensus of industry role players is that outbreaks of FMD have a high economic impact on the industry (Mitchley, 2019; Dean, 2019), while the OIE notes that FMD has a "significant economic impact" (OIE, 2021[a]). However, as this impact has not been quantified, this research study will involve the use of an Engle-Granger (Engle and Granger, 1987) approach to develop an understanding of and quantify the drivers that influence a change in the average beef carcass price in South African (Francois and Hall, 1997). As an outbreak of FMD results in the immediate shutdown of the export market, the average beef carcass price might be indirectly impacted upon due to trade disruptions. Therefore, it is important to determine whether South Africa's export volume of beef has a statistically significant relationship to the average South African beef carcass price. Accordingly, this study hypothesises that:

> *H_0: The volume of beef exported by South Africa has a statistically significant long-run relationship with the South African average beef carcass price at a 5% level of significance.*

If this hypothesis is determined, it would be possible to use the volume of beef exported by South Africa as a proxy variable to indicate an FMD outbreak. Using trade as a proxy variable, the volume of beef exported would change as the country enters into various bilateral trade agreements (see Section 1.1). As such, the nuanced FMD-specific impact on the average South African beef carcass price could be quantified. In the long run, this impact is not expected to be large, as the market is expected to return to equilibrium. Accordingly, this study also hypothesises that:

> *H_0: The volume of beef exported by South Africa, and by proxy, an outbreak of FMD, has a negative impact on average South African beef carcass price with a relatively fast speed of adjustment back to long-run equilibrium.*

1.5 Academic Value and Contribution

While an FMD outbreak is said to have an economic impact, to date, this impact has not been quantified for South Africa. As such, this study aims to determine whether South African beef export volumes could be used as a proxy for an outbreak of FMD, and to quantify then the impact of an outbreak on average South African beef carcass prices. As the beef industry is a large contributor to the overall agricultural industry in South Africa (DAFF, 2019), quantifying the impact of an outbreak on beef prices would indicate the effect on turnover within the beef industry, given that South Africa makes use of quarantine and movement control as control measures to mitigate the spread and impact of FMD (Section 1.2) (OIE, 2021[a]). This could then be extrapolated to quantify the impact on overall agricultural industry turnover. During these periods of disease outbreak, South Africa has had to introduce strict control measures and biosecurity, as set out in the global foot and mouth disease control strategy,[3] including quarantine and movement control of livestock, equipment and vehicles (OIE, 2021[a]).

By performing statistical modelling, this study will show the potential quantitative impact that an animal disease outbreak has on its associated domestic industry. This would allow industry stakeholders and public and government officials to better understand the need for adequate animal health control and potential disease outbreaks.

Additionally, the results of this study will indicate which modelling techniques would be best suited to accurately quantify the impact of past and forecast the possible impact of future FMD outbreaks on the beef industry in South Africa (Brückner et al., 2003).

1.6 Chapter Outline

This study has six chapters; the first chapter outlines the background, problem statement, research objectives and hypotheses. The second chapter provides an overview of the beef industry in South Africa, including the demand, supply and trade of beef. It also provides an overview of foot and mouth disease and a history of outbreaks in South Africa (Brückner et al., 2003). The literature review, presented in Chapter 3, breaks down studies focusing on FMD (both international and South African-based) as well as studies using modelling techniques to estimate the impact of other animal disease outbreaks on their specific industries.

The methodology used in this study, namely the Engle-Granger two-step cointegration procedure, is outlined in Chapter 4. The chapter starts with the definition, source and expected signs of data variables. Then it moves on to explain the theoretical framework and the

3 As a contingency plan, the OIE has identified recommended measures in an attempt to eradicate potential outbreaks. This includes measures such as surveillance, tracing, quarantine and movement control of livestock, as well as movement control of vehicles and the disinfection of premises, vehicles and any materials, including implements and clothes. It also outlines measures regarding the humane destruction and appropriate disposal of animals and animal products (OIE, 2021[a]).

estimation technique of the method, including unit root tests, error correction models and diagnostic testing. Chapter 5 presents the results of the method applied. Finally, Chapter 6 concludes by summarising the findings and shortcomings of the study and proposing suggestions for future research.

Chapter 2:
Overview of the South African Beef Industry

2.1 Introduction

The purpose of this chapter is to describe the beef industry in South Africa to ensure context for the rest of the analysis. This includes an understanding of the beef value chain and the extent to which the domestic industry can supply domestic demand. Understanding South Africa's trade of beef is needed to determine role of the export market in the industry, and, with this, an understanding of Foot and Mouth Disease and its effect on infected animals. An overview of previous FMD outbreaks in South Africa and the country's responses to these outbreaks will provide an indication of how the 2019 outbreak resulted in a structural shift in the South African beef industry. Together, this will provide the reader with adequate background knowledge on the importance of the beef industry to the economy of South Africa, and how a disease outbreak is seen to have devastating effects.

2.2 The South African Beef Value Chain

Many industry associations and studies have provided an overview of the value chain for beef in South Africa (DAFF, 2019; Karan Beef, 2021; South African livestock breeding, 2004:10; Agribook Digital, 2020; DALRRD, n/d). For the purposes of this study, it is important to highlight the interconnectedness of the stakeholders within the chain (DAFF, 2019; Karan Beef, 2021) to understand the ease of the spread of an FMD outbreak across the value chain. Figure 2.1 below outlines the beef value chain in South Africa.

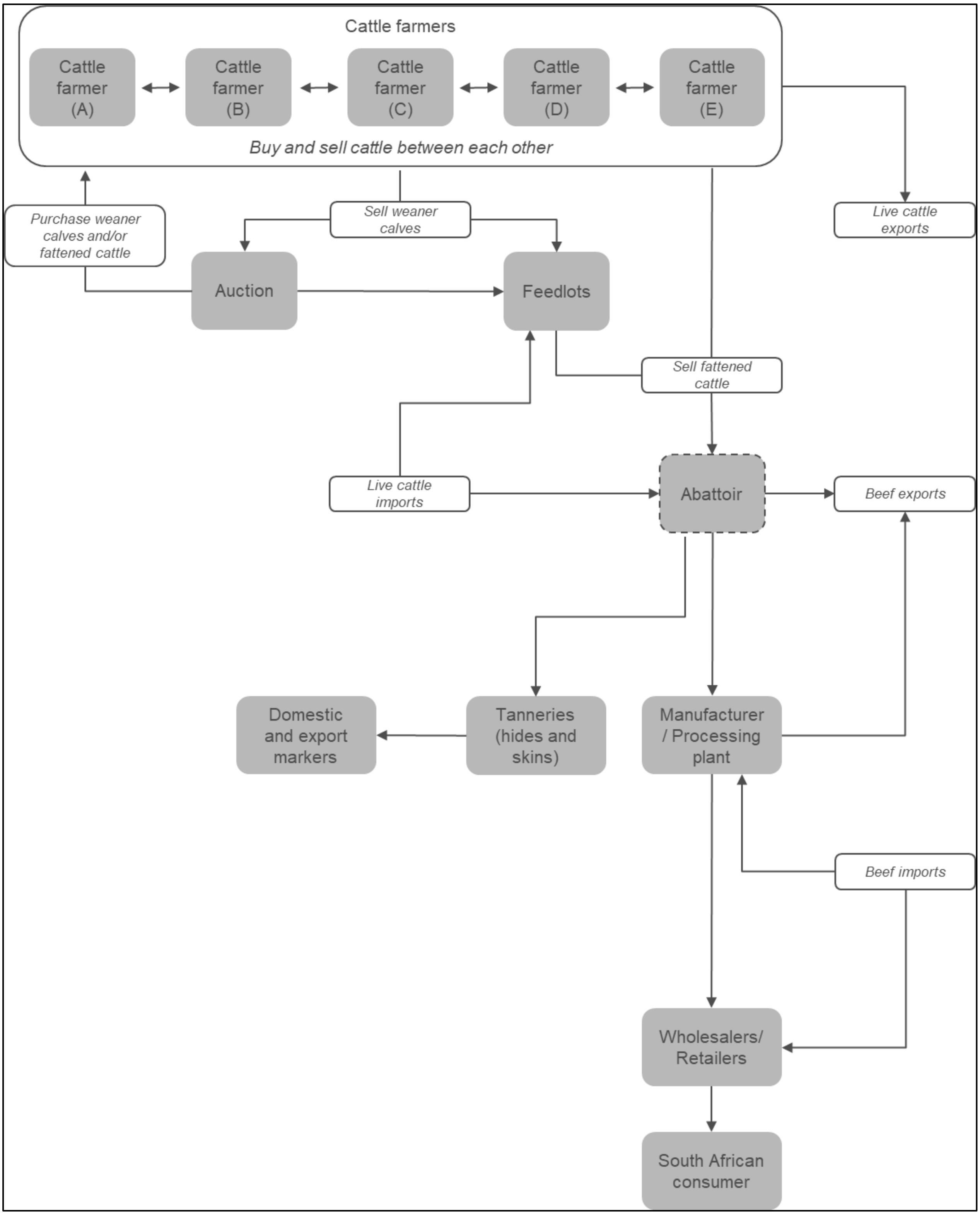

Figure 2.1 South African beef value chain

Sources: DAFF (2019) and Karan Beef (2021)

Most of the beef production, farmed by large-scale commercial farmers, communal farmers, and subsistence farmers, is located in the Eastern Cape, Kwa-Zulu Natal and the Free State provinces of South Africa (DALRRD, 2023). Many farmers will buy and sell their cattle between each other, and at auctions, where cattle would be sharing feed and water sources. Weaner calves might be fattened on the farm and sold directly, or through auctions, to feedlots, or to commercial farms where they will be fattened for slaughter. Larger feedlots may also import live weaner calves. Once the animal has reached a weight of approximately 450 kg, it will either be exported or taken to the abattoir for slaughter (Absa Agribusiness, 2020). The abattoir will receive fattened weaners from feedlots, from commercial farmers directly, or in some cases, the abattoir may even import live, fattened cattle (Karan Beef, 2021).

At the abattoir, the cattle are rested, sometimes overnight if they were transported over a longer distance and given water. Any sick animals are identified and placed in quarantine. After slaughter, the hide, hooves, and head of the animal will be removed during a process called skinning. The hides will be sent to tanneries for further processing to make leather products for the retail and automotive sectors, and these products or the processed hides might also be exported. The majority of South African hides and leather are exported to Asia and Europe (Nortjé, 2019).

Evisceration is the removal of the internal components of the carcass, such as the heart, lungs, liver, kidneys, gallbladder and the stomach.[4] After this step, the carcass is inspected by a professional meat inspector or veterinarian and graded (FAO, 1991). While many abattoirs are vertically integrated to process the carcasses themselves, there are some that will transport the whole carcasses, using cold transport, to processing plants for further processing. Figure 2.2 illustrates the process followed at the abattoir and processing plant. The processing of the carcass includes sectioning the quarters, followed by cutting the major specific cuts for consumers, including the chuck, brisket and ribs from the forequarter, and the sirloin, rump and flank from the hindquarter (Karan Beef, 2021).

4 In cattle, the term ‘stomach’ refers to four parts: the rumen, reticulum, omasum and abomasum, which together form the ruminant digestive system (Eilerts, 2019).

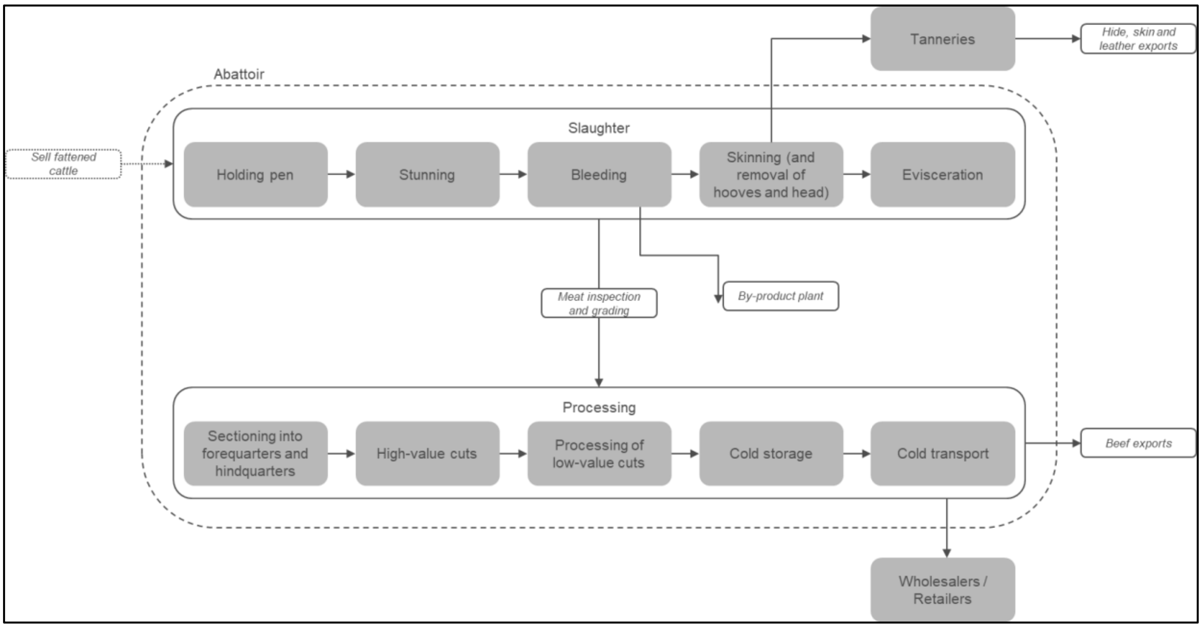

Figure 2.2 The slaughter and processing of beef within the South African value chain
Sources: DAFF (2019) and Karan Beef (2021)

Beef cuts of lower value are processed into mince, meatballs and hamburger patties, or they might be canned, while beef cuts of higher value are sold to retailers and butchers, or are exported (Karan Beef, 2021 and DAFF, 2019). Once cut and packaged, the beef needs to be stored at a temperature of −1.5°C to 0°C and needs to be transported via cold trucks in order to comply with sanitary and phytosanitary requirements and ensure the meat is safe for human consumption (FAO, 1991).

Retailers receive beef carcasses, chilled beef products, frozen beef products and canned beef from the abattoirs and/or processing facilities in South Africa, and some retailers also import beef products from outside South Africa, for sale to the South African consumer.

2.3 South African Demand and Supply of Beef

To understand the importance of beef production within South Africa, it becomes necessary to analyse the demand and supply elements that drive production. This includes highlighting the production, import, consumption, and export beef markets.

2.3.1 Domestic beef production

In South Africa, cattle are kept for a variety of reasons across different cultures, including for religious purposes and as an indication of wealth. The South African beef industry is dualistic in nature, ranging from a highly developed commercial sector to an emerging and subsistence sector (DAFF, 2019). In certain areas of South Africa where the condition allows, it is common to see producers making use of a mixed-farming enterprise, in which grains are planted on the most fertile lands and beef cattle are kept on the lands that are not suitable for planting (Kriel, 2021). There are currently an estimated 12.3 million cattle in South Africa, of which beef cattle constitute 80%, with dairy cattle making up the remaining 20% (DALRRD, 2021:56; DAFF, 2019),

South Africa's beef production has been following an increasing trend since 2008, with the total number of cattle slaughtered across all provinces being 18% higher in 2021 than in 2008 (Figure 2.3; RMLA, 2022). However, during that period of time, beef production peaked during 2015, when approximately 3 million head of cattle were slaughtered, which was 37% more than the number of cattle slaughtered in 2008. Since that peak, production has been following a decreasing trend, with a 7% drop in slaughter numbers from 2016 to 2017, followed by a further 4% drop in 2018, likely attributable to the knock-on impact of drought conditions experienced in 2015 and again in 2018.

