Final report

Analysis of market cycles and price transmission in the red meat sector

Part 1: Market Cycle Analysis

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Abstract

AMPC commissioned SG Heilbron Economic and Policy Consulting to complete a detailed analysis of market cycles and price transmission in the red meat sector. This report presents the findings with regard to the existence of cycles in the beef and sheep meat markets (Part 1). The project methodology included design confirmation, literature review, contextual analysis, data gathering, and analysis using time series methods.

The analysis found no statistical evidence of the often-mentioned 8–10-year cycle in the Australian beef industry, which has been found to exist in the United States beef industry for more than 150 years. Further, the analysis found the Australian and US markets have become uncoupled in recent years, moving independently based on external factors.

The only significant correlations between current and lagged annual values are found in the beef slaughterings and prices (around 4 years peak to peak), however, the 4-year cycle in prices is not confirmed in the quarterly data analysis. The short-term analysis found significant 2-3-year cycles in mutton sector prices and quantities. These results are indicative of much shorter-term red meat industry variability in Australia, more likely to be caused by changes in world market conditions on the demand side, and by changes in environmental conditions on the supply side, than by the decisions of beef cattle producers making decisions based on belief that the past will continue into the present and the future.

While there may still be ‘cyclical tendencies’ evident in industry data such as a graph showing an apparent regular movement of prices of a farm product up and down over a previous time period, these tendencies are not statistically significant. Such tendencies should not be called a ‘cycle’. It should not be presumed that such patterns will happen in the future, and it should not be the information on which to base decisions about future production levels.

Executive summary

Research was commissioned by the Australian Meat Processor Corporation (AMPC) and was conducted by Dr Selwyn Heilbron of SG Heilbron Economic and Policy Consulting, and Professors Garry Griffith and Bill Malcolm of the University of Melbourne, exploring market dynamics in the Australian red meat sector.

The research involved three parts and is presented in separate reports with linked findings.

- Part 1: Analysis of market cycles in the red meat sector **(this report)**
- Part 2: Analysis of price transmission in the red meat sector
- Part 3: Processor-specific and regional analysis

Both the analysis of market cycles and price transmission involved a separate review of the literature and analysis of long-term (annual) data and short-term (quarterly) data.

Cattle and sheep market cycles

The use of the term ‘cycles’ in livestock industry analyses commonly means regular, predictable cyclical patterns in breeding numbers (cows, ewes, sows, etc.) (Tomek and Kaiser, 2014; Griffith, 1977; Rosen et al., 1994). Livestock producers’ decisions about expanding or contracting breeding numbers initiate the cycle based on expectations about future profitability. These patterns in breeding numbers then result in closely related but lagged patterns in slaughterings and production of meat and opposite patterns in farm prices.

Method

The initial research stage involved the analysis of five decades of annual market data, using a time series econometrics technique known as autocorrelation analysis. For each series examined, correlations between the current values of that series and the values lagged by one, two, … up to 10 were calculated and statistical tests at the 95 per cent level of probability were applied to determine the strength of these relationships. The same analysis was then completed using quarterly data series.

Findings

The initial analysis using annual data found there was no evidence of the typical 8–10-year cycle found in the United States beef industry and in previous studies in Australia. The only significant correlations between current and lagged values were found in the beef slaughterings series (negative at lags 2 and 3 (cycles of around 4 years)) and in the cattle price series (negative at lag 2 (cycle of 4 years)).

The above patterns were confirmed in the analysis of quarterly slaughterings and production data series. In addition, there were found to be significant annual cycles in all these series. However, for the beef price series, the 4-year cycle found in the annual data was not confirmed in this analysis using quarterly data. Nor was there any significant seasonal cycle, although there was some evidence of other significant very short-term regular patterns.

For lamb markets, the short-term quarterly analysis confirmed the findings of the annual analysis showing no evidence of cyclical behaviour apart from cross linkages with the beef industry through prices. However, the analysis did find significant 2-3 year cycles in the mutton sector prices and quantities. In addition, there were found to be significant annual cycles in all these series.

These results are indicative of much shorter-term variability in Australian meat and livestock markets, which is more likely to be caused by changes in world market conditions on the demand side, and by changes in environmental conditions on the supply side, than by the decisions of livestock producers making decisions based on belief that the past will continue into the present and the future. While the real price of beef is moderately negatively correlated with beef production, the fact that beef prices do not follow the same cyclical patterns as domestic production variables suggests a much greater influence of world market conditions on domestic beef prices. This seems logical given the high proportion of Australian beef production that is exported.

While there may still be 'cyclical tendencies' evident in industry data such as a graph showing an apparent regular movement of prices of a farm product up and down over a previous time period, these tendencies are not statistically significant. Such tendencies should not be called a 'cycle'. It should not be presumed that such patterns will happen in the future, and it should not be the information on which to base decisions about future production levels.

Implications

The broad implication of this analysis is that other external influences on world and Australian beef markets (human- and animal-health-related disruptions, exchange rates, trade disruptions, political instability, market access, drought and flood and the growing industrialisation of production), have become increasingly significant and relevant in recent years, and have effectively outweighed the cyclical tendencies embedded in expectations processes and biological lags. The result of this analysis suggests the need for more attention to be paid to risk management in light of uncertainties in the future about these external influences.

While no formal testing of these significant external influences has been done, a broad-brush variable representing variations in rainfall Australia-wide from long-run averages was obtained from the Bureau of Meteorology. Keeping in mind that at any time across Australia, regional differences in rainfall and environmental conditions are most often quite marked, the results suggest that Australia-wide rainfall is moderately positively related to beef numbers (0.45) and negatively related to beef slaughterings and prices, but at lower levels of association (-0.18 to -0.26). With these levels of association Australia-wide, it would seem sensible to examine the linkage between numbers, output, and prices on a more localised level, such as by state or even by major saleyard. The rainfall variable has little relationship to any of the sheep industry series. The result of this analysis suggests the need for more attention to be paid to risk management in the light of uncertainty.

Recommendations

The findings within this report lead to the following recommendations:

- The findings of the existence of much shorter-term market ups and downs in the Australian beef industry rather than the longer-term cycles evident in the US industry, and similar patterns of shorter-term cyclical behaviour in the sheep industry, should be brought to the attention of meat and livestock industry stakeholders.

- The meat and livestock industries should consider undertaking a collaborative research and engagement initiative to examine the implications of this finding for the industry's supply chain.

- The collaboration should explore the risk management options currently available to supply chain participants, and the potential for future development of risk management approaches and instruments, in order to better address the inherent volatility and uncertainty associated with the short-term ups and downs and hence to ensure mutually beneficial outcomes for chain participants in terms of productivity, profitability and long-term industry growth.

The above recommendations are in addition to the following recommendations from Part 2 of the project (analysis of price transmission).

- The findings indicating the absence of market power should be brought to the attention of meat and livestock industry stakeholders.
- The findings should in particular be brought to the attention of the authorities undertaking reviews of competition in relevant inquiries, including that relating to the grocery sector of which the meat processing industry is a part.
- The collaboration should explore the risk management options currently available to supply chain participants, and the potential for future development of risk management approaches and instruments, in order to better address the inherent volatility and uncertainty associated with the short-term ups and downs and hence to ensure mutually beneficial outcomes for chain participants in terms of productivity, profitability and long-term industry growth.

1 Introduction

Research was commissioned by the Australian Meat Processor Corporation (AMPC) and was conducted by Dr Selwyn Heilbron of SG Heilbron Economic and Policy Consulting, and Professors Garry Griffith and Bill Malcolm of the University of Melbourne, as part of a two-stage project. The first part was to investigate the cattle and sheep cycles in Australia and the second part was to analyse the transmission of prices along the cattle and sheep supply chains.

This project came about because of the need to explain to stakeholders the basis of price transmission in the industry. The reasoning was that the information would help to improve the understanding by stakeholders, including livestock producers, industry organisations, consumers and regulators, of the nature and functioning of the red meat processing industry and the key factors influencing its competitive environment.

There was seen to be a need for objective, economic analysis of price transmission, to address subjective views on the nature of the industry and its market which can fail to reflect the industry's competitive market conditions.

The project has undertaken the detailed econometric analysis required and placed it in the broader context of the industry and its stakeholders, enabling objective, rigorously generated research information to be used in a wide variety of forums including in engagement with producers, consumers and regulators as required by the industry and its participants.