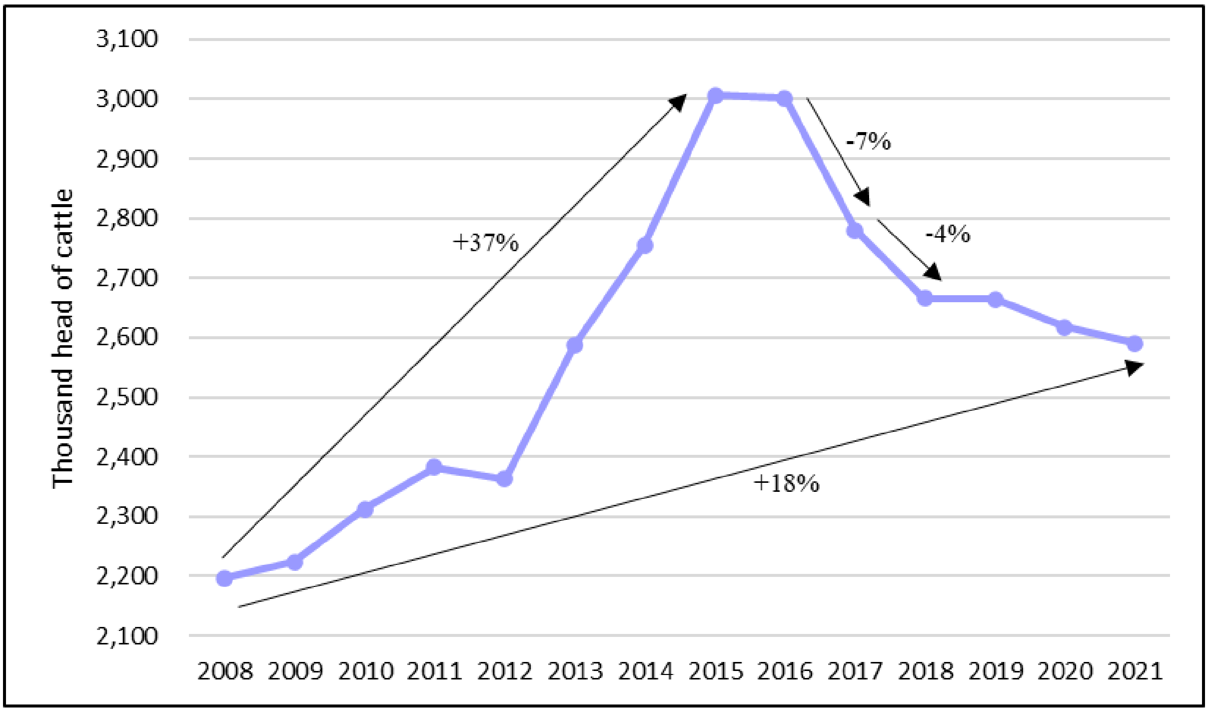

Figure 2.3 Total number of cattle slaughtered across all provinces of South Africa (2008-2021)
Source: RMLA (2022)

2.3.2 Domestic beef consumption

Within the South African meat market, the beef industry has the second fastest growing commodity demand, which is likely attributable to the variety of options available to consumers at retail level (De Beer, 2009). While the bulk of beef products fall in the mid- to higher-priced categories, there are some products, such as mince and offal, that are more affordable beef options for a consumer in a lower income bracket (BFAP, 2020).

Domestic demand is measured by per capita consumption in South Africa (Figure 2.4). In terms of beef, the per capita consumption decreased from 20.16 kg/person/year in 1990 to 12.69 kg/person/year in 2000; however, as mentioned in Section 1.1, it then began to increase, having reached 18.12 kg/person/year in 2020. Overall, this results in a 10% decline in South Africa's per capita beef consumption between 1990 and 2020. During that period, the per capita consumption of sheep/goat meat decreased by 47%, while that of poultry increased by 65%. The significant increase in the consumption of poultry is likely because of its affordability, leading to it being increasingly used as a substitute for red meat products (Maré, 2020).

According to the Bureau for Food and Agricultural Policy's (BFAP) baseline published in 2020 (BFAP, 2020), South Africa's beef consumption is expected to increase by 12% by 2029.

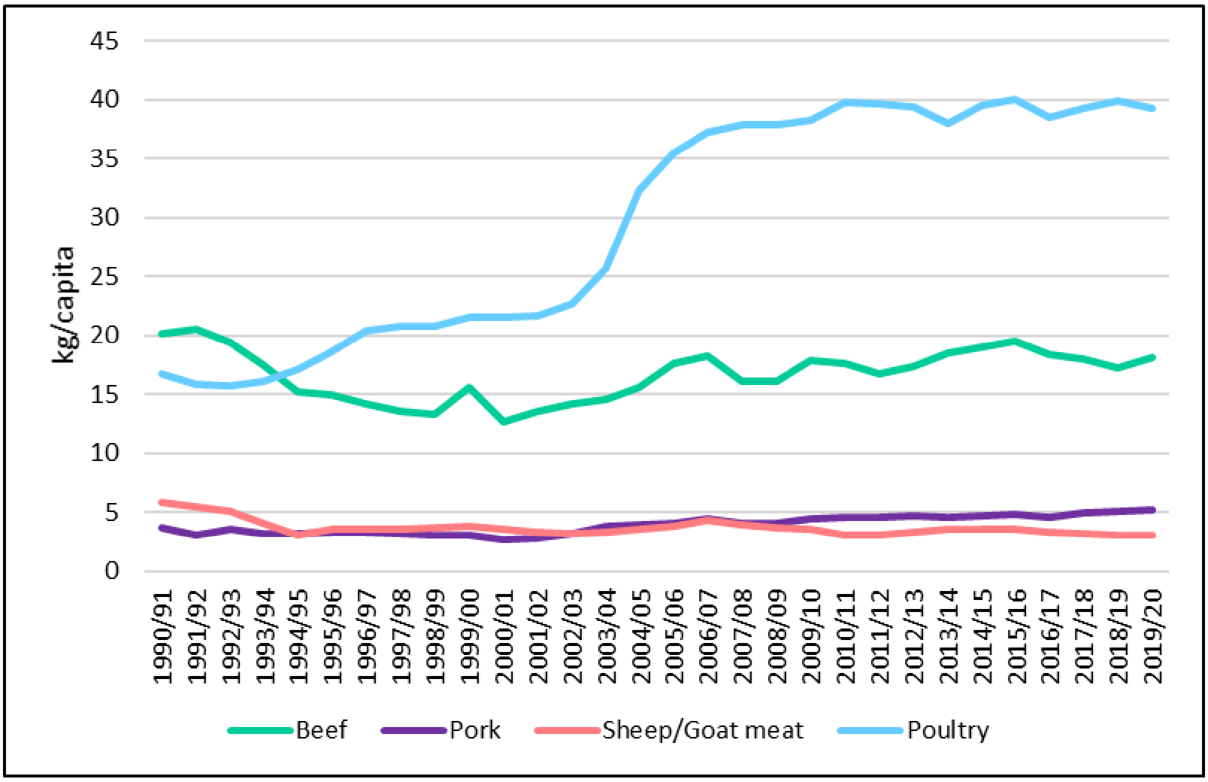

Figure 2.4 Per capita consumption of meat in South Africa

Source: DALRRD (2021:58, 60, 62, 66)

2.4 South African Trade of Beef

2.4.1 South African imports

South Africa imports beef products in a fresh or chilled form, as well as a frozen form. Imports of fresh or chilled beef products mainly consist of boneless portions, which include cuts of the fore and hindquarters, such as rump, flank, fillet, boneless loin, topside and silverside. Carcasses and half-carcasses are generally imported in a fresh or chilled state, rather than a frozen state, which indicates that they likely undergo further processing at local butcheries into more specific cuts (South African Revenue Services (SARS), 2022).

Since spiking in 2012, South Africa's imports of bovine meat have been on a declining trend (Figure 2.5). The COVID-19 pandemic in 2020, which lead to global lockdown restrictions, including restrictions on trade, created an external shock to the industry that resulted in the substantial 82% drop in imports from 2019 to 2020. While some recovery was evident in 2021, the level of South Africa's beef imports remains low (SARS, 2022).

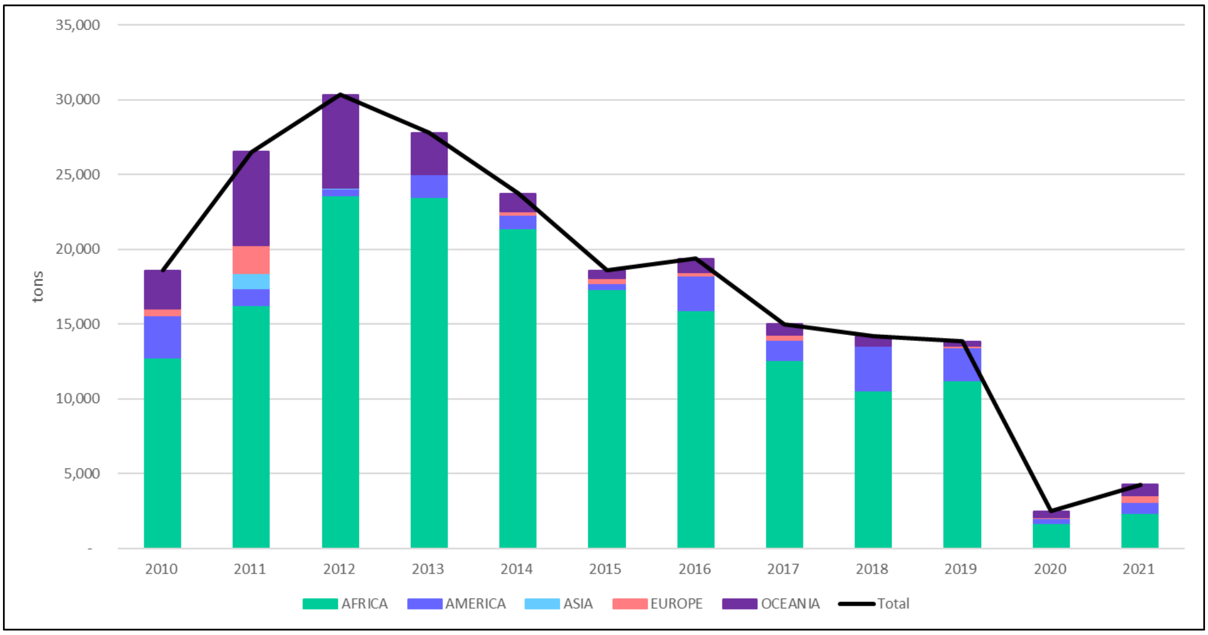

Figure 2.5 South African annual global import of bovine meat in fresh, chilled, or frozen state (tons)

Source: SARS (2022)

The majority of bovine meat imported by South Africa originates from neighbouring countries, specifically Botswana and Namibia, each of which have made up, on average, 41% and 35%, respectively, of total beef imports since 2010 (Figure 2.6).

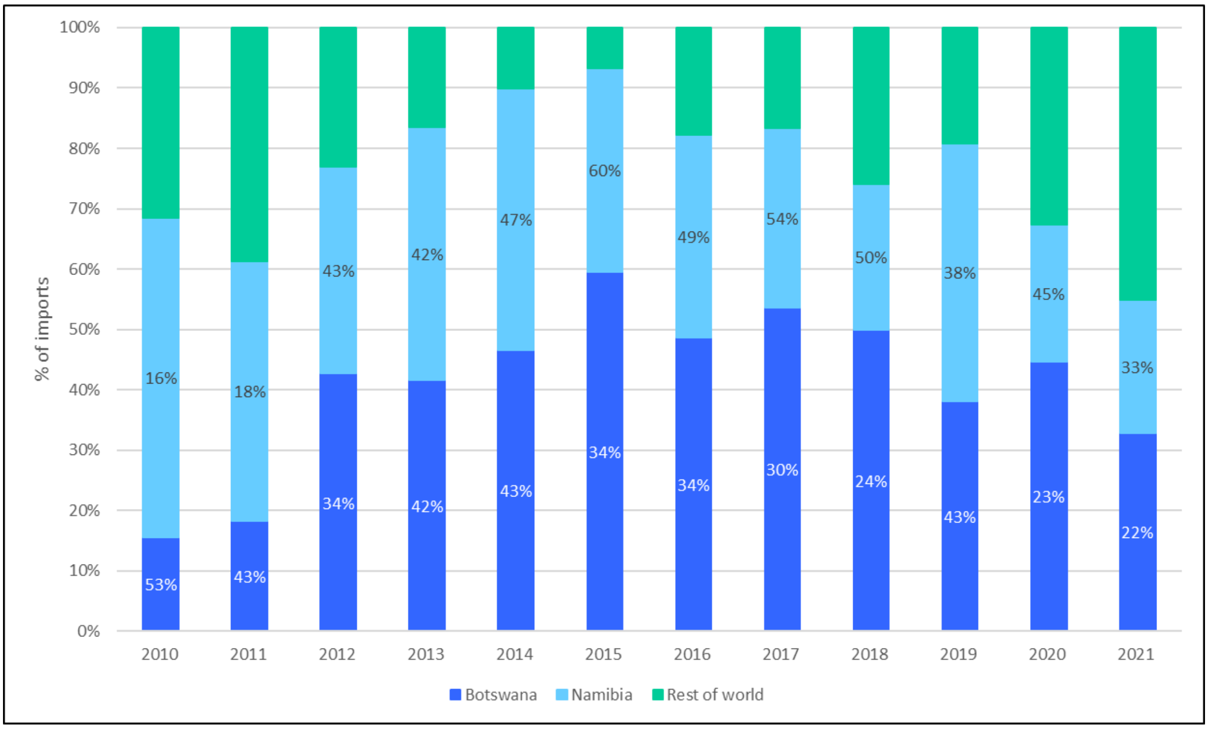

Figure 2.6 South Africa's main import origins of bovine meat in a fresh, chilled, or frozen state (tons as a percentage of total bovine meat imports)

Source: SARS (2022)

From Figure 2.7, it is visible that poultry imports continue to be the largest meat imported into South Africa, followed by swine meat (pork) imports. While remaining higher than imports of sheep meat (lamb and mutton), beef imports have been on a declining trend, which can be explained by the increase in domestic beef production volumes catering for the increased South African consumer demand discussed in Section 2.3.2 (SARS, 2022).

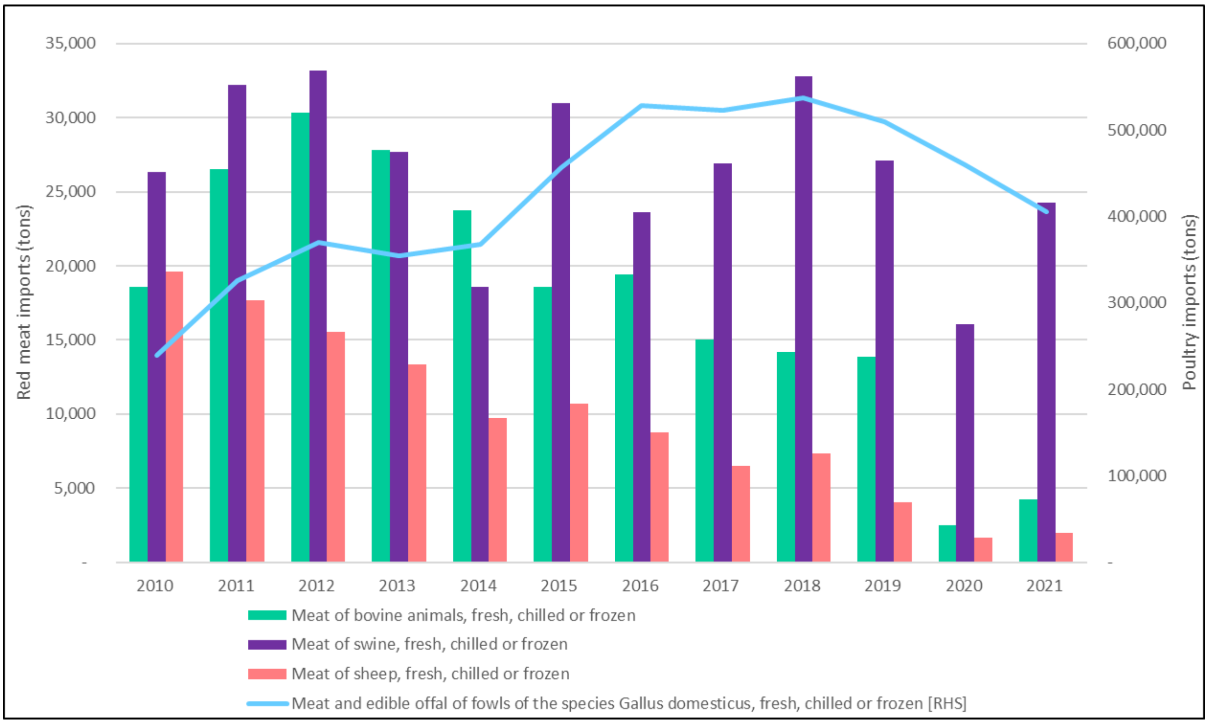

Figure 2.7 South African annual imports of bovine, sheep, swine, and poultry meat in a fresh, chilled or frozen state (tons)

Source: SARS (2022)

2.4.2 South African exports

Global exports of South African bovine meat has increased since 2010. From 2017 to 2019, SA's beef exports went through a decreasing cycle with a 19% drop in 2017 followed by a 5% drop in 2018. For the 2019 year, the year in which the FMD outbreak occurred (see Section 1.2), South Africa's exports of bovine meat dropped by another 19% from the prior year, this is compared to the 2020 year, which saw a 50% increase in bovine meat exports, despite the external shock of the COVID-19 pandemic. While the 2019 decrease in beef exports may be attributable to the decreasing cycle, it may indicate how losing the FMD-free-zone status of the country could negatively impact export demand (Figure 2.8).

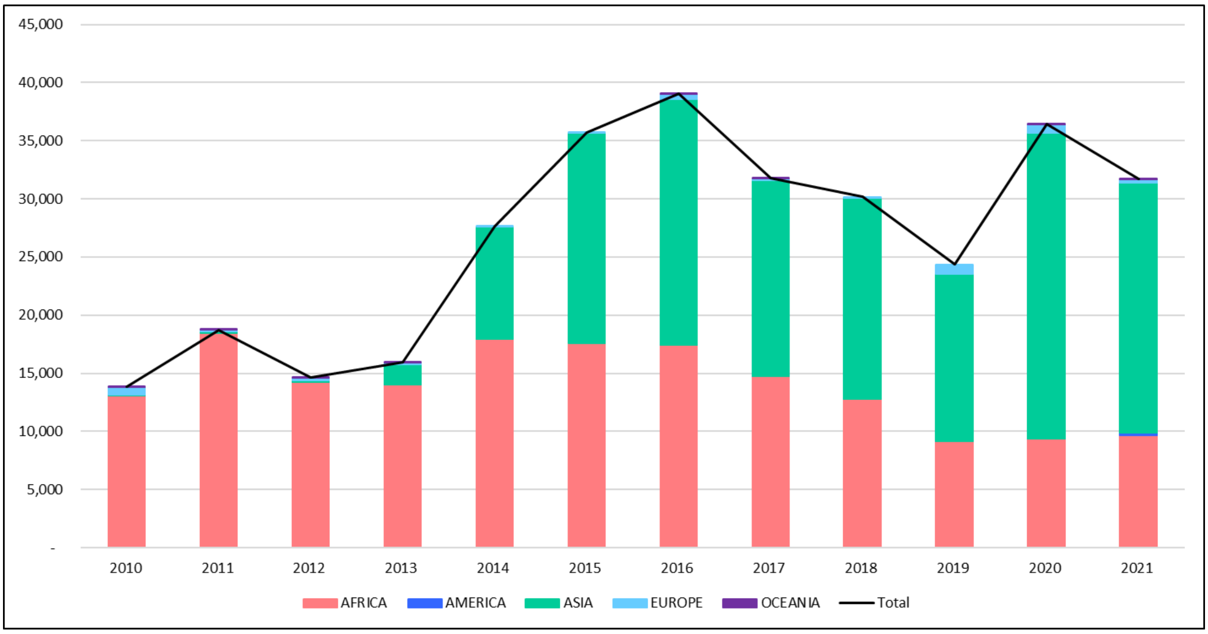

Figure 2.8 South African annual global export of bovine meat in fresh, chilled, or frozen state (tons)

Source: SARS (2022)

In 2010, the majority of bovine meat exported by South Africa was destined for the rest of Africa; however, the volume of bovine meat that South Africa exports to Asia has been increasing and, in 2015, surpassed the amount of bovine meat destined for Africa (Figure 2.9). From 2010 to 2021 (Figure 2.9), the main African export destinations for South African beef are Mozambique, eSwatini and Lesotho, while in Asia, China was the largest importer since 2018 (SARS, 2022).

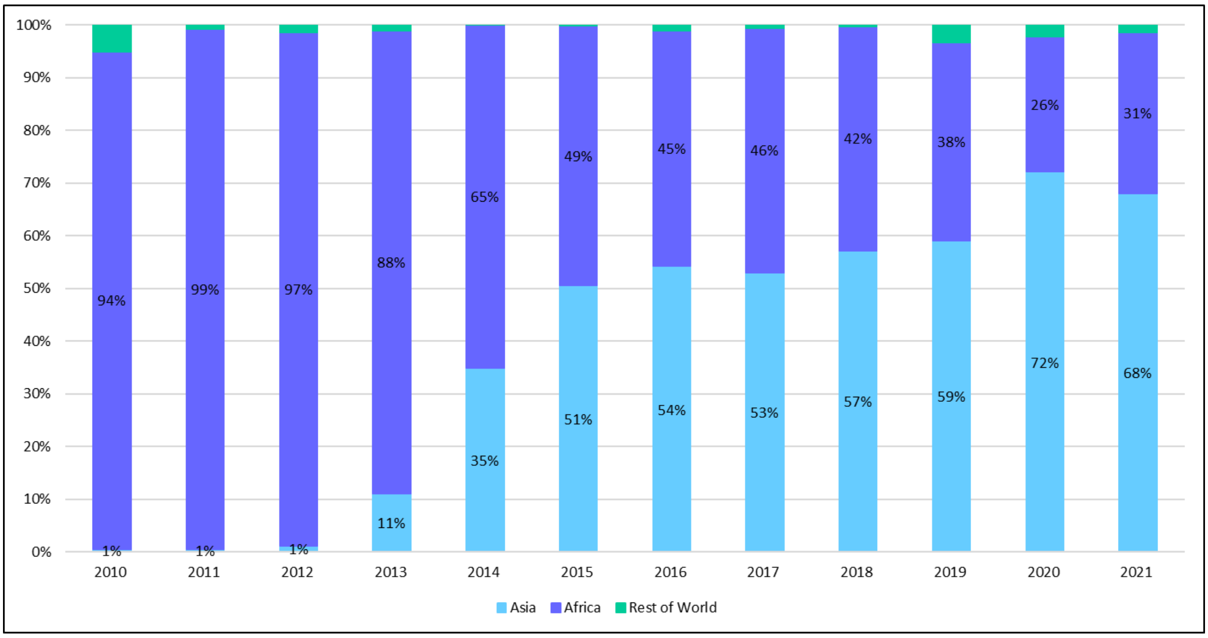

Figure 2.9 South Africa's main export destinations for bovine meat in a fresh, chilled, or frozen state (tons as a percentage of total bovine meat exports)

Source: SARS (2022)

Although poultry is still the highest volume of meat exported by South Africa (De Beer, 2009), bovine meat exports have increased as a percentage of total meat exports, surpassing swine and sheep since 2012 (SARS, 2022) (Figure 2.10).

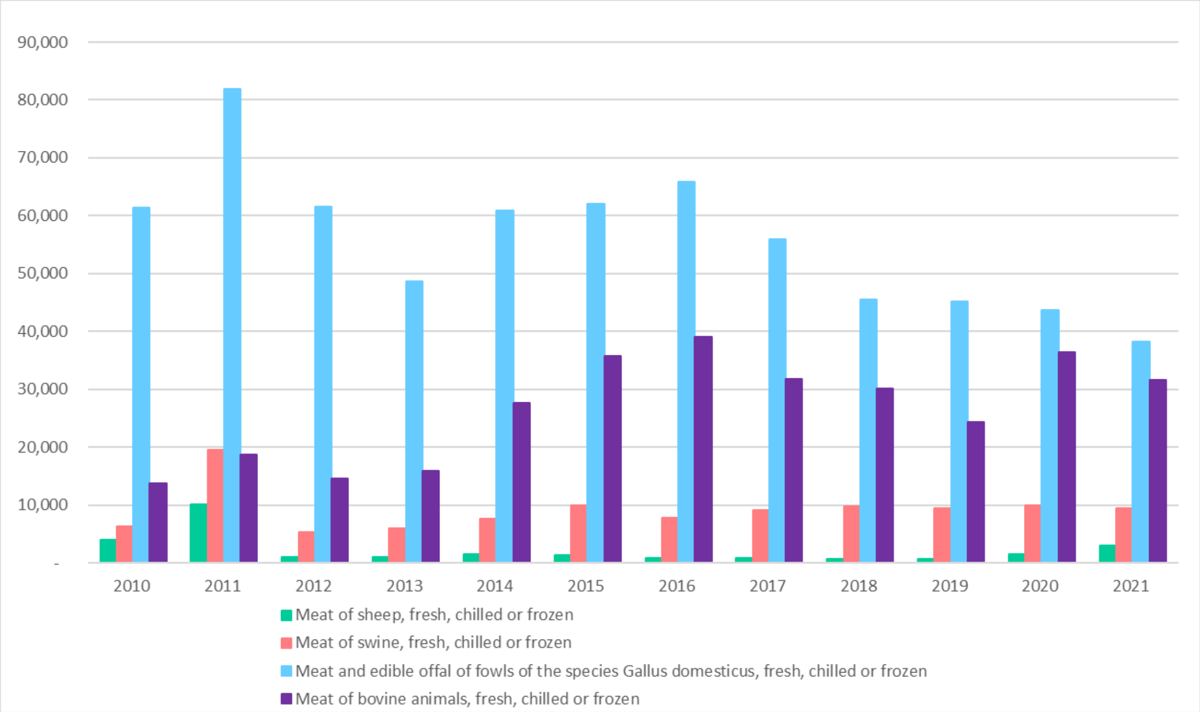

Figure 2.10 South African annual exports of bovine, sheep, swine, and poultry meat in a fresh, chilled or frozen state (tons)

Source: SARS (2022)

2.4.3 Balance of trade

Prior to 2014, South Africa was a net importer of bovine meat (DAFF, 2022). However, in 2014, there was a 73% increase in the volume of bovine meat exported from South Africa, globally (Figure 2.11). China has become the main key export destination, and this increased export volume may be attributable to the official recognition by the OIE of South Africa's FMD-free zone, resulting in broader market access (OIE, 2019:1).

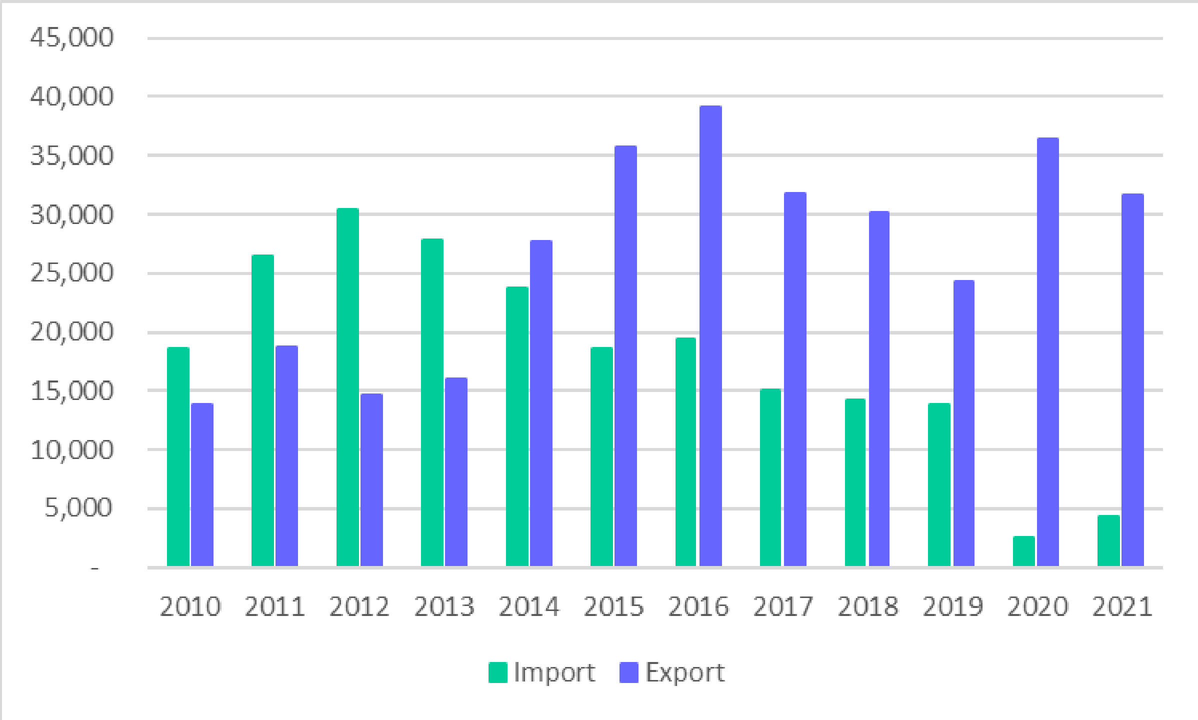

Figure 2.11 South Africa's balance of trade of bovine meat in a fresh, chilled, or frozen state
Source: SARS (2022)

2.5 Foot and Mouth Disease

As mentioned in Section 1.1, Aphthovirus causes FMD, and is endemic to South Africa as it is carried by African buffalo (*Syncerus caffer*). Considered a public health risk, it was the first disease for which the OIE (OIE, 2021[a]) developed an official recognition status, despite not being transmissible to humans. The virus is highly contagious and can be spread to cloven-hooved ruminants[5] through all excretions and secretions of an infected animal, including through respiratory or oral routes as infected animals breathe out aerosolised virus (Biden, Ker and Duff, 2022).

Because of the significant economic impact that FMD can have on a country's livestock industry, those countries that are officially recognised as being free from FMD, or have an FMD-free zone, are afforded the ability to export their meat products of cloven-hooved animals

5 This includes cattle, swine, sheep and goats.

to a wider range of countries, globally (OIE, 2021[a]). South Africa was officially recognised has having an FMD-free zone without vaccination in 2014 (OIE, 2021[a]).

However, since then, South Africa has experienced some cases of FMD that were found within the zone designated as free from FMD. During these periods of disease outbreak, South Africa has had to introduce strict control measures and biosecurity, as set out in the global foot and mouth disease control strategy[6], including quarantine and movement control of livestock, equipment and vehicles (OIE, 2021[a]).

As a result of an outbreak, the OIE would suspend South Africa's FMD-free zone status and, as such, South Africa would be unable to export live cattle or meat products from cloven-hooved animals to many countries, globally, until South Africa's FMD-free zone status was reinstated (Brückner and Vosloo, et al., 2003). Since the initial reoccurrence in 2019, South Africa has experienced ongoing outbreaks of FMD. While beef exports to various countries have resumed as the result of mutual bilateral trade agreements being concluded, the country is yet to regain its status from the OIE of having an FMD-free zone. This has created a structural shift in the industry. The map depicted in Figure 2.12 shows FMD outbreaks in South Africa that are considered to still be on-going (as at 5 March 2023) under the official status recognised by the OIE.

6 As a contingency plan, the OIE identified recommended measures in an attempt to eradicate potential outbreaks. These include measures such as surveillance, tracing, quarantine and movement control of livestock, as well as movement control of vehicles and the disinfection of premises, vehicles and any materials, including implements and clothes. It also outlines measures regarding the humane destruction and appropriate disposal of animals and animal products (OIE, 2021[a]).

Figure 2.12 On-going FMD outbreaks in South Africa

Source: OIE (2023)

Chapter 3:
Literature Review

3.1 Introduction

The World Health Organization (WHO) has noted the importance of economic impact studies which indicate that measuring the adverse impacts of disease would provide decision-makers with an indication of the extent of disruption to the economy affected (WHO, 2009). While the WHO specifically referred to diseases that infect the human population, their arguments for the importance of performing these studies also hold for diseases affecting an animal population. The general belief among many of those in the public health community is that information on the economic consequences of a disease will aid in attracting funding to control the disease (WHO, 2009).