Significant value was expected to be generated for the industry:

- Enabling the industry to better engage with its stakeholders, whether they be producers, consumers, other industry organisations or regulators, by having at its disposal objective independent economic information on the industry's competitive market operation.
- Having this information for engagement with stakeholders to help improve producer, consumer and regulatory confidence, improve the industry's social license to operate, and facilitate increased economic sustainability.
- Having access to uniquely up-to-date information and analysis which provides an advantage in engaging with stakeholders.
- Like previous analyses conducted by the consultants, having very long 'shelf-lives' to be utilised by the industry for its benefit for many years to come.

2 Project objectives

- Undertake advanced analysis of the cattle cycle and the sheep cycle in Australia (Part 1)
- Undertake advanced analysis of the transmission of prices along the supply chain to indicate market efficiency (Part 2)
- Use the results to educate stakeholders about the cattle and sheep cycles and other factors that have a significant impact on beef and sheepmeat market conditions. Thereby improve the understanding of, support for and efficient functioning of the red meat processing industry.

3 Methodology

The methodology for Part 1 of the project (cattle/sheep cycles) was as follows:

- Project Part 1 design confirmation with input from the Steering Committee
- Literature review of cattle/sheep cycles in Australia and relevant international industries
- Contextual analysis of industry evolution and relevant economic and policy issues
- Development of data list and sources with input from the Steering Committee
- Data gathering from public sources
- Analysis using time series methods
- Analysis of implications and recommendations
- Production of draft report
- Feedback from AMPC/Steering Committee
- Production of final report.

4 Project outcomes

Part 1 of the project analysed the medium-term relationships between the prices of cattle/sheep and beef/sheepmeat and other key factors such as herd size, slaughter numbers, and weather to illustrate the functioning of the 'cattle cycle' and the 'sheep cycle' and educate stakeholders as to the nature and implications of these cycles. Data was gathered from public sources and processors to do the analysis and prepare a report on the findings, produced with full referencing and identification of the data and the econometric methods used suitable for public use.

Key findings of Part 1 were:

- Objective evidence that the conventional wisdom as to the existence of long-term predictable cycles in cattle and sheep production in Australia, like the cattle cycle in the US, is not correct. Instead, the picture that has emerged is of an inherently more volatile industry here that reflects external climatic and global market conditions.
- The purported existence of medium-term cycles naturally leads to expectations on the part of livestock producers and processors about the likely duration of price upswings and downswings, which are likely to be confounded if the ups and downs are short term.
- Much of the concern about a purported lack of competition amongst processors occurs during cattle price downturns. However, as experience has shown, and this research confirms, market ups and downs are likely to be short-lived rather than prolonged.
- The inherently more volatile market in Australia reflects climatic and global market conditions. This suggests that processors have little ability to exert sustained market power over a prolonged period, as market conditions are continually changing to reflect climate and global

markets, over which processors have no control. It also suggests the need for a primary focus along the supply chain on market risk management as opposed to a focus on regulatory intervention as a means of dealing with the normal ups and downs of a competitive marketplace.

5 Literature review and industry context

All economic time series are mixtures of long-run trends, cyclical behaviour of various types, lengths and amplitudes, and shorter-term irregular variations (Tomek and Kaiser, 2014). A simple definition is that “a cycle is a pattern that repeats itself regularly over a period of years”. The notion that there exists cyclical behaviour in some agricultural industries, particularly in livestock industries, became evident more than a century and a half ago after efforts were made to monitor and record market transactions through local authorities, and then later and more formally through government market reporting agencies. However, just as markets progressed from small, local locations of exchange to global value chains, the interest of researchers expanded to include a multitude of other influences on this cyclical behaviour.

5.1 Academic research on commodity cycles in general

Some cyclical behaviour in commodity markets is very long-term. Commodity super-cycles are defined as extended periods when commodity prices are considerably more, or less, than the long-term trend, usually lasting more than a decade. Erdam and Unalmis (2016) and Erten and Ocampo (2013) reviewed this area of economic literature. They cite the research of Kondratiev (1925), who examined long cycles in commodity prices, industrial production, interest rates and trade over 40 to 60 years, and Kuznets (1940), who defined long cycles of 25 years or more related to the lifecycles of innovations. Many well-known economists have been interested in long-term trends in commodity prices, including Radetzki (2006), Grilli and Yang (1980), Cuddington (1992), Pindyck and Rotemberg (1990) and Reinhart and Wickham (1994). Radetzki (2006) found there were three longer-term commodity booms:the early 1950s, the early to mid-1970s, and 2003 onwards. Labys et al. (2000) found that commodity price movements often lead to, and sometimes cause, major turns in business cycles, with cycles in prices of cocoa, tea and corn being of low amplitude and related to the broader macroeconomic cycles. There are strong links between what is happening in individual commodity markets, and what is happening in domestic and global economies. These links are stronger for countries that have economies heavily dependent on agriculture and on trade.

In the economics literature, there are cycles of articles focussing on cycles in prices, approximately following the cycles in the prices themselves, coinciding with runs of prices that are considerably higher or lower than median prices. Relatively higher or lower prices spark media and industry attention, and the interest of researchers follows this trend. The current interest in high food prices in Australia is a prime example. To take another example, the food price boom of 2008 (of roughly 75 per cent in real terms) led to a host of articles about the reasons why this price peak happened. In Jacks (2013), evidence was presented about the effects of demand and supply shocks on real commodity prices, looking at 12 agricultural, metal, and soft commodities from 1870 to 2013. Jacks and Stuermer (2017) showed that ‘commodity demand shocks strongly dominated commodity supply shocks in driving prices over a broad set of commodities across a lengthy time period. While commodity demand shocks have gained importance over time, commodity supply shocks have become less relevant’ (p.1).

In a piece on the history of booms and busts, Spatafora and Tytell (2010) of the International Monetary Fund looked at commodity price spikes in the 1970s and 1990s as well as the 2008 food price rise. They observed that the factors contributing to the 2008 food price rise were ‘burgeoning food demand in developing and transition economies, sharply higher energy prices that boosted production costs of agricultural products, increased demand for corn and oilseeds for bioenergy, the depreciating U.S. dollar, production shortfalls due to weather, and policy responses of both importing and exporting countries’ (p.1). Many of these factors were also present and played a similar role, in previous price spikes. Jacks and Stuermer (2017) also looked at real commodity prices from 1900 to 2015 for 40 commodities and found (i) real commodity prices have been on the rise - albeit modestly - from 1950; (ii) there is a pattern - in both past and present - of commodity price cycles, entailing large and long-lived deviations from underlying trends, and (iii) these commodity price cycles are themselves punctuated by boom/bust episodes which are historically pervasive. The ‘cycle within the cycle’ is relevant.

In the context of cycles in the prices of agricultural commodities there too are, and will be, ‘cycles’ in political actions either causing, or responding to, rises and falls in prices of some commodities such as those supplying energy, or in protectionist trade actions, and of course, the weather. The supply and demand circumstances of an agricultural commodity and apparent resulting ups and downs in prices are only ever a part of the current and potential future story.

When thinking about commodity price cycles such as the cattle cycle or the sheep cycle, prices at any point in time need to be seen in the context of what else is happening in the nation and the world, around the supply, demand and prices of the commodity in question. Related commodities may also be part of the price-influencing phenomena. Experience has shown that every two or three decades there have been episodes where agricultural commodity prices rise very high and often drop quite rapidly with the price spikes being brought about by unexpected events that are impossible or difficult to predict, such as wars and currency devaluations or access to markets being inhibited. Examples include grain prices during World War 2, wool prices during the Korean War, cattle and grain prices in the oil shocks and inflationary 1970s, the food price rises of 2008 caused by weak currency and strong economic growth, and biofuels policy, and many food and agricultural commodity prices in the 2020s with the Ukraine war, the Covid-19 pandemic, and so on.

Many commodities are linked in both the demand and supply spheres. Interchangeable feed grain crops like wheat, corn and soybean, and oil prices too, are linked. Wool prices and oil prices are linked with oil being a key input to wool substitutes. Livestock prices are often closely linked because the meat derived from livestock are substitutable in demand and livestock often use the same feed resources. A common feature when price rises occur is for some participants in the relevant markets to convince themselves and others that agricultural commodity prices have reached ‘a new plateau’. It has never been the case so far. There have always been rapid supply responses to high agricultural prices worldwide. Booms eventually bust and busts eventually recover. The self-equilibrating nature of competitive markets is a powerful but often misunderstood concept.