Chapter 3 begins by investigating studies that have been performed using statistical estimation techniques to determine the impact of FMD on international markets. To my knowledge, no studies have been done that use statistical modelling techniques with an aim to quantitatively evaluate the impact of an FMD outbreak on the beef sector. As such, in Section 3.2.2, studies on South Africa's management of FMD are discussed, followed by a discussion of South African studies that use statistical methods to determine the effects of other animal diseases on their respective industries in South Africa (Section 3.2.3). The objective of this chapter is to present an overview of the methods used and the results found in determining the effect of an FMD impact on a region.

3.2 Studies Relating to the Economic Effects of FMD

3.2.1 International FMD studies

As a result of increasing biosecurity concerns, globally, Tozer, Marsh and Perevodchikov (2015: 163-184) noted that an outbreak of FMD was considered a major policy concern because of the potential for severe economic consequences; as such, they developed and applied a dynamic model to a simulated FMD outbreak in Canada in order to capture changes to the economy, specifically concerning the producer, consumer and government impacts. Their findings were used as rationale for policymakers to provide for increased surveillance of cattle movement in an attempt to contain an FMD outbreak, as soon as possible. By using a discrete time-optimal control model, Tozer et al. (2015: 163-184) demonstrated the economic welfare effects of mitigation measures. Importantly, the authors assumed that trading partners would not recognise zoning as effective, and as such, it is assumed that all exports of beef and beef products would be restricted.

In order to introduce the hypothetical FMD outbreak to the model, Tozer et al. (2015: 163-184) adjusted the breeding herd dynamics, and introduced dissemination rates at which the disease would be spread from one infectious herd to another. The dissemination rates vary, as mitigation strategies (stamping-out, pre-emptive slaughter and movement control)[7] are introduced in the third week. Various scenarios were run, and it was found that, as the depopulation rate increased, the number of latent infections decreased, thereby improving total economic welfare. Vaccination proved effective, showing the lowest overall economic loss of all national outbreak scenarios; however, the Canadian control process did not allow for vaccination and therefore it is rarely recommended in the event of an outbreak.

The level of depopulation had varying impacts on the short- and long-term supply levels and, in turn, beef prices. Interestingly, Tozer et al. (2015: 163-184) noted that it took two cattle cycles[8] for the beef prices to return to equilibrium levels. After the FMD outbreak, higher prices were seen for one cattle cycle as a result of restricted supply, as producers retained breeding females in order to increase future production. However, these higher prices would result in reduced consumer demand, thereby causing a fall in beef prices to below equilibrium levels, which would remain in place for another cattle cycle, before reaching equilibrium.

7 Stamping-out, pre-emptive slaughter and movement control are the three mitigation strategies used in the study by Tozer et al. (2015). There are additional strategies that could be used when controlling disease outbreaks. Pre-emptive slaughter and stamping-out involve the slaughter of high-risk cattle (prior to displaying signs of infection) and cattle displaying signs of infection, respectively. Movement control consists of a 5 km quarantine area around an infected premises.

8 A cattle cycle is regarded as being the eight years it takes from when a female enters the breeding herd until she is culled at 10 years old.

Another study that examined a simulated FMD outbreak in Canada was conducted by Cairns, Tolhurst and Poon (2017: 159-183), who developed a partial equilibrium model and used OLS regression in log-log functional form to estimate the welfare impact on the beef sector of Ontario, Canada. While their framework of a partial equilibrium model was limited in scope to only incorporate the Ontario beef sector, this was outweighed by the ability of the framework to allow for the disaggregation of impacts across market participants along the value chain (producers, processors, retailers and consumers). Cairns et al. (2017: 159-183) noted that the study could be expanded to a national level, although each province or region would need to be modelled separately. Their findings ascertained that welfare losses were mainly attributable to movement restriction. One scenario modelled by Cairns et al. (2017: 159-183) indicated that zoning could reduce the overall loss of an outbreak by over 65%.

Similar to the two above-mentioned studies, many international studies that examine the impact of an outbreak do so by using a hypothetical outbreak and have, in fact, not experienced an FMD outbreak (see also Gohin and Rault, 2013: 97-107).

Park et al. (2008) investigated the impacts of multiple disease outbreaks, covering foot and mouth disease in Korea in 2000, avian influenza in Korea in 2000, and bovine spongiform encephalopathy (BSE) in the United States in 2003. However, when comparing the results between the different disease outbreaks, it is interesting to note that, compared with the FMD outbreak, the Avian Influenza and BSE outbreaks resulted in changes that were more significant in Korean beef prices. For the purposes of this dissertation, I will be focusing on their findings relating to the impacts of the FMD outbreak, which was to become the largest outbreak in Korea, with a total of 2 216 head of livestock (cows, pigs and sheep) being slaughtered by the end of April 2000.

Park et al. (2008) used various models, including an error correction model, historical decomposition, and directed acyclic graphs, to analyse the impacts on meat prices and margins along the supply chain, and price interdependence in the Korean meat market. They found that animal disease outbreaks, regardless of the disease and whether within Korea or outside its borders, caused a temporary price shock to the Korean meat market, with retail prices tending to recover faster than farm and wholesale prices did, while the retailers' margins relative to those of the farmers and wholesalers became larger. Specifically, the outbreak of FMD was seen to have a negative impact on beef and pork markets, while having a positive short-term substitution effect on the poultry market. The Korean meat market was able to partially recovery from an FMD outbreak within 16 months, except for pork prices, which remained below pre-outbreak levels for more than three years, perhaps because of supply disruptions caused by the mitigation strategy.

A common thread across these studies is that it is imperative that disease outbreaks should be quickly brought under control in order to quickly regain access to export markets. Unlike Tozer et al. (2015: 163-184), who assumed a complete shut-down of trade, Cairns et al. (2017: 159-183) included zoning as a scenario in their modelling and noted a significant reduction in overall loss. Park et al. (2008: 183-195) noted that, as they lacked quantity data, they were unable to directly incorporate supply shock into their model. Importantly, as of 2003, Korea had become the fourth largest beef-importing country in the world, relying heavily on imports to meet demand (Park et al., 2008). This differs from the South African markets that, as noted in Section 2.4.2, are net exporters of beef. Furthermore, Tozer et al. (2015: 163-184), Cairns et al. (2017: 159-183), and Parks et al. (2008: 183-195) noted that restricted supply, whether experienced through trade bans or meat shortages attributable to depopulation or high herd retention, had a significant impact on prices.

3.2.2 South African FMD studies

Studies conducted on FMD in South Africa have tended to focus on two main topics: either the biological characteristics of the disease itself, or the control of it. A study reported by Sirdar, et al. (2021: 376) examined the spread of FMD disease outbreaks in terms of location across South Africa, from 2005 to 2016, and found that outbreaks in cattle tended to be closer to the fences of game reserves, which is consistent with wildlife interactions being one of the main contributors to FMD occurrences. On the other hand, Vosloo, Thompson, Botha, Bengis and Thompson (2009: 18-31) confirmed that Impala (*Aepyceros melampu*) also contribute to the spread of FMD as areas with larger numbers of Impala had a higher transmission of the virus from buffalo to Impala which can then infect livestock.

After reviewing how FMD is controlled across sub-Saharan Africa, Maree, et al. (2014: 119-138) noted that, because different regions are in varying stages of development, with many lacking the needed skills or equipment, it would be impossible to implement a single control method across Africa. Adding to the complications are limited financial resources, poor infrastructure, and the consideration of animal disease control as being low priority, given the more pressing concerns such as human health or education. South Africa is used as an indication that the successful control of FMD is possible to implement across the rest of Africa, if the primary endemic areas and the factors influencing the spread of the disease are known and can be included in the design of the control strategies (Maree et al., 2014: 119-138).

Roberts and Fosgate (2018: 38-48) asked various stakeholders in the beef value chain, including FMD experts, veterinarians, wildlife sector stakeholders and the general public, what their opinions were of the various control measures used in South African to restrict FMD from spreading out of the infected zone (refer to Section 1.1 to review the FMD control zones in SA). The results found that individual stakeholder groups ranked the control measures differently, based on effectiveness, feasibility, human welfare, cattle welfare, and environmental welfare, as well as the financial effect on cattle owners, the industry, and the government. The deterministic analysis used in their study resulted in the finding that the most preferable control method would be a disease-control fence, while routine vaccination of cattle was rated as being the least preferable. However, Roberts and Fosgate (2018: 38-48) noted that the vaccine being used at the time of their study was developed in another African country and, as such, many stakeholders were reporting the ineffectiveness of that vaccine locally. Their study is therefore considered as being a preliminary analysis of stakeholder perceptions as the reasons behind the observed differences require further investigation.

3.2.3 South African studies using statistical modelling techniques

While noting that previous papers studying the supply response of beef had used OLS multiple regression techniques, Ogundeji, Jooste and Oyewumi (2011: 44-58) found that this methodology often results in multicollinearity arising, and does not allow for the underlying causal mechanism behind the relationship to be investigated; hence, they used the ECM methodology in order to analyse the short- and long-run factors affecting the number of cattle marketed for slaughter in the South African market. Their ECM results found that, in the long run, producers responded to economic, climate, demographic and trade factors. However, in the short-run, producers only responded to climate and trade factors (Ogundeji et al., 2011).

Following the 2017 outbreak of Highly Pathogenic Avian Influenza (HPAI), Davids, Louw, Smit and Meyer (2018) analysed the impact on the South African economy using both a retrospective and a forward-looking analysis. The forward-looking analysis made use of a partial equilibrium model, based on quarterly data for the layer (egg) sub-sector, which was then aggregated to an annual basis so that it could be introduced to the BFAP sector model (a dynamic, recursive partial-equilibrium model). This model covers over 50 agricultural sectors in South Africa and is used to show the linkages between the grain and livestock industries that are discernible through feed use. The forward-looking analysis aimed to determine the price impact associated with the production loss caused by the outbreak and found that the overall effect on the South African agricultural GVA and economy was relatively small, because price increases, caused by the reduced production volumes, mitigated the bulk of the effect on the national GDP. Davids et al. (2018) noted that the affects were not evenly distributed, as producers who did not experience an outbreak benefited from the higher prices, while those producers who did experience the outbreaks experienced severe losses.

3.3 Concluding Remarks

This chapter presented an overview of literature currently published surrounding FMD outbreaks worldwide. While this literature review provided insights into the methods and results found when analysing the regional economic impact of international FMD outbreaks, a lack of South African specific literature available was noted. A research gap in which the need to quantify the impacts on the South African beef industry therefore becomes evident.

Accordingly, this literature review utilised studies conducted regarding various disease outbreaks to their respective industries in South Africa to aid in identifying the appropriate research technique to use to achieve the main objective of this study.

As noted by Ogundeji et al. (2011: 44-58), it is important to make use of an ECM in order to correct for the limitations of the OLS methods. Once the model is developed, as shown by Davids et al. (2018), forward-looking analysis can be performed, in which various shocks (such as disease outbreaks) can be introduced to determine the potential impact that would be felt by the sector.

While most studies employ regression analysis in determining the relationship between variables, many studies are prone to a spurious regression problem, in which OLS regression indicates the presence of a relationship where it logically does not make sense that the two variables would be related (Granger and Newbold, 1974: 111-120; Wooldridge, 2013). To solve for this spurious regression problem, Engle and Granger (1987: 251-276) developed a new approach, referred to as the Engle-Granger test, which tests whether two timeseries variables are cointegrated. The Engle-Granger two-step procedure, which will be used as the methodology for this study, involves determining whether the OLS residuals are cointegrated in the long run, followed by using an ECM to determine the short-run equilibrium relationship.

3.4 Concluding Remarks

Of the estimated 12.3 million cattle in SA, 80% are beef cattle (DALRRD, 2021:56; DAFF, 2019). The majority of beef production in South African takes place in the Eastern Cape, Kwa-Zulu Natal and the, Free State areas, and is 18% higher in 2021 than it was in 2008. Beef has the second fastest growing commodity demand with per capita consumption reaching 18.12 kg/person/year in 2020, additionally, BFAP (2020) estimates that South Africa’s beef consumption will increase by a further 12% by 2029.

The majority of bovine meat imported by South Africa originates from the rest of Africa, specifically Botswana and Namibia. Since spiking in 2012, imports have been on a declining trend. Exports of South African bovine meat have been on an increasing trend since 2010, with most exports being destined for the rest of Africa. However, the volume of bovine meat exported to Asia has been increasing and, in 2015, Asia became South Africa's main export destination. In 2014, there was a 73% increase in the volume of bovine meat exported by South Africa, possibly due to the official recognition of the FMD-free zone by the OIE, which resulted in broader market access (OIE, 2019:1).

FMD, which is endemic to South African as it is carried by African buffalo, is a highly contagious virus, leading to production losses and death of the animals. FMD outbreaks found within the zone designated as free from FMD result in the suspension of South Africa's FMD-free zone status. As a result, South Africa would be unable to export live animals or meat products of cloven-hooved animals to many countries, globally, until the country's FMD-free zone status were to be reinstated, or until a bilateral agreement is put in place with a receptive country.

This chapter provided an understanding of the beef industry, including the demand and supply elements of beef production in South Africa, as well as an overview of FMD and the outbreaks experienced within the country. Given the interconnectedness of the beef value chain, it becomes apparent how FMD might spread across the country so rapidly and why its economic impact could be so severe. This provides the basis for the need to quantify the impact of an FMD outbreak.

Chapter 4:
Methodology

4.1 Introduction

The objective of this chapter is to provide an overview of the empirical techniques employed in this study by explaining the theoretical framework of the estimation, followed by outlining the estimation techniques used. Namely, this consists of unit root tests, the Engle-Granger cointegration test, Error Correction Models, and diagnostic tests, which will allow the overarching objective of this study to be achieved.

As indicated in the previous chapters, there are multiple factors that influence beef prices in the South African market. While an outbreak of FMD has an immediate impact on the trade of beef from South Africa, there are other exogenous variables that need to be considered. As such, Section 4.4 of this chapter outlines the definition, source and expected signs of the data variables used in the estimation.

4.2 Theoretical Framework

Testing for the presence of unit roots to determine stationarity is done by using the Augmented Dickey-Fuller (ADF) (Dickey and Fuller, 1979) and Phillips Perron (PP) tests (Phillips and Perron, 1988, n.d.). After using OLS to determine the long-run relationship between variables, the Engle-Granger cointegration test can be performed (Engle and Granger, 1987; Price, 2003). After this, an error correction model (ECM) can be used to determine the short-run dynamics, given the cointegrating long-run relationship (De Beer, 2009; Omoke, 2010). Finally, to justify the use of the results for interpretation across the broader population, diagnostic tests are performed.

4.2.1 Understanding cointegration

Cointegration is defined as “the notion that a linear combination of two series, each of which is integrated of order one, is integrated of order zero” (Wooldridge, 2013). It therefore becomes important to first understand what the order of integration means, and how this links to the stationarity of a variable. The quantity of unit roots (example *d*) determines the order of integration of a variable (integrated of order *d)*. Stationary variables have a constant mean, variance, and covariance over time, while non-stationary variables trend either upwards or downwards over time. Figure 4.1 provides a graphical representation of variables that are non-stationary, but become stationary after being differenced once, i.e. are I(*1*) (Streimikiene, Ahmed, Vveinhardt, Ghauri and Zahid, 2018: 722-754).