While cycles in activity in the economy and in parts of it have long fascinated people in economics and business, as referenced in the studies cited above, Tomek and Kaiser (2014) and other analysts have noted that these cycles are 'typically not observable from a simple data plot’ (p.179). Autocorrelation between the annual prices of agricultural commodities (i.e. the price in this year is correlated with prices in previous years) has been demonstrated often. For example, Deaton and Laroque (1992) showed the prices of many commodities were autocorrelated. Mundlak and Huang (1996) looked at beef cattle numbers and prices in four countries and found evidence of autocorrelation. But, separating out the components of a time series of prices that are systemic (trends and cycles) from those that are random is no simple task. It is far more complex than observing apparent movement on a graph, calling it a cycle, presuming it will happen in the future and proceeding to base decisions on this expectation.

How price and production cycles evolve

It is well-understood how price and production cycles evolve. The length of time of a cycle for an agricultural commodity is related most importantly to the time it takes to produce another generation of animals or crops. In the case of animals, this can be complex, as saleable products can be produced at a range of ages for different classes of products. With crops, the time it takes for perennial crop plantings to come fully onstream varies, too.

The two factors that are present in all analyses and speculations about cycles in agricultural commodity prices are expectations about future prices, and the costs of changing the timing and form of output from a farm from year to year, as happens when herd or flock numbers, or area cropped to activities, are increased or decreased.

Tomek and Kaiser (2014) explain that the usual conceptual model underlying cyclical behaviour in the prices of crop and livestock products is based on alternative explanations about how producers form expectations about future prices and thus decisions to increase or reduce output in a certain time. The starting point is the judgement that the quantity of a commodity supplied in a current time is determined by the prices that producers expected to be present at the earlier time when they decided what to produce and acted on it.

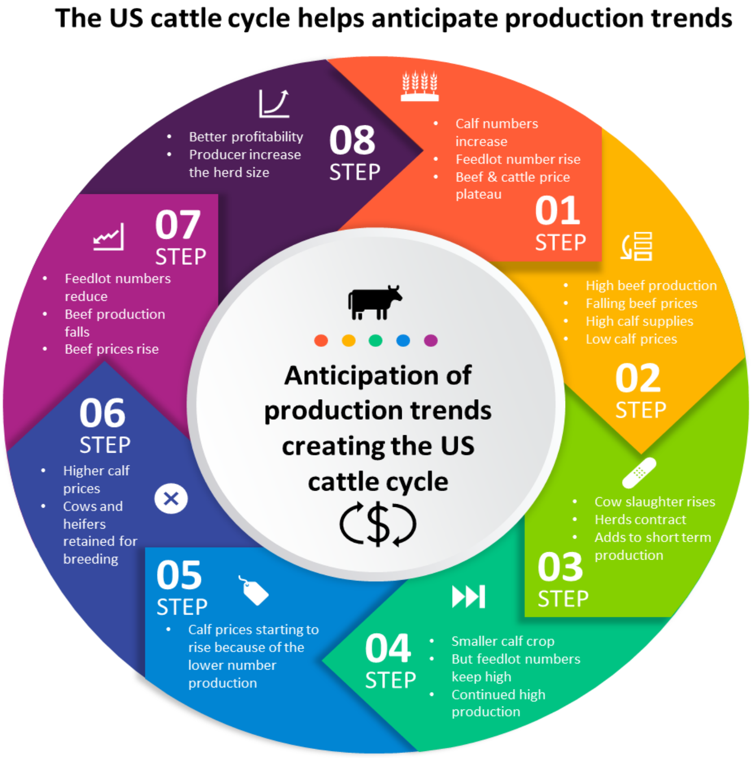
The lag between decision and action and receiving the price for their product comes about because of the biological nature of agricultural production activity; it takes time for animals to reproduce and grow, it takes time for crops to grow and mature. Obviously, this time varies between products. This leads to the well-known cobweb model. The size of the web depends on the type of product.

With respect to livestock, decisions to sell or keep young stock that could be retained for breeding are based on the current expected profit from selling versus the future expected profit from retaining them and selling extra offspring later. There are numerous figures explaining this process in the cited references (see in particular Alford and Griffith, 2002; Helmi and Griffith, 2023). **Figure 1** from Helmi and Griffith (2023) is copied below. There are also many published graphs of the outcomes of this process (see the Figures in the next section).

There are four standard explanations of expectations about future prices:

- Naïve expectations which simply hold that the current price will prevail in the future
- Adaptive expectations which hold that the expected price is a weighted average of current and past prices (Nerlove,1956)
- Rational expectations where the information that sets the price that is expected is all the current information about all the variables affecting supply and demand that are thought to influence prices in the coming time (Muth, 1961) and
- The Futures Price Model for commodities that have a futures market (Gardner, 1976) which holds that the current futures price quoted for a future time is the rationally expected price containing all the information available at the current time about factors that affect prices.

Figure 1 The different stages in beef producer decision-making processes



Source: Author's own, based on Alford and Griffith (2002)

In practice, little is known about how farmers and those to whom they sell their output go about forming their expectations about future prices, except that each farmer will do it in their own unique way. That method may change from time to time, depending on circumstances. Still, the combination of expectations, the cost of change and lags in production make it possible for cycles in agricultural commodity prices to occur. This is particularly the case for livestock production because of the long lag times involved from mating to the sale of offspring.

During this lag time things inevitably change and actual prices will not be those that were expected to occur when the animals that are being produced are expected to be sold. For the supply of animal products to increase at a future time beyond the increases that occur naturally through the effects of favourable seasonal conditions increasing reproduction performances, the number of breeders must first be increased. An implicit assumption here for the generation of a smooth cyclical pattern is that either farmers are uninformed about these 'other factors' happening in their industry, or that they assume these other factors do not matter.

In livestock production enterprises, decisions to increase the breeding herd or reduce it will contribute to 'cyclical tendencies' that will occur, but these decisions and their consequences occur amidst many other things that are happening, most notably good and bad seasons contributing to increases and decreases in the quantity and quality of output. Cumulatively, these factors lead to increased or decreased prices. Overlaying all these events are longer-term trends that may exist in an industry, such as the long-run trend downwards in the US beef cattle herd since the peak size of 1975, the increasing 'industrialisation' of production in most agricultural industries, and the increasing access to a range of information about these industries. As a final straw, purely random events upset the best-laid plans for production: events like disease outbreaks, extreme droughts and floods and temperatures, loss of access to markets, political disturbances, and so on.

The relative importance of the 'cyclical tendencies' compared to this multitude of other factors is not well understood. Many commentators have argued that a simplistic belief or excessive faith in the potential pervasiveness or reliability of the amplitude or duration of an apparent cycle is folly: if there is a cycle, why don't I see it? (Longmire and Rutherford, 1992).

Academic research on livestock price and production cycles

The supply, demand and prices of livestock and their associated derived products change over time in many ways, as described above. A time series of historical prices is made up of a regular component and an irregular component. The regular components are underlying long-run trends and longer and shorter cycles of varying lengths and amplitudes. The irregular components are random variations from external shocks in this market or in related markets, that is, events that cause demand and supply shifts.

There are patterns of supply and prices within a year as the animal breeding decisions of producers are aligned with expected seasonal feed supplies. Meat is costly to store. Scope for storing and carrying the product into different times of the year is limited by supplies of feed and to the extent seasonal patterns of prices are changed by supply being diverted to different times of the year the storage and carrying costs accrue to the live animal not their meat products. Prices of animals change from year to year as the conditions of domestic and global supply and demand shift. All these decisions are influenced by the prevailing and expected seasonal conditions and longer-term climate forecasts.

One of the first livestock industries to be formally recognised for cyclical behaviour was the pig industry. In a comprehensive review, Zawadzka (2010) found that this 3–4-year cycle was first formulated and described in the United Kingdom in 1895. The factors causing such behaviour are well-known as described in the previous section: myopic expectations held by large numbers of small independent (and uninformed) pig producers who make long-term breeding and production decisions based on short-term changes in prices, overlaid by the time required for the reproductive process to occur and changes in output to be made available to the market. For example, if current prices were high, and the way pig producers formed expectations about the future caused them to believe that these prices would stay high, this would encourage them to expand their breeding herd, which in 18-24 months would increase the supply of pigs, which would decrease prices, which, again with myopic expectations, would induce producers to contract their breeding herd, etc.

This regularity in pig market behaviour, as with the regularity in more general commodity cycles mentioned above, created significant interest in the broader economics profession. For example, the famous theoretical economist Ronald Coase and his colleagues published a series of papers on the pig cycle in the United Kingdom in the 1930s (for example, Coase and Fowler, 1937). In the US, Harlow (1960) was one of the first economists to examine the US hog cycle. In Australia, Griffith (1975, 1977) published analyses using time series methods showing that the expected 3-4-year cycle found in European and North American studies did, in fact, exist in pig prices in Australia, but not in pig production. Griffith (1977) argued that the traditional pig cycle in Australia was much less evident during the 1960s and early 1970s because the industry had become much more capital-intensive. Fifteen years later, Longmire and Rutherford (1992) also used time series methods and found that the Australian pig cycle still existed but appeared to have been dampened. They stated that 'this corresponds with earlier findings and would result from the restructuring of the pig industry to large specialist units in which variations in pig numbers are less likely' (p.11).

The other major livestock industry that has been investigated for cyclical behaviour is the beef cattle industry. The same factors influencing the pig cycle have been found to influence the cattle cycle, the difference being that the length of the reproductive and growing out phase is much longer for cattle, resulting in a roughly 8-10-year cycle as shown in **Figure 1**. Extrapolating backwards from the published data, Rosen et al. (1994) found that cyclical activity in the US cattle industry has been evident for around 150 years. They (p.468) referred to the US cattle cycle as '… among the most periodic time series in economics.' As with the pig cycle, in addition to the work of Rosen and colleagues, many other influential economists have examined this phenomenon (for example, Breimyer, 1955; Maki, 1962; Mundlak and Huang, 1996; Chavas, 2000).

While the research on pig cycles has almost always been confined to domestic industries, the research on cattle cycles has often had an international focus. The reason for the focus on the US cattle cycle was that these regular fluctuations in US beef numbers and prices have spill-over effects worldwide via variations in US traded quantities since the US has a very large beef industry and traditionally has been both a major exporter of beef and a major importer of beef. Even small variations in US output impact traded quantities and hence global prices. Considerable previous research has shown the impact of the US cattle cycle on the beef market globally (Rosen et al., 1994; Mundlak and Huang, 1996; Mathews, et al., 1999; Aadland and Bailey, 2001).

The cattle cycle in Australia was first highlighted by Gutman (1950). The rationale for the presence of the cycle in Australia was re-examined in Reynolds (1977), who argued that it was likely to be sizeably shocked by random external factors. It was analysed using spectral analysis by Hinchy (1978). Longmire and Rutherford (1992) found that a cattle cycle still existed in Australia, and despite the restructuring of the cattle industry that had occurred, the cycle 'appears to be lengthening and strengthening' (p.11).

Alford and Griffith (2002) found that there was an Australian cattle cycle and that it and the US cattle cycle were closely synchronised. This was shown in two ways. First, US cattle prices and Australian cattle prices moved closely together in a positive way, with a correlation coefficient between the two prices (not corrected for exchange rate movements) of (r=0.67). Second, the study showed there was an equally strong inverse relationship (r=-0.6) between the ratio of US cow slaughterings to total cow inventory (the indicator of cow herd expansion or contraction) and the prices received by Australian producers, in a similar way to the relationship with US producer prices. Both indicators suggested strong positive relationships between the US and Australian cattle cycles up until the turn of the century. Several other external influences were mentioned as impacting the cycles in both countries (human- and animal-health-related disruptions, exchange rates, climate influences and the growing pattern of the industrialisation of production), but none of these influences was formally tested.

As indicated by the dates on the papers cited above, most academic interest in the US cattle cycle was around 20-25 years ago. Government and industry market intelligence agencies such as the US Department of Agriculture (USDA) the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) and Meat and Livestock Australia (MLA) I have kept track of the cycles, but only recently have academic interest been renewed (Petry, 2015; Fliessbach and Ihle, 2020; dos Santos, et al., 2022a,b).

Much of this recent interest has arisen from the growing presence and influence of South American beef exporters in the world market.

As mentioned elsewhere, the latest study of the Australian and US cattle cycles was by Helmi and Griffith (2023). The study found that in the last decade, the US and Australian cattle cycles had become uncoupled. Prices in both countries, and cattle numbers in both countries, have moved in opposite directions. This major change was put down to the growing importance of the external influences mentioned above (human and animal-health-related disruptions, exchange rates, climate influences and the growing pattern of the industrialisation of production), and a call was made for a more formal examination of the role played by these influences (for example, Belasco et al. (2015)). These findings are re-examined below.

Finally, in relation to the other major Australian extensive livestock industry, the sheep industry, in spite of several mentions in the rural press, a formal search of the Google Scholar database of published articles and reports did not find one single mention of the term ‘sheep cycle’, or of any of several alternative phrases with the same meaning, anywhere in the world.

In the unpublished literature, only one study was found that even mentioned a sheep cycle. Longmire and Rutherford (1992) included sheep numbers and slaughter figures in their study of Australian livestock cycles. Using autocorrelation analysis, for sheep numbers, they found no evidence of a regular cycle. Using spectral analysis, they found a weak but insignificant cycle in sheep numbers with length ranging between 4-6 years. It is fair to conclude that there has been no academic recognition of the existence of a sheep cycle.

5.2 Evolution of the industry and price transmission

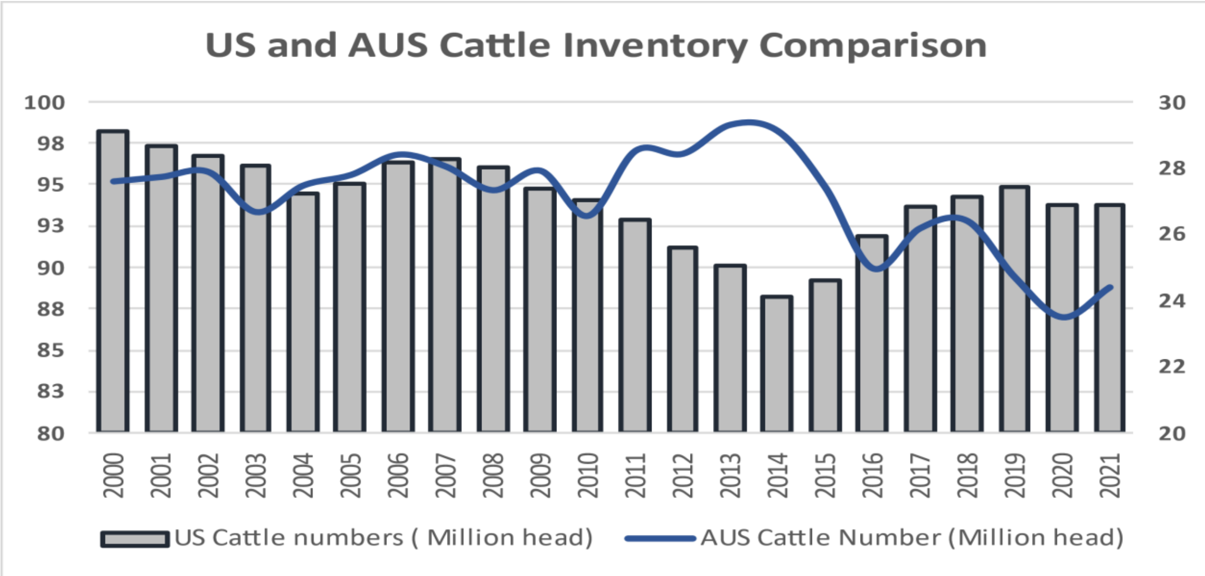
An analysis by Helmi and Griffith (2023) is the most recent piece of work done on Australian cattle cycles. However, it focuses on the relationship between the US and Australian cycles, rather than Australian cycles per se. It also does not cover sheep cycles. There is visual evidence in the analysis of the existence of a cattle cycle in Australia. For example, **Figure 2** below shows herd inventories in the two countries point to at least three trough-peak-trough ‘cycles’ in the Australian herd since 2003. As mentioned above, such graphical evidence needs to be corroborated by statistical analysis. As noted, traditionally, a key aspect of the Australian cattle cycle has been its relationship to the US cycle. For example:

> *“However, as Australia only produces about four per cent of the total world beef supply, its share and pricing ability in the world market has always been susceptible to the influences of production levels in other major beef-producing nations. One such factor, which greatly influences the profitability of Australian beef production, is the USA cattle production cycle. Peaks in this cycle have occurred about every 10 to 12 years and are usually triggered by high levels of grain production in the USA” (ABS, 2005).*