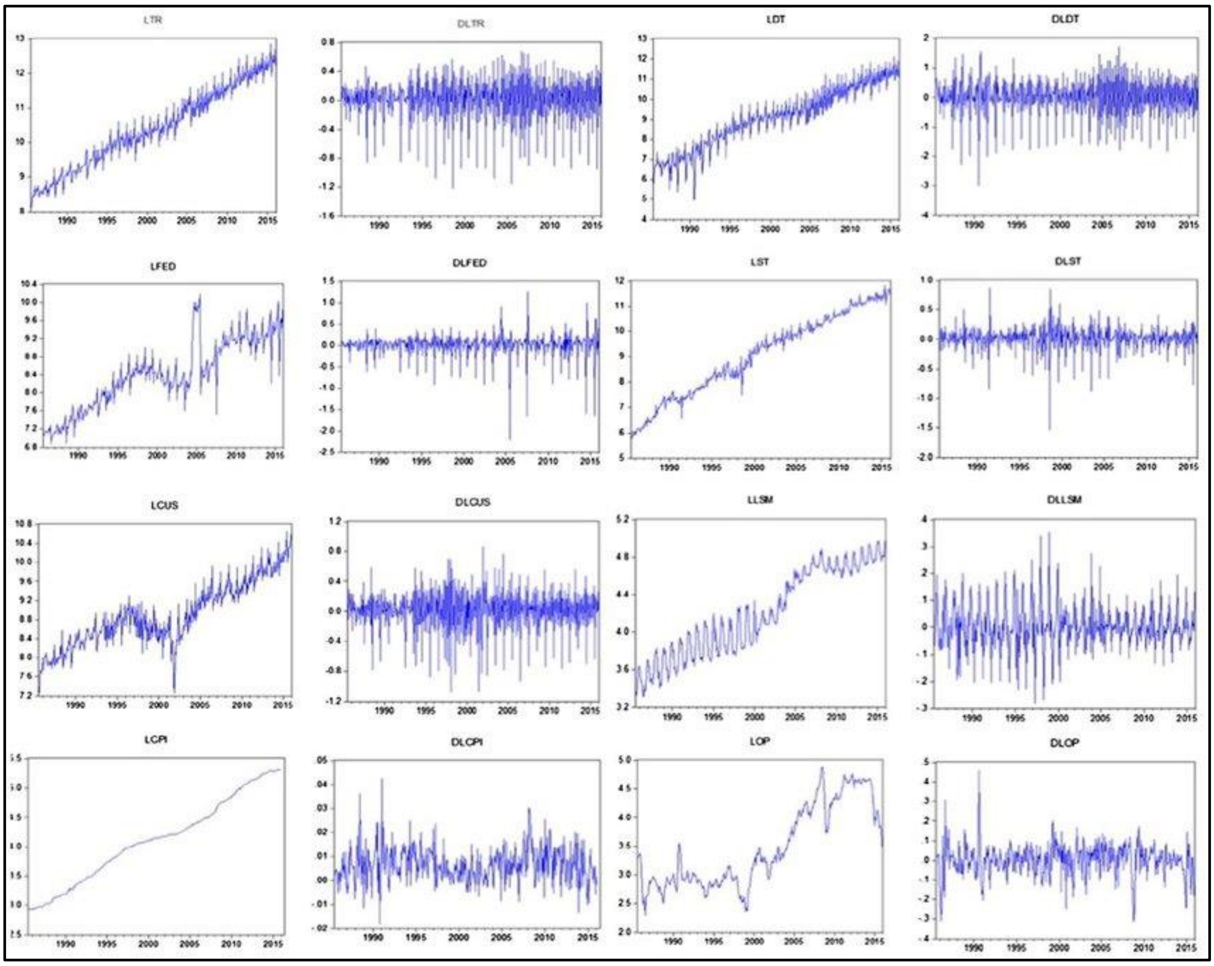

Figure 4.1 Graphical representation of non-stationary variables becoming stationary at I(*1*)
Source: Streimikiene et al. (2018: 722-754)

Using the tale recounted by Murray (1994: 37-39) of a drunk and their dog leaving a bar, the concept of cointegration can be illustrated (Figure 4.2). Firstly, let us assume that the dog is not attached to a leash and therefore wanders further from its owner, over time: this shows that both the owner (Y) and their dog (x) are non-stationary variables of I(d), with it being difficult to calculate the distance (ε) between the two. However, if we assume that the dog is on a leash, it would only be able to move a certain distance from its owner (the length of the leash). Therefore, the distance (ε) between the drunk (Y) and their dog (x), two non-stationary variables of I(d), would form a long-run equilibrium that is stationary I(0), with the conclusion that the drunk and their dog are cointegrated.

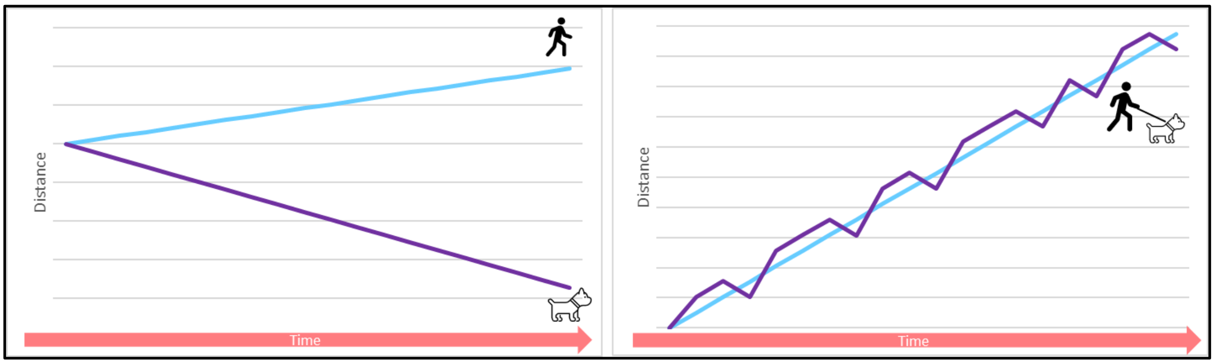

Figure 4.2 A drunk and their dog: an illustration of cointegration

Therefore, to show cointegration would require the proof that the residuals (ε) of two non-stationary variables ($y_1 \sim I(1)$ *and* $x_t \sim I(1)$)) (Equation 4.1) are proved stationary ($\omega_t \sim I(0)$) I(0) (Equation 4.2) (Wooldridge, 2013).

$$y_1 = \alpha + \beta x_{t1} + \beta x_{t2} + \cdots + \beta x_{tz} + \varepsilon_{tz} \tag{4.1}$$

$$t = 1,2, \dots, z$$

$$Where\ Y_1 \sim I(1) and\ x_t \sim I(1)$$

$$\Delta\varepsilon_{tz} = p^* \varepsilon_{t-1} + \sum_{i=1}^{p-1} p_i^* \Delta\varepsilon_{t-1} + \omega_t \tag{4.2}$$

$$Where\ \omega_t \sim I(0)$$

4.2.2 Understanding Error Correction Models (ECM)

An ECM is defined as "a time series model in first differences that also contains an error correction term, which works to bring two I(*1*) series back into long-run equilibrium" (Wooldridge, 2013: 848). Once the presence of long-run cointegration is determined, the lagged residuals (ε_{t-1}) are used together with the first difference forms (*D*) to create an ECM allowing for the short-run dynamics of the variables to be determined (equation 4.3) (Wooldridge, 2013 and De Beer, 2009). By using the lagged residuals, the model corrects any disequilibrium that may have occurred in the short-run (Wooldridge, 2013).

$$D(y_1) = \alpha + D(\beta x_{t1}) + D(\beta x_{t2}) + \cdots + D(\beta x_{tz}) + \varepsilon_{t-1} \qquad (4.3)$$

$$t = 1,2, \ldots, z$$

4.3 Estimation Technique

As noted in Section 4.2, the Engle-Granger two-step procedure requires testing for the presence of unit roots (Section 4.3.1), followed by determining long-run cointegration (Section 4.3.2). Once established, an ECM estimates the rate of correction of the short-run dynamics (Section 4.3.3). Diagnostic tests used to justify the interpretation of results for the population (Section 4.3.4) conclude the methodology. All tests will be run by using Version 12 of the computer software, EViews (IHS Markit, 2017).

4.3.1 Unit root tests

All variables must display a common order of integration I(*d*), as discussed in Section 4.2.1. Therefore, in order to run the Engle-Granger test, all variables in the model need to be I(0), or I(1), etc., but cannot include variables of I(1) and I(2) within the same model (Engle and Granger, 1987; Wooldridge, 2013).

While the graphical representation of a variable may be visually appraised to determine stationarity (as shown in Figure 4.1), formal tests are also needed to ensure the presence or absence of unit roots, and as to what order of integration the variable becomes stationary. Both the Augmented Dickey-Fuller (ADF) (Dickey and Fuller, 1979) and the Phillips Perron (PP) (Phillips and Perron, 1988) tests will be used in this study. Wooldridge (2013) describes three methods to test for unit roots: a random walk with drift, a random walk without drift, and a distribution with both trend and drift, where β represents the drift and γ represents the trend (De Beer, 2009).

$$y_t = \alpha_0 + \gamma_{t-1} + \varepsilon_t \tag{4.4}$$
$$t = 1,2, \ldots$$

$$y_t = y_{t-1} + \varepsilon_t \tag{4.5}$$
$$t = 1,2, \ldots$$

$$y_t = \alpha_0 + \beta_t + \varepsilon_t \tag{4.6}$$
$$t = 1,2, \ldots$$

Both the ADF and the PP have the null hypothesis that the underlying series is non-stationary (Zaman, Ikram and Shah, 2009). By evaluating the t-statistic compared with the critical T-values at the 10%, 5% and 1% levels of significance,[9] a t-statistic below the critical T-value would result in the rejection of the null hypothesis (Wooldridge, 2013).

9 Within hypothesis testing, the level of significance indicates the probability of a Type I error occurring, for example if a 5% level of significance is used in hypothesis testing, it indicates the mistaken rejection of the null hypothesis 5% of the time (Wooldridge, 2013).

4.3.2 Engle-Granger cointegration test

Used to identify the presence of a long-run cointegrating relationship between variables, the Engle-Granger test has a null hypothesis that there is no cointegration among variables, implying that the residuals are non-stationary (Engle and Granger, 1987; Price, 2003). This test evaluates the p-value of the underlying series at a 10%, 5%, and 1% level of significance, where a p-value below α (where α represents the significance level) would result in the conclusion that the underlying series is cointegrated (reject H_0) (Wooldridge, 2013).

4.3.3 Estimating the Error Correction Model (ECM)

Used to study the short-run adjustment mechanism, the error correction term within an ECM operates to restore two cointegrated series to their long-run equilibrium state (Wooldridge, 2013). If we take the model in Equation 4.8, which is integrated of order I(*0*), and difference it to its first order level I(*1*), we would get Equation 4.9, where $t = 1,2, \ldots$ for both equations. Using the Engle-Granger cointegration test, we can conclude that y_t and x_t are cointegrated with parameter β, which would allow us to add an additional variable, namely s_t, to Equation 4.8, where $s_t = y_t - \beta x_t$ (Equation 4.10). The lag of s_t can therefore be included in Equation 4.9, resulting in Equation 4.11, which represents the ECM and $\delta(y_{t-1} - \beta x_{t-1})$ indicates the error correction term (Wooldridge, 2013).

$$y_t = \alpha_0 + \gamma_0 x_t + \varepsilon_t \tag{4.8}$$

$$\Delta y_t = \alpha_0 + \alpha_1 \Delta \gamma_{t-1} + \gamma_0 \Delta x_t + \gamma_1 \Delta x_{t-1} + \varepsilon_t \tag{4.9}$$

$$\begin{aligned} y_t &= \alpha_0 + \gamma_0 x_t + s_t + \varepsilon_t \\ &= \alpha_0 + \gamma_0 x_t + \delta(y_t - \beta x_t) + \varepsilon_t \end{aligned} \tag{4.10}$$

$$\begin{aligned} \Delta y_t &= \alpha_0 + \alpha_1 \Delta \gamma_{t-1} + \gamma_0 \Delta x_t + \gamma_1 \Delta x_{t-1} + \delta s_{t-1} + \varepsilon_t \\ &= \alpha_0 + \alpha_1 \Delta \gamma_{t-1} + \gamma_0 \Delta x_t + \gamma_1 \Delta x_{t-1} + \delta(y_{t-1} - \beta x_{t-1}) + \varepsilon_t \end{aligned} \tag{4.11}$$

The error correction term induces either positive or negative changes in y to restore equilibrium. Simply, in Equation 4.11, if $y_{t-1} > \beta x_{t-1}$ when $\delta < 0$, then y overshot the equilibrium in the previous period, and the error correction term would work to lower y back toward equilibrium. Similarly, if $y_{t-1} < \beta x_{t-1}$ when $\delta < 0$, then y undershot the equilibrium in the previous period, and the error correction term would work to push y up, back toward equilibrium (Wooldridge, 2013). The resulting coefficients of the ECM indicate the speed of adjustment back toward equilibrium (Omoke, 2010; Wooldridge, 2013).

4.3.4 Diagnostic tests

Four individual diagnostic tests, as outlined below, are used to justify the interpretation of the statistical results for the study population. The Jarque-Bera test assesses the normality of observations and regression residuals (Thadewald and Buning, 2007). Specifically, the test will estimate the kurtosis (sharpness of peak) and skewness (symmetry) of data to determine the distribution (Figure 4.3) (Jarque and Bera, 1987; Wooldridge, 2013; Glen, 2016).

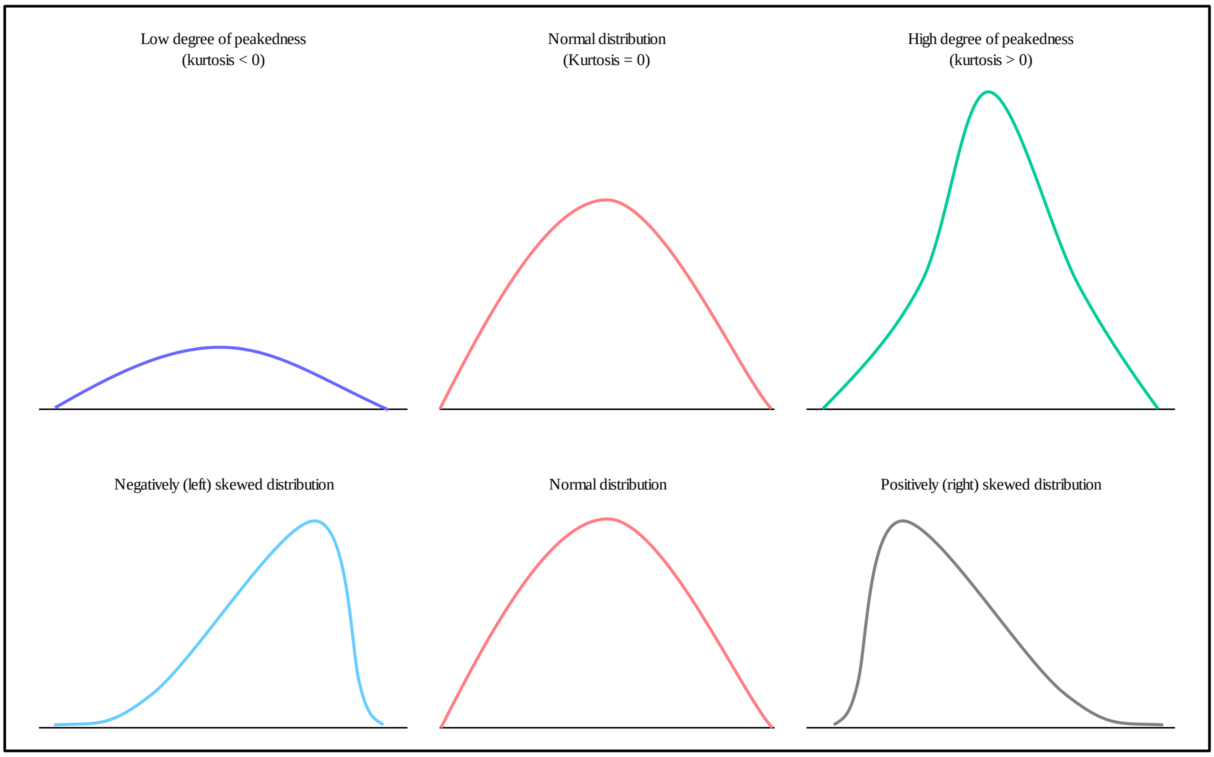

Figure 4.3 An illustration of kurtosis and skewedness

Adapted from Wooldridge (2013)

The White test for heteroskedasticity tests whether the variances of the residual terms are equal (H_0: no heteroskedasticity) (Williams, 2020). Heteroskedasticity refers to the spread (or scatter) of data (Figure 4.4), where data that is heteroskedastic is unequally distributed, while data that is equally distributed is referred to as homoskedastic (White, 1980; Wooldridge, 2013).