An illustration of the nature of the US cattle cycle is indicated below in Figure 3 (see also Figure 1). As Helmi and Griffith (2023) have pointed out:

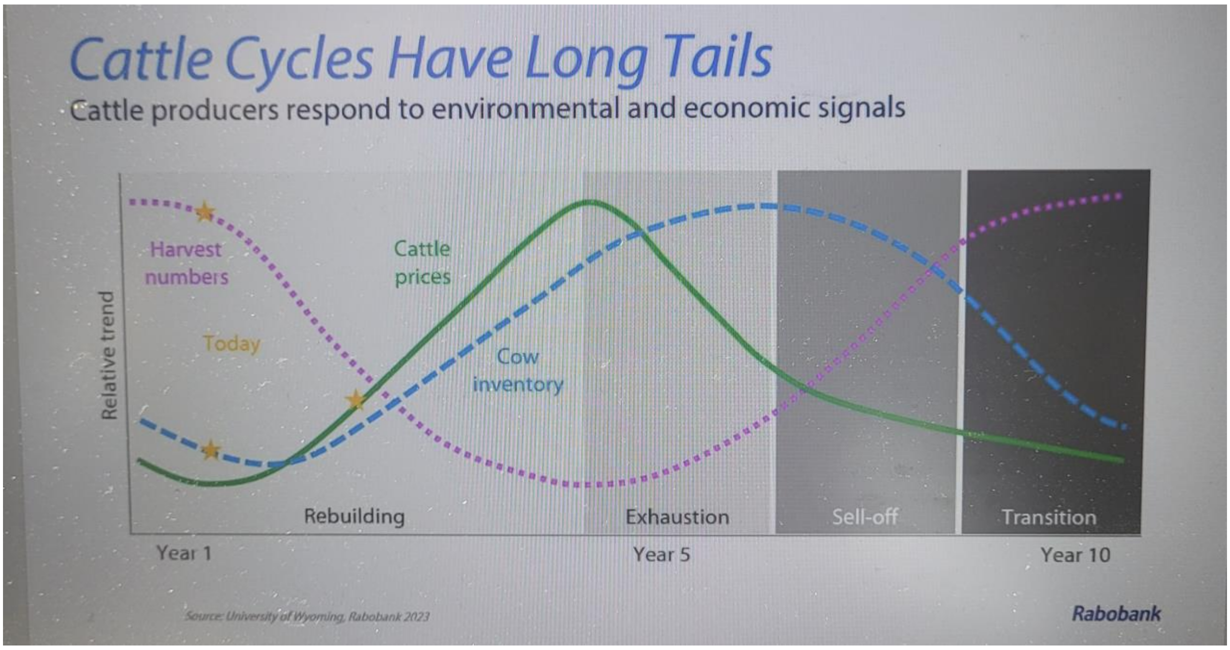
> *“In 2019, Australia produced only four per cent of the world's beef but contributed 16 per cent of global trade. In that year, Australia exported 70 per cent of total national beef production (MLA, 2019a). Over seven decades, Australia has consistently ranked among the top three beef-exporting countries (MLA, 2019a)…This situation results in a reliance of the Australian beef industry on international market conditions, and previous research has shown a strong link between cattle prices in the US and in Australia. In particular, given the relative sizes of the two industries and their relative export shares, changes in the US beef industry have been recognised as critical factors influencing the Australian beef industry (Howden and Zammit, 2016).”*

Figure 2 **US and Australian cattle inventories**



Source: Helmi and Griffith (2023)

Figure 3 **US cattle cycles**



Source: University of Wyoming reproduced by Rabobank (undated mimeo).

Further, "Alford and Griffith (2002) found that the cattle inventory in the US had an inverted relationship with the Australian beef prices. A higher number of slaughtered cattle in the US resulted in a lower beef price in Australia, and vice versa. Similarly, Bindon and Jones (2001) argued that the crash in international and Australian beef prices between 1995 and 1998 was caused by increased cow slaughter, reduced calf prices, and unprofitable feed lotting activities in the US." However, they also state:

> *"Recently, the Australian beef industry has undergone major changes. Australian beef suppliers to export markets are no longer just price takers, supplying low-quality beef into commodity markets. Australia has gained ground in high-marbled products and high-value markets such as Japan and South Korea, which has caused an increase in the Australian average herd size over the last decades (Siriwardana, 2015). The value added to Australia's red meat and livestock sectors has climbed 89 per cent over the last decades, mostly because of increasing demand for high-quality protein in international markets (MLA, 2020c). Australia has expanded its market reach by also supplying high-quality meat products to the US, in addition to the traditional lean beef trade. This has involved greater reliance on feedlots to meet the higher quality specifications demanded, causing the production system to change."*

As Alford and Griffith (2002) wrote, cattle price troughs in both countries occurred at a time when a high proportion of cattle slaughterings occurred, and a period of industry pessimism followed.

However, in three separate periods since 2010, prices and the slaughter rate moved in the same direction. The correlation coefficient is a little weaker in the second half of the data set (-0.27). This is further evidence that the US and Australian cattle cycles are no longer closely aligned.

The data in Figure 2 clearly show that since about 2010 the US and Australian beef industries have been uncoupled. The reasons for this recent lack of alignment are to do with the external factors noted earlier. There are three key factors:

- Periods of adverse climate are a major cause, where slaughterings often must be accelerated because of shortages of feed resources.
- Food safety scares have influenced policy settings and export demand.
- The way the two countries interact in world markets. According to MLA (2017), there is a tendency for Australian beef to fill gaps in supply left by the US.

Relevant economic and policy issues

There are several relevant economic and policy issues that could arise from any cyclical tendencies in red meat production.

The impact of the cycles on market conditions facing livestock producers.

If there was a longer-term predictable cycle, the stage of the cycle could have a significant impact on market conditions facing producers. When the herd is rebuilding, all other things being equal, slaughter numbers will tend to decline, and prices of livestock will tend to be firm. However, supply trends may be altered because of factors such as a change in seasonal conditions. And as with any market, what happens on the supply side is only half of the story. Changes in market demand can accentuate or moderate the impact of changes in supply.

But all things being equal, a reduction in supply will lead to upward pressure on prices in a rebuilding phase and vice versa in a liquidation phase. Whilst producers can undertake actions on production and pricing aimed at maximising the profit arising from market conditions facing them, the stage of the cycle would create an underlying economic environment which would influence their returns.

A recent media article (Beef Central, 2023a) illustrates this:

> *"The industry has changed from the lofty price period of 2020–2022. The cyclical nature of the herd has reached its maturity stage and ever-changing confidence, and sentiment has*

> *genuinely dictated market performance in the face of typical supply and demand fundamentals."*

However, clearly the absence of medium-term cycles undermines any conclusions as to long term outcomes derived from an assumption as to their existence.

The impact of the cycles on market conditions facing processors.

The market conditions facing processors as purchasers of animals would then also be impacted by the stage of the animal cycle in which they are operating. All things being equal, during a rebuilding stage, processors will have to pay higher prices to compete for relatively scarce supplies of animals for processing, and in a liquidation stage the opposite applies.

Similarly to the case applying to producers, whilst processors can undertake actions on processing output and pricing aimed at maximising the profit arising from market conditions facing them, the existence of a cycle would create an underlying economic environment that will influence their returns.

The existence of short-term market fluctuations as opposed to medium-term cycles would tend to confound the expectations of producers and processors and place a premium on risk management.

The impact of the cycles on risks

In theory, the existence of cycles should generate opportunities for improved management of risks. On the assumption that the cycles create a degree of certainty about market outcomes, it should be possible to ameliorate the impact of the cycles on economic outcomes. For example, if there is a level of certainty about the stage of the cycle prevailing at a point in time - say if liquidation is well underway and rebuilding is looming - then producers could purchase breeding animals instead of continuing to liquidate them. This would reduce the amplitude of price movements associated with the cycle. Clearly the key consideration here is the level of confidence that producers have about future cyclical conditions (related to expectation formation as discussed earlier).

The impact of the cycles on competition and competition policy.

Given the above impacts of the cycles on producers and processors respectively, it is not surprising that these cycles could have been considered to have an impact on the competitive market conditions prevailing in the industry, and hence attract the interest of competition policy authorities.

For example, the ACCC (2017) has stated that:

> *“There is also a cyclical element to many of the concerns about the competitiveness of market structures in the Australian industry. For instance, there were particularly strong concerns about market concentration and buyer power during the peak of the drought in 2013 and 2014. In 2014 the industry was characterised by high rates of cattle turn-off and strong overseas demand for Australian beef in export markets. These conditions were favourable to the profitability of cattle processors, especially export processors, and placed them in a stronger than usual bargaining position relative to producers. During this period, however, producers’ profits suffered due to the high costs of supplementary cattle feed and low cattle prices.*

The high cattle turn-off in 2013–14 is also said to have resulted in abattoirs operating at or near full capacity. Some producers reported especially difficult trading conditions and relationships with processors during this time. Alleged behaviours by processors ranged from apathy toward negotiating with producers, to frequent and arbitrary discounting of carcase prices.

Since 2015 and the end of drought conditions in several areas, the supply of cattle to processing plants has altered dramatically. Favourable seasonal conditions have encouraged many producers to begin herd rebuilding, which has led to a significant reduction in turn-off. In addition, producers have entered markets to purchase cattle to rebuild herds, resulting in greater numbers of buyers in cattle acquisition markets and upward pressure on prices. The reduction in the supply of cattle is also reflected in the under-utilisation of processing facilities, with processors reporting significant excess capacity in the past year".

What this indicates is that concerns on the part of producers about the competitive conditions in the market tend to be accentuated when the herd is liquidating and recede when the herd is rebuilding. However, this again assumes the existence of the cycles.

There is also a link between the cycles and concerns about the efficiency of the market in terms of price transmission along the chain. Especially when herd liquidation is underway and prices are weak, producers tend to look at retail prices to see if they have also fallen in tandem. If not, producers may be concerned that the market is not competitive, and that retailers are not passing on price falls to consumers to stimulate demand for meat.

For example, a recent media report (Beef Central, 2023b) states:

> *"Much has been said about the relationship between this year's collapsing livestock prices and relatively stable retail meat prices over the past six months.*
>
> *In a recent commentary, Meat & Livestock Australia noted that while livestock prices for cattle and sheep have declined significantly this year following historic highs in 2022, the reduction in average retail price of red meat lagged prices paid to producers by approximately eight months".*

Further, the article indicates:

> *"Livestock prices are only one component of retail meat prices. Producing retail meat requires investment in energy costs, transport and freight costs, labour costs, packaging and disposal costs, retailer margins, processor margins, PPE, and hygiene, all of which have increased in price over the last year, along with almost everything else.*
>
> *This is important to remember when considering when livestock prices increased as they did to historical highs last year. When saleyard prices were at those highs a year ago, retail prices increased but not at the same rate. What we are seeing now is that same trend, just in the opposite direction. Consumers need a degree of certainty for their shopping basket and retailers smooth the retail pricing impact over the longer term, rather than sharply increase or decrease the price of meat in accordance with livestock prices."*

A few points should be made in relation to this aspect of cycles and their impact on competition.

Firstly, the smoothing of prices along the chain from producers to retailers (known as price levelling) is a well-known feature of price transmission in the meat industry. This levelling was analysed for example in Griffith et al. (1991). However, what is important in terms of market efficiency in an economic context is whether such levelling occurs just in the short term (which implies a competitive market still prevails) or also in the long term (which implies it does not). The economic analysis done on this matter confirms that downstream prices are responsive to farm prices in the longer term.

Secondly, the economic considerations just described for defining what constitutes non-competitive markets are reflected in the provisions applying to competition policy. From a competition policy perspective, what indicates the ability of a seller (or purchaser) to alter unilaterally prices from competitive market levels and hence act in a manner that is contrary to competitive norms, is whether a material difference in price over and above competitive levels can be maintained over a sustained period of time.

Competition concerns about monopolistic conditions arise for example if the party can impose a small but significant, non-transitory increase in price (or SSNIP).

The ACCC Merger Guidelines (2008) for example state:

> *"In general, the exercise of market power by the hypothetical monopolist is characterised by the imposition of a small but significant and non-transitory increase in price (SSNIP) above the price level that would prevail without the merger, assuming the terms of sale of all other products are held constant".*

A small but significant increase has been stated in the merger context to "consist of a price rise for the foreseeable future of at least 5 per cent above the price level that would prevail without the merger".

The duration of 'non-transitory' has been indicated as being at least 12 months (see https://www.tcd.ie/Economics/staff/masseyp/term1lecture4.htm)

Similarly in the context of abuse of market power (ACCC, 2018):

> *"Market power comes from a lack of effective competitive constraint. A firm with market power can act with a degree of freedom from competitors, potential competitors, suppliers, and customers. The most observable manifestation of market power is the ability of a firm to profitably sustain prices above competitive levels."*

Hence whilst lags in the transmission of prices may have short-term impacts on the profits of various participants along the chain, what matters is whether prices at the retail stage where consumers decide on purchases of the final product reflect prices at the farm stage over the longer term. This will be analysed in Part 2 of this project.

Finally, a recent Issues Paper (NFF, 2023) describes price transparency as follows:

> *"Price transparency refers to the information available to a farmer to accurately compare the price offered with product supply, demand, market conditions, and prices paid to other farmers. In other words, can a farmer know they are being offered a fair price for what the market demands?*
>
> *In the agricultural supply chain, the lack of market price transparency is used against farmers. Increasing market concentration across the Australian economy has allowed businesses with a large market share to use their market power to exploit the lack of price transparency within the supply chain."*

However, if prices are demonstrated to have been transmitted efficiently, subject to the possible meat marketing phenomena of price levelling and averaging behaviour by retailers, then it logically suggests they would be expected to have been sufficiently transparent at least, to enable the market to operate efficiently.

A key element of this project is to determine whether reliable and predictable cycles in cattle and sheep production exist, in the sense of there being predictable, multi-year cycles of production formed predominantly because of producer expectations and biological time lags, and which form the basis for making current decisions about future action. While producer expectations and biological cycles are a factor in numbers of stock at any time, the effects of the many other factors that also play a role in determining prices of stock are trumps: if there's strong, predictable, routine cycles in stock prices, then we surely should be able to find them.

All things being equal, the lack of existence of medium-term cycles and the prevalence of short-term market fluctuations would suggest a reduced ability of processors to exert market over a sustained period, which is the key consideration in respect of competition regulation. The transmission of prices along the supply chain, which is an important indicator of competitive conditions in a marketplace, will be the subject of the second Part of this project.

5.3 Relevant economic and policy issues

Cycles and price transmission

If there was a longer-term predictable cycle, the stage of the cycle could have a significant impact on market conditions facing producers. When the herd is rebuilding, all other things being equal, slaughter numbers will tend to decline, and prices of livestock will tend to be firm. However, supply trends may be altered because of factors such as changes in weather conditions. And of course, as with any market, what happens on the supply side is only half of the story. Changes in market demand can accentuate or moderate the impact of changes in supply.

But all things being equal, a reduction in supply will lead to upward pressure on prices in a rebuilding phase and vice versa in a liquidation phase. Whilst producers can undertake actions on production and pricing aimed at maximising the profit arising from market conditions facing them, the stage of the cycle would create an underlying economic environment that would influence their returns. However clearly the absence of long-term cycles undermines any conclusions as to long-term outcomes derived from an assumption as to their existence.

The market conditions facing processors as purchasers of animals could then also be impacted by the stage of the animal cycle in which they are operating. All things being equal, during a rebuilding stage, processors will have to pay higher prices to compete for relatively scarce supplies of animals for processing, and in a liquidation stage, the obverse applies.

Similarly, to the case applying to producers, whilst processors can undertake actions on processing output and pricing aimed at maximising the profit arising from market conditions facing them, the existence of a cycle would create an underlying economic environment that will influence their returns. The existence of short-term market ups and downs as opposed to long-term cycles would tend to confound the expectations of producers and processors and place a premium on risk management.

6 Analysis

6.1 Long-term analysis of market cycles

Data for market cycle analysis

The data required for this part of the project is outlined **Table 1**. It is consistent with the type of data used in previous studies of livestock cycles. All the data required was obtained from public sources. The time period covered in the data set was generally from 1974 to the most recent year available in the public databases, usually 2022, although a couple of series were of shorter duration.

It was noted above that separating out the components of a time series of prices or quantities that are systemic, from those that are random, is no simple task. It is more complex than observing apparent fluctuations on a graph, calling it a cycle, presuming it will happen in the future, and proceeding to base decisions on this expectation. This is naive empiricism, and not helpful to decision-makers.