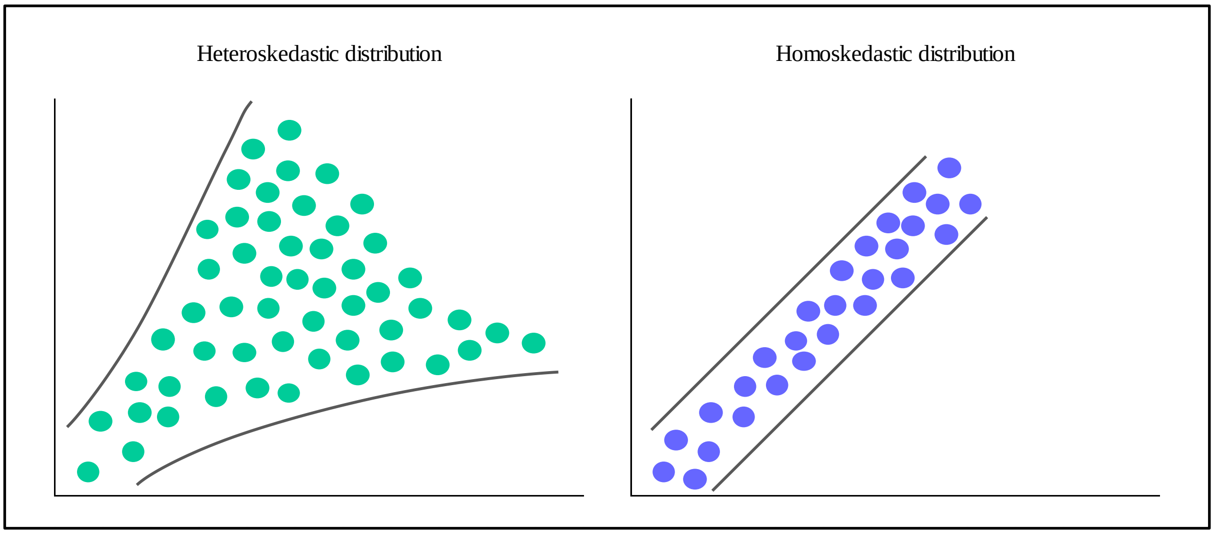

Figure 4.4 An illustration of heteroskedastic and homoscedastic distributions
Adapted from White (1980) and Wooldridge (2013)

The Breusch-Godfrey test for autocorrelation is a Lagrange multiplier test that is run on the residual terms, with a null hypothesis that no correlation exists among the residuals of different time periods (Figure 4.5) (Wooldridge, 2013; Pedace, 2016).

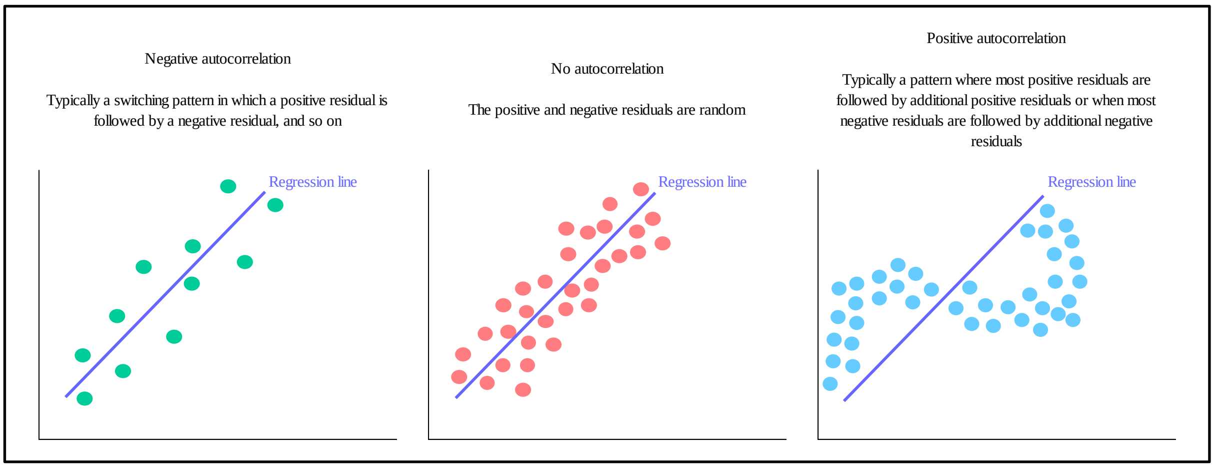

Figure 4.5 An illustration of autocorrelation patterns

Adapted from: Pedace (2016)

Lastly, general form misspecification is tested by using the Ramsey regression specification error test (RESET) (Adil, Hatekar and Sahoo, 2020). It should be noted, however, that the Ramset RESET test is purely a functional form test and does not provide an indication of what the precise misspecification identified might be (omitted variables or heteroskedasticity for example), nor does it offer an immediate suggestion on next steps needed to rectify the misspecification (Wooldridge, 2013).

4.4 Definition, Source and Expected Signs of Data Variables

This study will evaluate the effect of FMD on the average beef carcass price in South Africa. The theoretical specification is provided in Equation 4.12.

$$f(BEEF\_PRICE) = f(BEEF\_EXP; YMAZ; WEANER; BEEF\_VOL; POULTRY; ZAR) \qquad (4.12)$$

The monthly data from January 2010 to December 2021, amounting to 144 observations per variable, was gathered from multiple sources, as shown in Table 4.1. Data, daily and weekly, was converted to monthly data by using the averages across the relevant days and/or weeks, as applicable.

Table 4.1 Definition, source and expected sign of data variables

Data variable	Abbreviated name of data variable	Unit	Source	Expected relationship	High-level reasoning
Average South African beef carcass price[10]	BEEF_PRICE	South African rand per kilogram (R/kg)	Absa Agribusiness (2022)	Dependent variable	N/A
South African live weaner auction calf price	WEANER	South African rand per kilogram (R/kg)	Absa Agribusiness (2022); RMAA (2022)	Positive	If a farmer or feedlot needs to pay a higher price for a weaner calf, they may attempt to pass this increased cost on to the abattoir and therefore to the final consumer. As such, it is broadly assumed that an increase/decline in weaner calf prices could result in an increase/decline in beef prices.
SAFEX yellow maize closing spot price	YMAZ	South African rand per metric tonne (R/t)	Datastream International (2022)	Positive	As maize is a large component of feed in the raising of beef cattle, an increase in the price of yellow maize would make the input costs of raising cattle more expensive (Barkley, 2012). As such, farmers and feedlots may attempt to pass this increased cost on to the abattoir and therefore to the final consumer. As such, it is broadly assumed that an increase/decline in yellow maize prices would result in an increase/decline in beef prices (Westhoff et al., 2004).
Volume of beef (fresh, chilled, or frozen) of South African origin	SA_BEEF_EXP	Kilograms (kg).	SARS (2022)	Positive	South Africa's exports of beef are used as a proxy[11] to show the presence of the FMD outbreak. During the height of the FMD outbreak, South Africa was unable to export beef products. However, over time, the South African

[10] Weighted average across classes A, AB, B and C

11 The use of a dummy variable to show that the FMD outbreak would not have been able to capture the nuances of these bilateral trade agreements, whereby some of South Africa's beef could be exported, albeit only to certain destinations, typically at lower volumes, than if the outbreak had not occurred.

exported to the rest of the world					government entered into bilateral agreements with various countries who would accept beef from South Africa, provided it had necessary certifications in place. An increased/reduced demand for SA's beef exports would result in an increase/decline in beef prices.
The last traded mid-price (mid-point between the bid and offer price)	ZAR	South African rand per one US dollar (R/US$)	Datastream International (2022)	Positive	It is expected that, as the South African exchange rate, compared with the US dollar, strengthens, beef carcass prices would increase as exporters earn more income in Rand terms for their sale. A strengthening/weakening in the exchange rate would result in an increase/decline in beef prices.

4.5 Concluding Remarks

An overview of the empirical techniques that were employed in the study and of the associated theoretical framework of these techniques is provided in this chapter. Additionally, it provides a definition and the expected signs of the variables that would be used. This study made use of Version 12 of the computer software, EViews (IHS Markit, 2017).

Visually appraising the data, as well as using the ADF and PP tests, will indicate the presence of unit roots (Phillips and Perron, 1988; University of Washington, n.d.). Following OLS, the Engle-Granger cointegration test will determine the presence of a long-run cointegrating relationship between variables (Engle and Granger, 1987; Price, 2003); thereafter, the ECM will be developed to account for short-run dynamics of variables (Omoke, 2010; Wooldridge, 2013). Finally, diagnostic tests for normality, heteroskedasticity, serial correlation and general misspecification, will be performed to justify the interpretation of the results for the study population.

Chapter 5:
Presentation of Findings and Interpretation of Results

5.1 Introduction

This chapter will provide the results of the empirical tests performed across the model being used to quantify the impact of FMD on the average beef carcass price in South Africa. Firstly, all variables are visually appraised to gain an understanding of their stationarity, followed by applying the formal ADF and PP tests to determine the order of integration. Once determined, OLS regression and the Engle-Granger cointegration test are used to estimate the long-run relationship, while the results (Engle and Granger, 1987) of the ECM provide an indication of the short-run dynamics (De Beer, 2009). The results of the diagnostic tests are provided to validate the interpretation of the results for the study population.

5.2 Unit Root Test Results

Determining the number of unit roots that the variables in this study contain is achieved through visually appraising the graphical depiction of the variables, in both their level and differenced forms, as well as with formal testing through the ADF and PP tests for unit roots.

The average beef carcass price (BEEF_PRICE), volume of beef cattle slaughtered (BEEF_VOL), volume of beef exported by South Africa (SA_BEEF_EXP), weaner calf live price (WEANER), yellow maize price (YMAZ), and the South African rand to US dollar exchange rate (ZAR) are all visually non-stationary, i.e. they have a varying mean, variance and covariance, showing either upwards or downwards trends, over time, which in their level form, however, become stationary once differenced (Figure 5.1).

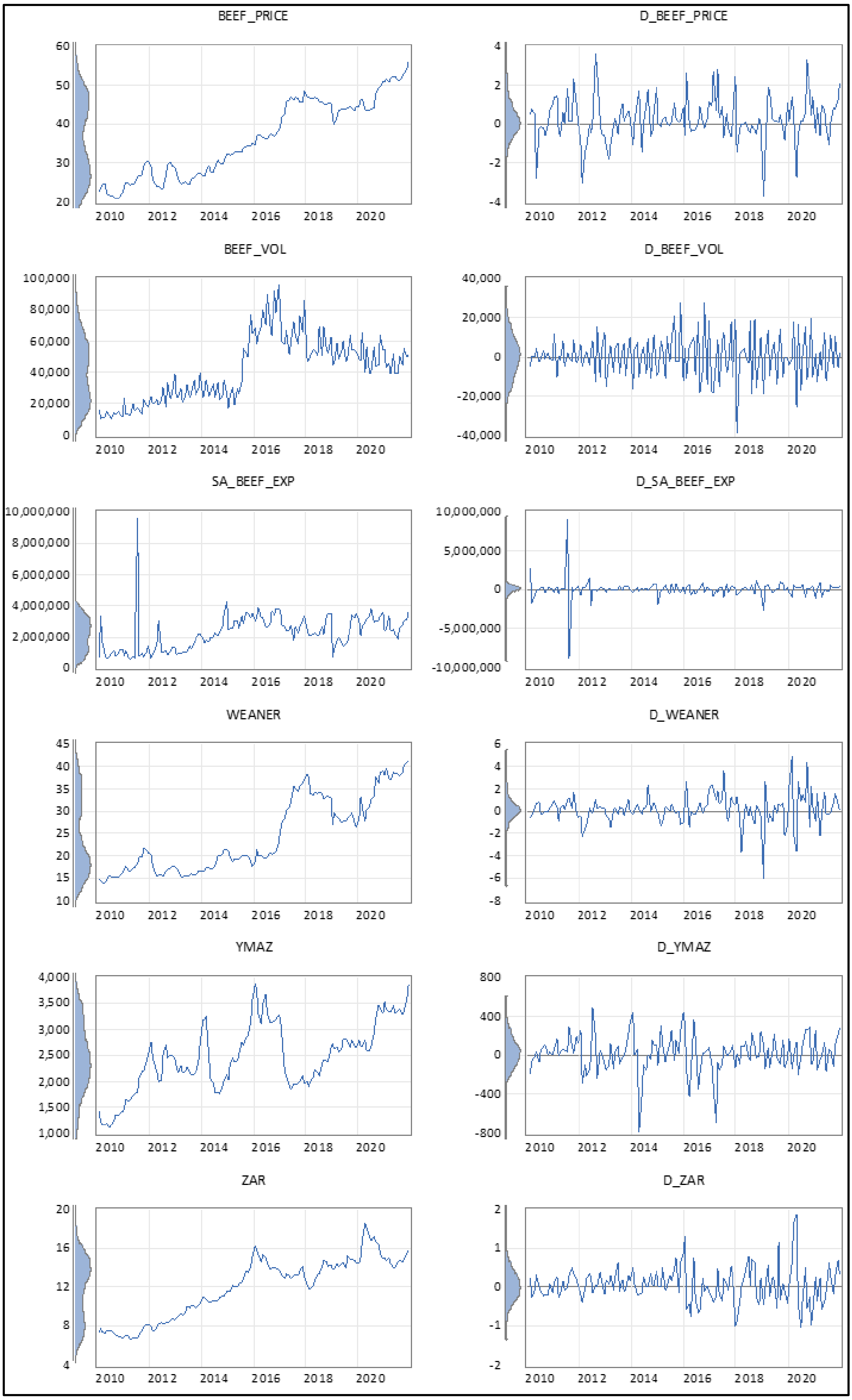

Figure 5.1 Visual representation of variables in level and differenced form

Following this visual appraisal, the ADF and PP formal tests confirm the presence or absence of unit roots for all variables used in this study (Phillips and Perron, 1988; IHS Markit, 2017; University of Washington, n.d.). Both test the null hypothesis (H_0) that the underlying series contains a unit root (Phillips and Perron, 1988; Wooldridge, 2013) and needs to be differenced before becoming stationary, a significant test result that would result in the rejection of H_0 and indicate that the underlying series is stationary (Section 4.3.4).

Table 5.1 Augmented Dickey-Fuller and Phillips Perron tests for unit roots in the level and differenced form of variables[12]

Variable in level and first differenced (Δ) form	Model	Augmented Dickey Fuller (ADF)		Phillips Perron		Conclusion
		Lags	τ_τ, τ_μ, τ	Bandwidth	PP	
BEEF_PRICE	Trend and intercept	1	-3.018	2	-2.598	Fail to reject H_0 Series is non-stationary
	Intercept	1	-0.129	0	0.195	
	None	1	1.728	0	2.444	
Δ BEEF_PRICE	Trend and intercept	0	-8.845***	2	-8.818***	Reject H_0 Series is stationary
	Intercept	0	-8.827***	2	-8.803***	
	None	0	-8.565***	2	-8.543***	
BEEF_VOL	Trend and intercept	2	-1.724	4	-4.217***	Fail to reject H_0 Series is non-stationary
	Intercept	2	-1.692	4	-2.721*	
	None	2	-0.019	43	-0.884	
Δ BEEF_VOL	Trend and intercept	1	-14.605***	23	-29.501***	Reject H_0 Series is stationary
	Intercept	1	-14.618***	21	-27.483***	
	None	1	-14.620***	20	-26.476***	
SA_BEEF_EXP	Trend and intercept	0	-8.759***	5	-9.096***	Reject H_0 Series is stationary
	Intercept	1	-4.791***	6	-8.004***	
	None	4	-0.492	6	-2.045**	
Δ SA_BEEF_EXP	Trend and intercept	3	-9.984***	141	-85.107***	Reject H_0 Series is stationary
	Intercept	3	-10.022***	141	-76.551***	
	None	3	-10.044***	141	-67.936***	
WEANER	Trend and intercept	0	-1.990	6	-2.223	Fail to reject H_0 Series is non-stationary
	Intercept	0	-0.223	5	-0.291	
	None	0	1.494	5	1.435	

12 * (**) [***] Statistically significant, at a 10% (5%) [1%] level.