This report examines whether it can be established that cycles in output and prices of sheep and cattle, of regular length and magnitude, with a high standard of proof, exist. In this section, an attempt is made to use some time series econometrics tools to see if there is any statistical evidence of cyclical activity in the Australian cattle and sheep markets, and if so, what the nature of this activity is and how this information can be used by industry. The methods used are in the class of methods called 'time domain', as they are simpler to implement and interpret and do not require sophisticated software packages. The more sophisticated 'frequency domain' methods, such as spectral analysis (Griffith, 1975,1977; Hinchy, 1978; Longmire and Rutherford, 1992) could be applied in future if required to confirm the time domain results.

Table 1 Data Definitions for long term analysis

Variable name used in the Figures and in the software outputs	Definitions
inallbfau	Total numbers of cattle and calves, Australia, thousands
incowau	Numbers of cows and heifers, Australia, thousands
inshau	Numbers of sheep and lambs, Australia, thousands
slbfau	Slaughterings of cattle and calves, Australia, thousands
pfbfauhsr	The real price of heavy steers, Australia, cents/kg DCW
pfbfautsr	The real price of trade steers, Australia, cents/kg DCW
pfbfcwr	The real price of cows, Australia, cents/kg DCW
pflbaur	The real price of lamb, Australia, cents/kg DCW
pfmuau	The real price of mutton, Australia, cents/kg DCW
rainanom	Variations in annual rainfall Australia-wide from long run averages
inallus	Total numbers of all cattle, US, thousands
incowus	Numbers of beef cows and heifers, US, thousands
inothus	Numbers of other cattle, US, thousands
slallus	Slaughterings of cattle and calves, US, thousands
pfbfusr	The real price of heavy steers, US, c/lb
futbfusr	The real futures price for US beef, c/lb

Methods

Several steps are required:

- First, the graphs presented by Helmi and Griffith (2023) are updated to see whether the same conclusions still hold. Simple correlation coefficients are also calculated and reported in **Table 2**.
- Second, the relevant economic time series are checked for 'stationarity'. Even though real prices are used, and the graphs do not suggest strong trends, it is necessary to test for stationarity before proceeding further. Most econometric estimation techniques assume that the time series being examined are stationary, that is "the mean and variance are constant over time and the covariance between two values from the series depends only on the length of time separating the two values and not on the actual time at which the variables are observed" (Hill *et al.*, 2001, p.335). If the series are non-stationary, spurious regressions may result, where significant relationships are found when there are none. High R^2 values together with low Durbin-Watson statistics are common indicators of non-stationarity.

The stationarity of a time series can be tested by using a unit root test. Here we use three different test statistics – the augmented Dickey-Fuller test, the Weighted Symmetric test, and the Phillips-Perron test. All allow the addition of constant and trend variables, and where appropriate, other exogenous variables such as dummy variables (Hall and Cummins, 2003, pp.42-48). Several 'augmenting' lags can be specified to control for additional serial correlation. Here, lags up to 10 are included, given the common perception based on the US cattle cycle that prices from peak to peak or trough to trough will often be about 10 years apart. For the various series to be considered as stationary, the various test statistics should be significantly different from zero (p values less than 0.05). The results of applying these tests are shown in **Table 3** and **Table 4**.

- Third, AutoRegressive Integrated Moving Average (ARIMA), or Box-Jenkins (1976), models are applied to the stationary time series variables such as numbers of cattle and sheep and prices of cattle and sheep. These models use only a series' own lagged values to forecast its future values. The lagged values can be either moving average terms and/or autoregressive terms, which statistically best describe the patterns in the past data. These methods are preferable to the full structural econometric approach where in addition to the information on the dependent variable, all the values of all the other explanatory variables that 'cause' future supplies, demands and prices must be either known or be reliably estimated. As mentioned earlier, they are easier to implement and interpret than 'time domain' methods such as spectral analysis.

Three phases of an ARIMA process are required:

- *identification* of the statistically significant characteristics of the variable of interest (is it moving average, autoregressive, or both?);
- *estimation* of the parameters of the model specified based on what was found in the identification phase (the actual empirical relationships between past and current values);
- *forecasts* into the future of the variable of interest based on the estimated model parameters.

The results of these procedures are reported in the results section below.

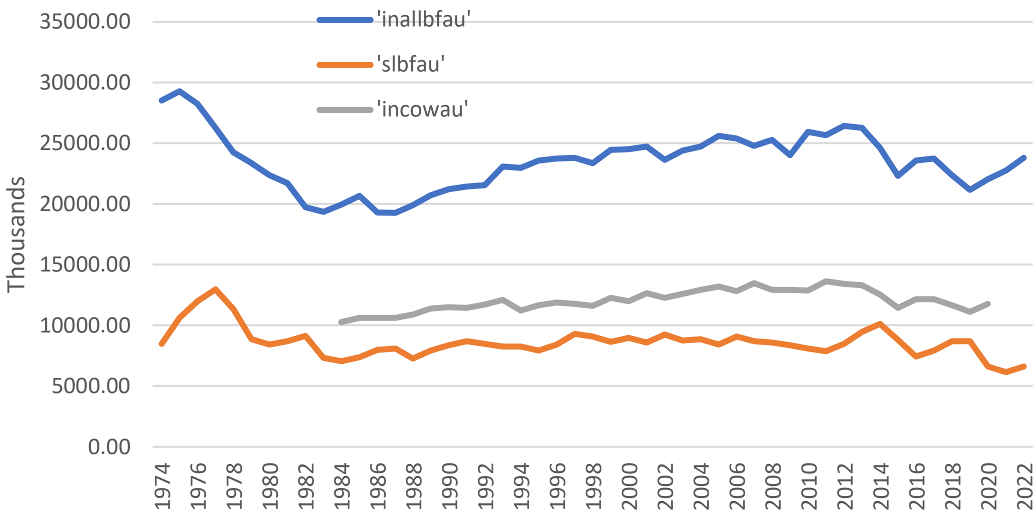
7.1.2 Results

Beef

Total Australian beef cattle numbers (the blue series labelled 'inallbfau'), cow numbers (the grey series labelled 'incowau') and beef slaughterings (the orange series labelled 'slbfau') are shown in Figure 4 for the period 1974 to 2022. The variable definitions were provided in **Table 1**.

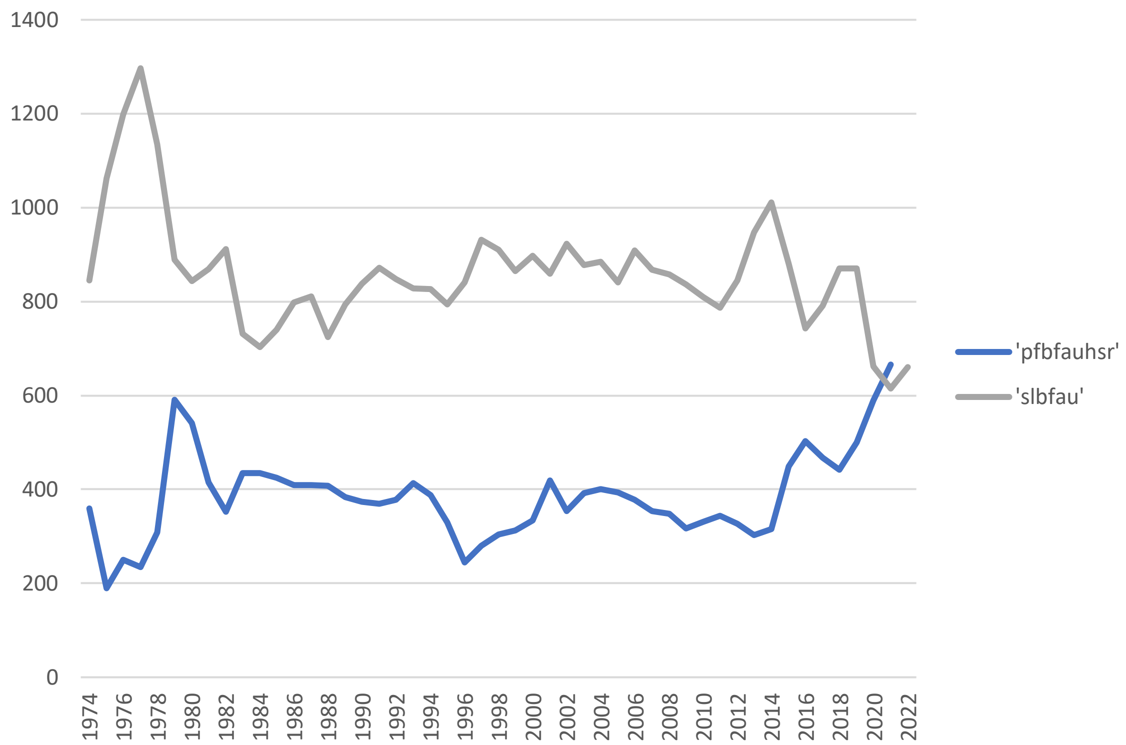
The long, drawn-out decrease in the beef herd following the 1974/75 Japanese import quota restriction is clearly shown. This was followed by the slow and partial rebuilding through to the mid-2000s, and then a period of increased variability and decline in both numbers and output. While there are periods of rises and falls in these data series, there is little indication of any regular, longer-term cyclical activity in the Australian cattle herd, at least on a similar scale as in the US herd as mentioned above and as shown in **Figure 4**.