	Trend and intercept	0	-11.644***	5	-11.649***	Reject H_0 Series is stationary
Δ WEANER	Intercept	0	-11.643***	5	-11.650***	
	None	0	-11.459***	6	-11.517***	
	Trend and intercept	1	-3.061	1	-2.437	Fail to reject H_0 Series is non-stationary
YMAZ	Intercept	1	-2.245	2	-1.767	
	None	1	0.351	3	0.473	
	Trend and intercept	0	-8.692***	8	-8.353***	Reject H_0 Series is stationary
Δ YMAZ	Intercept	0	-8.723***	8	-8.388***	
	None	0	-8.679***	7	-8.403***	
	Trend and intercept	1	-2.895	1	-2.421	Fail to reject H_0 Series is non-stationary
ZAR	Intercept	1	-1.161	3	-1.087	
	None	1	0.831	4	1.079	
	Trend and intercept	0	-9.108***	8	-8.855***	Reject H_0 Series is stationary
ΔZAR	Intercept	0	-9.142***	8	-8.895***	
	None	0	-9.056***	7	-8.875***	

When considering the overall results of the formal unit root test results shown in Table 5.1, in conjunction with the graphical visual analysis (Figure 5.1), the conclusion is that all variables, except for the volume of beef exported by South Africa which is stationary in its level and first differenced form, are non-stationary in their level form and become stationary after being differenced once.

5.3 Long-run Relationship (OLS Regression and Engle-Granger Cointegration) Results

Performing OLS regression, by using lagged weaner calf prices (lagged for one period, i.e. one month), logged beef export volumes, lagged yellow maize prices (lagged for one period, i.e. one month) and the exchange rate as independent variables (Equation 5.1), indicates the presence of a statistically significant, long-run relationship with an adjusted R^2 value of 0.9545 (Table 5.2). The coefficients of all variables make economic sense and are statistically significant at a 1% or 5% level, as outlined in Table 5.3. Furthermore, based on the Engle-Grange cointegration test results shown in Table 5.4, the null hypothesis is rejected at a 10% level of significance, and it can be concluded that the underlying series in Equation 5.1 is cointegrated (IHS Markit, 2017; Wooldridge, 2013; De Beer, 2009; Price, 2003).

$$Log(BEEF\_PRICE)_t = 2.1326 + 0.022\ WEANER_{t-1} + 0.0319\ Log(SA\_BEEF\_EXP)_t$$
$$3.70e^{-05}\ \text{YMAZ}_{t-1} + 0.0273\ ZAR_t + \varepsilon_t$$
$$t = 1,2,\ldots,143 \quad (5.1)$$

Table 5.2 OLS long-run estimation results

Dependent variable: LOG(BEEF_PRICE)				
Method: Least Squares				
Date: 11/05/23				
Sample (adjusted): 2010M02 2021M12				
Included observations: 143 after adjustments				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	2.132624	0.174925	12.19167	0.0000
WEANER(-1)	0.022209	0.000894	24.84538	0.0000
LOG(SA_BEEF_EXP)	0.031962	0.013332	2.397479	0.0178
YMAZ(-1)	3.70E-05	1.12E-05	3.310270	0.0012
ZAR	0.027311	0.003577	7.634366	0.0000
R-squared	0.954469	Mean dependent var		3.551737
Adjusted R-squared	0.953150	S.D. dependent var		0.279038
S.E. of regression	0.060398	Akaike info criterion		-2.741395
Sum squared resid	0.503407	Schwarz criterion		-2.637799
Log likelihood	201.0097	Hannan-Quinn criterion		-2.699298
F-statistic	723.2295	Durbin-Watson stat		0.479950
Prob (F-statistic)	0.000000			

Table 5.3 Interpreting the economical and statistical significance of OLS results

Variable	Co-efficient	Expected sign	Economic significance	Statistical significance
WEANER(-1)	0.0222	Positive	An increase in the weaner calf price from the previous period (prior month) would result in an increase in beef prices in the current period (current month).	Statistically significant at a 1% level
Log(SA_BEEF_EXP)	0.0319	Positive	Increased demand for SA's beef exports would result in an increase in beef prices.	Statistically significant at a 5% level

YMAZ(-1)	$3.70\ e^{-05}$	Positive	An increase in the yellow maize price from the previous period (prior month) would result in an increase in beef prices in the current period (current month).	Statistically significant at a 1% level
ZAR	0.0273	Positive	A strengthening in the exchange rate would result in an increase in beef prices.	Statistically significant at a 1% level

Table 5.4 Engle-Granger cointegration test results

Engle-Granger Cointegration Test					
Date: 11/06/23					
Series: LOG_BEEF_PRICE LAG_WEANER LOG_SA_BEEF_EXP LAG_YMAZ ZAR					
Sample (adjusted): 2010M02 2021M12					
Null hypothesis: Series are not cointegrated					
Cointegrating equation deterministic: C					
Automatic lags specification based on Schwarz criterion (maxlag=13)					
Dependent	Tau-statistic		Prob*	z-statistic	Prob.*
LOG_BEEF_PRICE	-4.367769		0.0705	-34.09765	0.0587
LAG_WEANER	-4.023672		0.1446	-30.59037	0.1058
LOG_SA_BEEF_EXP	-8.577361		0.0000	-93.39391	0.0000
LAG_YMAZ	-2.446451		0.8369	-12.90394	0.7919
ZAR	-4.388687		0.0672	-33.91146	0.0607
*MacKinnon (1996) p-values.					
Intermediate Results:					
	LOG_BEEF_ PRICE	LAG_ WEANER	LOG_SA_ BEEF_EXP	LOG_YMAZ	ZAR
Rho – 1	-0.240124	-0.215425	-0.657704	-0.090873	-0.238813
Rho S.E.	0.054976	0.053539	0.076679	0.037145	0.054416
Residual variance	0.001509	2.336832	0.115407	36421.73	0.592350
Long-run residual variance	0.001509	2.336832	0.115407	36421.73	0.592350
Number of lags	0	0	0	0	0
No. of observations	142	142	142	142	142
No. of stochastic trends **	5	5	5	5	5
** Number of stochastic trends in asymptotic distribution					

5.4 Error Correction Models

After performing the ADF and PP tests on the residuals of Equation 5.1, it is evident that the residuals are stationary in their level form (Table 5.5). As the residuals of an I(1) series are stationary at I(0), it can be inferred that there is a short-run relationship between the variables in Equation 5.1.

Table 5.5 Augmented Dickey-Fuller and Phillips Perron tests for unit roots on the residuals of Equation 5.1[13]

Residuals in level and form	Model	Augmented Dickey Fuller (ADF)		Phillips Perron		Conclusion
		Lags	τ_τ, τ_μ, τ	Bandwidth	PP	
Equation 5.1	Trend and intercept	0	-5.148***	1	-5.166***	Reject H_0 Series is stationary
	Intercept	0	-5.158***	1	-5.175***	
	None	0	-5.176***	1	-5.194***	

An ECM is used to determine the short-run dynamics with the coefficient of the ECM, indicating the speed of adjustment toward equilibrium (De Beer, 2009: Davids et al., 2018). Equation 5.2 indicates the relationship between variables in the short run, based on the ECM results (Table 5.6).

$$D(LOG\_BEEF\_PRICE_t) = 0.0043 + 0.0094\ D(WEANER)_{t-1} + 0.014\ D(LOG\_SA\_BEEF\_EXP)_t + 2.4e^{-05} D(YMAZ)_{t-1} - 0.0063\ D(ZAR)_t - 0.003\ \varepsilon_{t-1}$$
$$t = 1,2, \ldots ,142 \tag{5.2}$$

Table 5.6 Results of Error Correction Model

Dependent variable: D(LOG_BEEF_PRICE)				
Method: Least Squares				
Date: 11/06/23				
Sample (adjusted): 2010M03 2021M12				
Included observations: 142 after adjustments				
Variable	Coefficient	Std. Error	t-Statistic	Prob.

13 * (**) [***] Statistically significant at a 10% (5%) [1%] level

C	0.004368	0.002754	1.586132	0.1150
D(LAG_WEANER)	0.009453	0.002251	4.200347	0.0000
D(LOG_SA_BEEF_EXP)	0.014020	0.006383	2.196597	0.0297
D(LAG_YMAZ)	2.40E-05	1.49E-05	1.612936	0.1091
D(ZAR)	-0.006355	0.006116	-1.038952	0.3007
RESID_EQ3(-1)	-0.003004	0.001773	-1.694600	0.0924
R-squared	0.161030	Mean dependent var		0.006115
Adjusted R-squared	0.130186	S.D. dependent var		0.034350
S.E. of regression	0.032036	Akaike info criterion		-4.002584
Sum squared resid	0.139577	Schwarz criterion		-3.877690
Log likelihood	290.1835	Hannan-Quinn criterion		-3.951832
F-statistic	0.000204	Durbin-Watson stat		1.489565
Prob (F-statistic)				

The speed of adjustment coefficient of -0.003 (statistically significant at a 10% level of significance) means that 0.3% of long-run disequilibrium will be eliminated in the first month; following this, of the remaining disequilibrium, another 0.003% will be eliminated in the second month, and so on. This indicates an extremely low speed of adjustment back to equilibrium following an exogenous shock (De Beer, 2009; Davids et al., 2018), such as an outbreak of FMD.

5.5 Diagnostic Test Results

Based on the diagnostic test results shown in Table 5.7, the long-run equilibrium model (Thomsen, 2021), as depicted by Equation 5.1, contains defects and thus should not be used for hypothesis testing or forecasting. Specifically, the Jarque-Bera test showed that the residuals are normally distributed (Jarque and Bera, 1987), with a skewness value of 0.105 and a low degree of peakiness (kurtosis value of 2.438). However, at a 10% level of significance, the White test indicated that the residuals are heteroskedastic. Furthermore, the Breusch-Godfrey test indicated that there was serial correlation present up to the second order, and the Ramsey RESET test showed that the model was misspecified.

Table 5.7 Long-run diagnostic test results

Test	H_0	Test statistic	Conclusion
Jarque-Bera	Residuals are normally distributed	2.1411	Fail to reject H_0 Residuals are normally distributed
Breusch-Godfrey	No serial correlation (up to 2 lags)	93.825***	Reject H_0 Serial correlation is present up to the 2^{nd} order
White (no cross terms)	Homoskedasticity	2.055*	Reject H_0 at a 10% level Residuals are heteroskedastic
Ramsey RESET	No misspecification	9.169***	Reject H_0 Model is mis specified

Based on the diagnostic test results shown in Table 5.8, the short-run equilibrium model, as depicted by Equation 5.2, contains certain defects and would need to be used with caution, if used for hypothesis testing or forecasting because, although the model is specified correctly, there is serial correlation up to the second order, and the residuals are not normally distributed. Specifically, the White test indicated that the residuals are heteroskedastic. This was further proven by the Jarque-Bera test, which showed that the residuals are negatively skewed (skewness value of -0.009) and have a high degree of peakiness (kurtosis value of 6.163). Although serial correlation up to the second order is present, as evidenced by the Breusch-Godfrey test, this could be minimised or removed by including the lagged dependent variable as an additional independent variable. Moreover, the Ramsey RESET test showed that the model was not mis specified.

Table 5.8 Short-run diagnostic test results

Test	H_0	Test statistic	Conclusion
Jarque-Bera	Residuals are normally distributed	59.19***	Reject H_0 Residuals are not normally distributed
Breusch-Godfrey	No serial correlation (up to 2 lags)	7.247***	Reject H_0 Serial correlation is present up to the 2^{nd} order
White	Homoskedasticity	2.139*	Reject H_0 at a 10% level

(no cross terms)			Residuals are heteroskedastic
Ramsey RESET	No misspecification	0.2138	Fail to reject H_0 Model is not mis specified

5.6 Concluding Remarks

This chapter provided the results of the empirical tests that were performed. OLS regression and the Engle-Granger test indicated a statistically significant cointegrated relationship between the dependent variable and the independent variables in the long-run, as depicted by Equation 5.1, with 95.45% of long-run variation in the average South African beef carcass price, being caused by changes in the independent variables. In the short term, the ECM, as depicted by Equation 5.2, indicates a very slow speed of adjustment of 0.003% back to equilibrium, following an exogenous shock such as an outbreak of FMD (De Beer, 2009: Davids et al., 2018: Wooldridge, 2013).

By comparing Equations 5.1 and 5.2, it is evident that, in the long run, a 1% decrease in South Africa's exports of beef would result in a 0.03% decrease in the average beef carcass price, while in the short run, a 1% decrease in South Africa's beef exports would result in a 0.0142% decrease in the average beef carcass price.

However, based on diagnostic testing, it is clear that there are defects in both the long-run and short-run equilibrium models, as it was found that the residuals were heteroskedastic and serial correlation was evident, while overall misspecification was present in the long-run, but not in the short-run, equilibrium models. As such, the results are not suitable to be used for hypothesis testing or forecasting, and therefore cannot be used to provide an indication or to quantify the impact that an FMD outbreak has on the South African beef industry. Changes to the model specifications would be required. This is discussed further in Chapter 6.

Chapter 6:
Conclusion and Recommendations

6.1 Summary of the Study

As discussed in Chapter 1, Foot and Mouth Disease (FMD) is highly contagious and affects cloven-hooved ruminants, such as cattle, and is endemic to South Africa (OIE, 2021[a]). On the 2nd of January 2019, the OIE suspended South Africa's FMD-free zone status (OIE, 2021[a]) owing to the confirmation that the cattle in the Vhembe District of Limpopo had contracted FMD (Absa Agribusiness, 2020; DAFF, 2022; Dairy Global, 2022). The announcement of the FMD outbreak had an immediate impact on domestic beef prices, with class A beef carcass prices taking approximately 29 weeks to reach the same/similar price levels seen during the week prior to the outbreak announcement. While an FMD outbreak is considered to have a considerable impact on the beef industry, the overarching goal of this study aimed to gain an understanding of the level of impact that an outbreak of FMD would have on the South African beef industry by quantifying that impact.

Chapter 2 supported meeting the first two objectives of the study, namely mapping the key activities in the South African beef value chain and establishing the extent to which the export market plays a role in the South African beef industry and determining the major trading partners. By applying the methodology as set out in Chapter 4, it is evident that South Africa's beef export volumes have a statistically significant relationship to South Africa's average beef carcass prices and were therefore used as a proxy for an FMD outbreak, meeting the third objective of the study. A statistically significant long-run cointegrating relationship was evident from the results of the Engle-Granger test, while the ECM indicated a very slow speed of adjustment of 0.003% per month back to equilibrium, following an exogenous shock such as an outbreak of FMD.

The results of the study outlined in Chapter 5 indicate that, in the long run, a 1% decrease in South Africa's exports of beef would result in a 0.03% decrease in the average beef carcass price and in the short run a 1% decrease in South Africa's beef exports would result in a

0.0142% decrease in the average beef carcass price. However, the diagnostic tests indicate that there are clear defects in the long- and short-run models. As such, the results are not suitable to be used for hypothesis testing or forecasting, and therefore cannot be used to provide an indication or to quantify the impact that an FMD outbreak has on the South African beef industry.

6.2 Concluding Remarks

By first determining whether South Africa's exports of beef have a statistically significant relationship with the average beef carcass price in South Africa, the following hypothesis was developed:

> *H_0: The volume of beef exported by South Africa has a statistically significant long-run relationship with the South African average beef carcass price, at a 5% level of significance.*

Based on the OLS results provided in Chapter 5, I fail to reject the null hypothesis and conclude that South Africa's exports of beef have a statistically significant, long-run relationship with the average South African beef carcass price. As such, South Africa's beef exports were used as a proxy for an FMD outbreak.

In order to achieve the overarching objective of this study, to quantify the impact of an FMD outbreak on the average beef carcass price in South Africa, this study hypothesised:

> *H_0: The volume of beef exported by South Africa, and by proxy an outbreak of FMD, has a negative impact on average South African beef carcass price, with a relatively fast speed of adjustment back to long-run equilibrium.*

Based on the results presented in Chapter 5, as well as the summary given in Section 6.1, and as the model developed in this study contained defects and therefore is not suitable for hypothesis testing and forecasting, I can neither conclusively reject, nor fail to reject, the null hypothesis that the volume of beef exported, and by proxy, an outbreak of FMD, negatively impacts the average South African beef carcass price, with a relatively fast speed of adjustment back to equilibrium.

Given the results of this study, it is evident that the model would need to be re-specified in further research to overcome any shortcomings. Although unable to quantify the impact of an FMD outbreak on the South African beef industry, the literature review has found no other studies that have been done to quantify the outbreak specific impact of FMD, and accordingly, this study does support the need for further research to be conducted on the economic impact of an outbreak on the South African beef industry.

6.3 Shortcoming of Research and Proposal for Further Research

6.3.1 Shortcomings of the research

- South Africa's beef exports consist predominantly of high-value cuts of beef, and as such, using the total volume of beef exported by South Africa creates an inaccurate representation of the export market dynamics, including key trade partners and quantity of cuts exports.
- This study used price data in nominal terms and therefore likely modelled inflation.
- Given that the long-run model was identified as being misspecified, it is important to consider different specifications and combinations of data.
- The frequency of data should be considered, as the South African beef industry is fast-paced and, therefore, the impact of an FMD outbreak might be significant over a very short period, which then becomes insignificant when using monthly/annual data.

6.3.2 Proposals for further research

- Based on the shortcomings, the following proposals are made for further research:
    - Split out the South African export data into cuts of beef exported, and review the key export destinations for each cut;
    - Deflate price data into real terms;
    - Consider different specifications of the model, including bringing in substitute products;
    - Consider the exchange rate of the South African Rand relative to the currency of the top export destination for the high-value cuts of beef; and
    - Use data with a weekly frequency to enable a more accurate determination to be made of the fast-paced changes in the South African beef industry.
- The determination of an alternative indicator for the presence / absence of the FMD-free zone status of South Africa might yield more significant results and could incorporate the subtle changes made by the signing of bilateral agreements with various export destinations.
- As South Africa missed the deadline to reinstate its FMD-free-zone status, the full re-application process would need to be submitted to the OIE, and as this outbreak from January 2019 has signified a structural shift in the South African beef market, this should be taken into account in further studies.

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Annexure

A1 Long-run diagnostic tests results

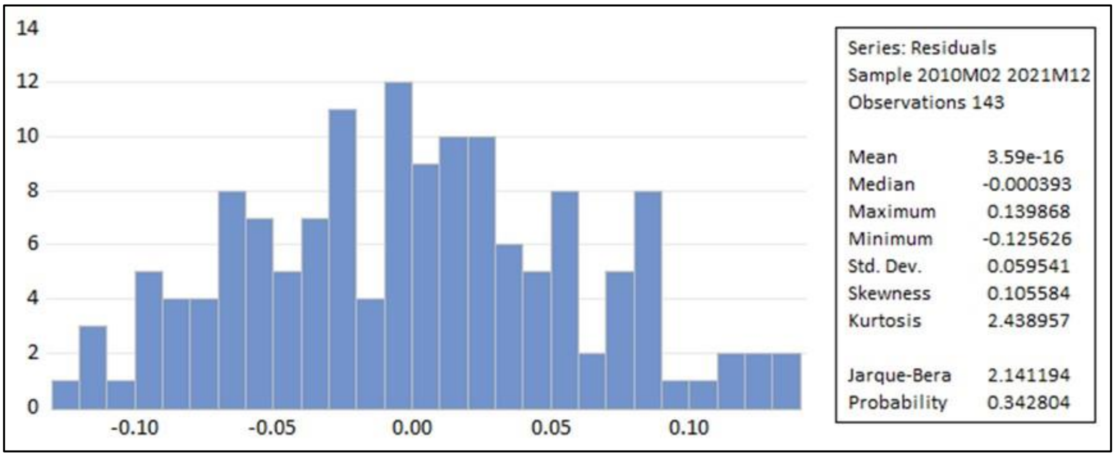

Figure A 1 Jarque-Bera test for normality

Heteroskedasticity Test: White
Null hypothesis: Homoskedasticity

F-statistic	2.054466	Prob. F(4,138)	0.0901
Obs*R-squared	8.037010	Prob. Chi-Square(4)	0.0902
Scaled explained SS	5.385158	Prob. Chi-Square(4)	0.2500

Test Equation:
Dependent Variable: RESID^2
Method: Least Squares
Date: 11/06/23 Time: 15:49
Sample: 2010M02 2021M12
Included observations: 143

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.017860	0.005805	3.076483	0.0025
WEANER(-1)^2	-3.96E-07	1.07E-06	-0.368860	0.7128
LOG(SA_BEEF_EXP)^2	-7.64E-05	3.06E-05	-2.493704	0.0138
YMAZ(-1)^2	-1.89E-10	1.48E-10	-1.278256	0.2033
ZAR^2	2.09E-05	9.29E-06	2.245049	0.0264

R-squared	0.056203	Mean dependent var	0.003520
Adjusted R-squared	0.028846	S.D. dependent var	0.004238
S.E. of regression	0.004176	Akaike info criterion	-8.084522
Sum squared resid	0.002407	Schwarz criterion	-7.980926
Log likelihood	583.0433	Hannan-Quinn criter.	-8.042425
F-statistic	2.054466	Durbin-Watson stat	0.966195
Prob(F-statistic)	0.090130		

Figure A 2 White test for heteroskedasticity

Breusch-Godfrey Serial Correlation LM Test:
Null hypothesis: No serial correlation at up to 2 lags

F-statistic	93.82518	Prob. F(2,136)	0.0000
Obs*R-squared	82.91047	Prob. Chi-Square(2)	0.0000

Test Equation:
Dependent Variable: RESID
Method: Least Squares
Date: 11/06/23 Time: 15:48
Sample: 2010M02 2021M12
Included observations: 143
Presample missing value lagged residuals set to zero.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.033622	0.114265	-0.294240	0.7690
WEANER(-1)	-0.000265	0.000584	-0.454119	0.6505
LOG(SA_BEEF_EXP)	0.002712	0.008709	0.311349	0.7560
YMAZ(-1)	7.09E-06	7.38E-06	0.960965	0.3383
ZAR	-0.001415	0.002353	-0.601342	0.5486
RESID(-1)	0.804459	0.085248	9.436690	0.0000
RESID(-2)	-0.049300	0.086383	-0.570709	0.5691

R-squared	0.579793	Mean dependent var	3.59E-16
Adjusted R-squared	0.561255	S.D. dependent var	0.059541
S.E. of regression	0.039439	Akaike info criterion	-3.580432
Sum squared resid	0.211535	Schwarz criterion	-3.435397
Log likelihood	263.0009	Hannan-Quinn criter.	-3.521497
F-statistic	31.27506	Durbin-Watson stat	1.990780
Prob(F-statistic)	0.000000		

Figure A 3 Breusch-Godfrey test for serial correlation

Ramsey RESET Test
Equation: EQ03
Omitted Variables: Squares of fitted values
Specification: LOG(BEEF_PRICE) C WEANER(-1) LOG(SA_BEEF_EXP) YMAZ(-1) ZAR

	Value	df	Probability
t-statistic	9.169731	137	0.0000
F-statistic	84.08396	(1, 137)	0.0000
Likelihood ratio	68.43431	1	0.0000

F-test summary:

	Sum of Sq.	df	Mean Squares
Test SSR	0.191459	1	0.191459
Restricted SSR	0.503407	138	0.003648
Unrestricted SSR	0.311948	137	0.002277

LR test summary:

	Value
Restricted LogL	201.0097
Unrestricted LogL	235.2269

Unrestricted Test Equation:
Dependent Variable: LOG(BEEF_PRICE)
Method: Least Squares
Date: 11/06/23 Time: 15:56
Sample: 2010M02 2021M12
Included observations: 143

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	4.263106	0.270335	15.76974	0.0000
WEANER(-1)	0.141949	0.013077	10.85466	0.0000
LOG(SA_BEEF_EXP)	0.181094	0.019376	9.346159	0.0000
YMAZ(-1)	0.000235	2.33E-05	10.07346	0.0000
ZAR	0.160308	0.014777	10.84870	0.0000
FITTED^2	-0.730698	0.079686	-9.169731	0.0000

R-squared	0.971786	Mean dependent var	3.551737
Adjusted R-squared	0.970756	S.D. dependent var	0.279038
S.E. of regression	0.047718	Akaike info criterion	-3.205970
Sum squared resid	0.311948	Schwarz criterion	-3.081655
Log likelihood	235.2269	Hannan-Quinn criter.	-3.155454
F-statistic	943.7411	Durbin-Watson stat	0.652381
Prob(F-statistic)	0.000000		

Figure A 4 Ramsey RESET test for misspecification

A2 Short-run diagnostic tests results

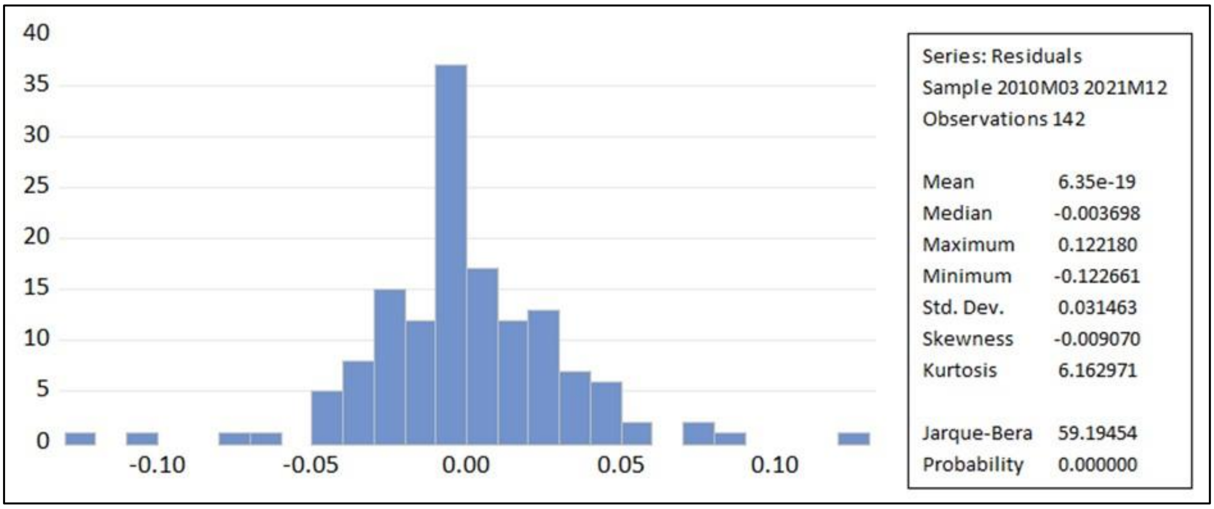

Figure A 5 Jarque-Bera test for normality

Heteroskedasticity Test: White
Null hypothesis: Homoskedasticity

F-statistic	2.139444	Prob. F(5,136)	0.0644
Obs*R-squared	10.35470	Prob. Chi-Square(5)	0.0658
Scaled explained SS	24.51931	Prob. Chi-Square(5)	0.0002

Test Equation:
Dependent Variable: RESID^2
Method: Least Squares
Date: 11/06/23 Time: 15:33
Sample: 2010M03 2021M12
Included observations: 142

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.000781	0.000258	3.021571	0.0030
D(LAG_WEANER)^2	-2.51E-05	4.60E-05	-0.545858	0.5861
D(LOG_SA_BEEF_EXP...	0.000102	0.000223	0.456519	0.6487
D(LAG_YMAZ)^2	7.74E-09	2.47E-09	3.134311	0.0021
D(ZAR)^2	-0.000203	0.000434	-0.469014	0.6398
RESID_EQ3(-1)^2	2.22E-06	4.46E-05	0.049872	0.9603

R-squared	0.072920	Mean dependent var	0.000983
Adjusted R-squared	0.038837	S.D. dependent var	0.002241
S.E. of regression	0.002197	Akaike info criterion	-9.361756
Sum squared resid	0.000657	Schwarz criterion	-9.236862
Log likelihood	670.6847	Hannan-Quinn criter.	-9.311004
F-statistic	2.139444	Durbin-Watson stat	1.750810
Prob(F-statistic)	0.064424		

Figure A 6 White test for heteroskedasticity

Breusch-Godfrey Serial Correlation LM Test:
Null hypothesis: No serial correlation at up to 2 lags

F-statistic	7.247114	Prob. F(2,134)	0.0010
Obs*R-squared	13.86034	Prob. Chi-Square(2)	0.0010

Test Equation:
Dependent Variable: RESID
Method: Least Squares
Date: 11/06/23 Time: 15:17
Sample: 2010M03 2021M12
Included observations: 142
Presample missing value lagged residuals set to zero.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.000526	0.002639	0.199353	0.8423
D(LAG_WEANER)	-0.002162	0.002245	-0.962769	0.3374
D(LOG_SA_BEEF_EXP)	0.003472	0.006177	0.562121	0.5750
D(LAG_YMAZ)	-5.88E-06	1.44E-05	-0.408740	0.6834
D(ZAR)	0.000212	0.005859	0.036232	0.9712
RESID_EQ3(-1)	-0.003463	0.002046	-1.692169	0.0929
RESID(-1)	0.392829	0.103830	3.783396	0.0002
RESID(-2)	0.024834	0.091382	0.271766	0.7862

R-squared	0.097608	Mean dependent var	6.35E-19
Adjusted R-squared	0.050468	S.D. dependent var	0.031463
S.E. of regression	0.030659	Akaike info criterion	-4.077121
Sum squared resid	0.125953	Schwarz criterion	-3.910596
Log likelihood	297.4756	Hannan-Quinn criter.	-4.009452
F-statistic	2.070604	Durbin-Watson stat	1.985775
Prob(F-statistic)	0.050901		

Figure A 7 Breusch-Godfrey test for serial correlation

Ramsey RESET Test
Equation: ECM_EQ3
Omitted Variables: Squares of fitted values
Specification: D(LOG_BEEF_PRICE) C D(LAG_WEANER) D(LOG_SA_BEEF_EXP) D(LAG_YMAZ) D(ZAR) RESID_EQ3(-1)

	Value	df	Probability
t-statistic	0.213852	135	0.8310
F-statistic	0.045733	(1, 135)	0.8310
Likelihood ratio	0.048096	1	0.8264

F-test summary:

	Sum of Sq.	df	Mean Squares
Test SSR	4.73E-05	1	4.73E-05
Restricted SSR	0.139577	136	0.001026
Unrestricted SSR	0.139529	135	0.001034

LR test summary:

	Value
Restricted LogL	290.1835
Unrestricted LogL	290.2075

Unrestricted Test Equation:
Dependent Variable: D(LOG_BEEF_PRICE)
Method: Least Squares
Date: 11/06/23 Time: 15:27
Sample: 2010M03 2021M12
Included observations: 142

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.004013	0.003223	1.245007	0.2153
D(LAG_WEANER)	0.009169	0.002621	3.498832	0.0006
D(LOG_SA_BEEF_EXP)	0.013575	0.006736	2.015300	0.0459
D(LAG_YMAZ)	2.36E-05	1.51E-05	1.558969	0.1213
D(ZAR)	-0.006204	0.006178	-1.004107	0.3171
RESID_EQ3(-1)	-0.002873	0.001882	-1.526300	0.1293
FITTED^2	1.795623	8.396559	0.213852	0.8310

R-squared	0.161314	Mean dependent var	0.006115
Adjusted R-squared	0.124039	S.D. dependent var	0.034350
S.E. of regression	0.032149	Akaike info criterion	-3.988838
Sum squared resid	0.139529	Schwarz criterion	-3.843129
Log likelihood	290.2075	Hannan-Quinn criter.	-3.929628
F-statistic	4.327688	Durbin-Watson stat	1.488024
Prob(F-statistic)	0.000502		

Figure A 8 Ramsey RESET test for misspecification