Figure 4 **Australian inventories and slaughterings of beef cattle, 1974 to 2022**



The real price of cattle at the farm gate (shown in the heavy steer category, labelled as 'pfbfauhsr' in blue) and slaughterings (shown in grey) is graphed in Figure 5 for the same period.

Figure 5 **Price of cattle and cattle slaughterings, Australia, 1974 to 2022**



The bust and boom in prices from 1975 through to about 1980 is due to the trade restrictions imposed in 1974 and the diversion of surplus export beef onto the domestic market, and then the subsequent shortage of stock as herd rebuilding occurred. Likewise, the boom in prices since the mid-2000s is due to herd liquidation and shortages of stock. Both these periods of price changes inversely match the periods of quantity changes as shown in the 'slbfau' series. In between however is a period of remarkably constant real prices, disturbed only by the aftermath of the widespread 1982 drought, the 1990s extended drought and the droughts of the early 2000s and 2018-2019.

The relationship between cattle prices and a variable representing variations in rainfall Australia-wide from long-run averages (the orange series labelled as 'rainanom'), and the relationship between cattle slaughterings and the same rainfall variable, are shown in Figure 6 and Figure 7. Both of these graphs suggest that there is an expected relationship between rainfall and cattle turnoff and beef prices respectively which may warrant exploring further. This could be considered with more regular (weekly or monthly) data to test any relationship between rainfall and cattle available for processing – as opposed to the annual data used for this research.

Figure 6 **Australian cattle prices and rainfall, 1974 to 2022**

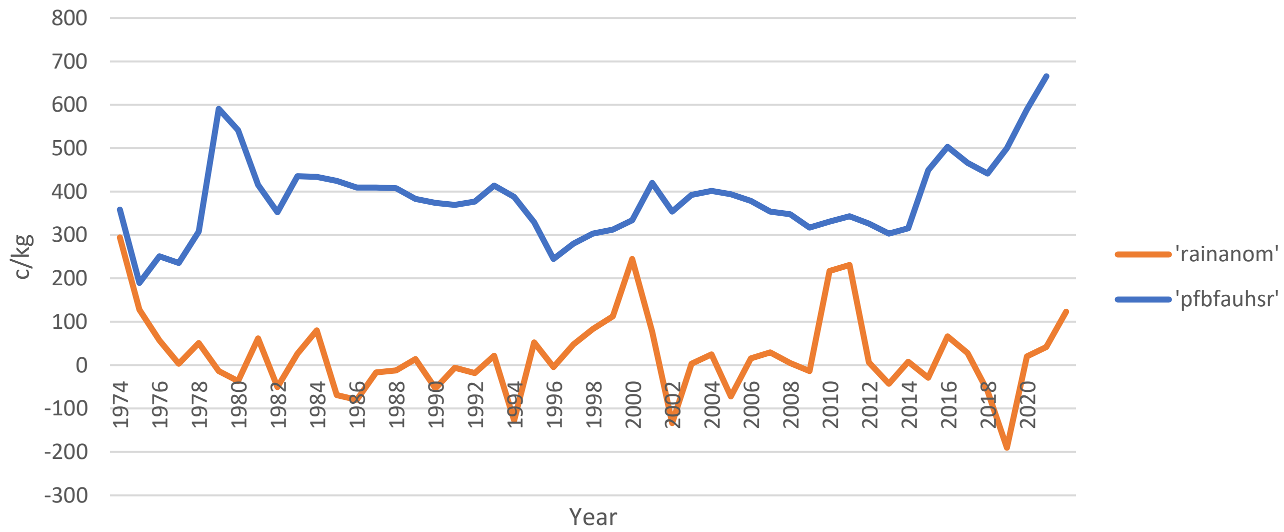
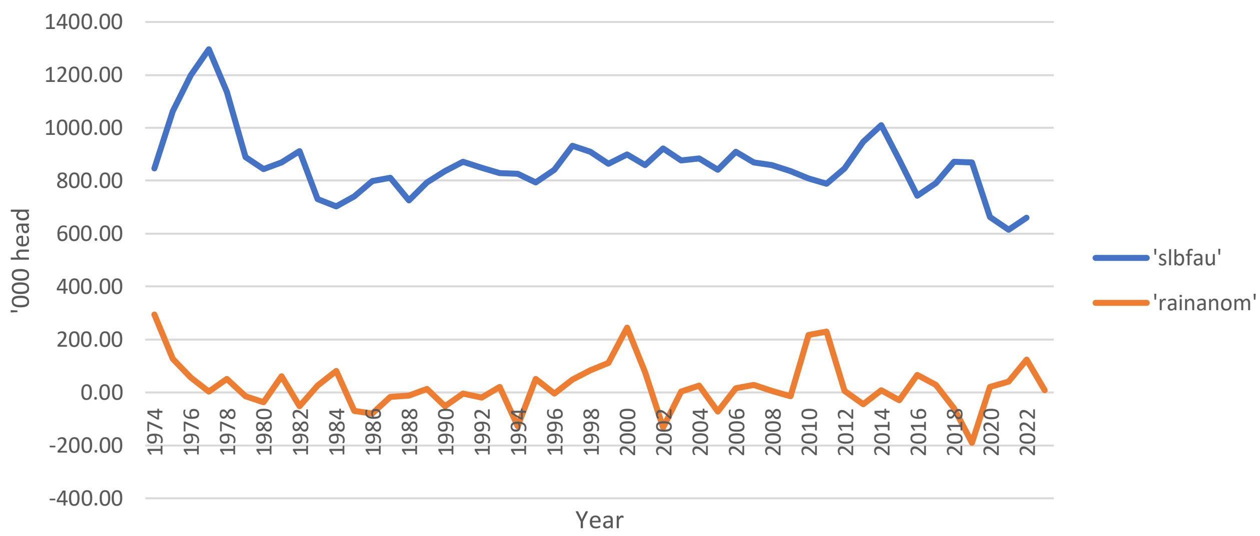


Figure 7 **Australian cattle slaughterings and rainfall, 1974 to 2022**



The results of the correlation analyses are provided in Table 2 (copied directly from the software output file to prevent any transcription errors).

Table 2 Correlation coefficients, US, and Australian beef data series, 1974-2022

	INALLUS	INCOWUS	INOTHUS	SLALLUS
INALLUS	1.0000			
INCOWUS	0.97626	1.0000		
INOTHUS	0.98737	0.93206	1.00000	
SLALLUS	0.85820	0.83626	0.85337	1.0000
PFBFUSR	-0.91433	-0.88459	-0.90730	-0.78985
FUTBFUSR	-0.29512	-0.23333	-0.34890	-0.47820
INALLBFAU	-0.0084956	0.051248	-0.021395	0.26150
INCOWAU	0.012675	0.063781	0.0020041	0.24608
SLBFAU	-0.10107	-0.014064	-0.14501	-0.018005
PFBFAUTSR	-0.019765	-0.062883	-0.012826	-0.26169
PFBFAUCR	0.048932	0.015437	0.045396	-0.24265
PFBFAUHSR	0.0060564	-0.038543	0.011356	-0.28440
RAINANONAU	0.11234	0.072933	0.15587	0.27271
	PFBFUSR	FUTBFUSR	INALLBFAU	INCOWAU
PFBFUSR	1.00000			
FUTBFUSR	0.42295	1.0000		
INALLBFAU	0.023318	-0.51717	1.0000	
INCOWAU	-0.036095	-0.64177	0.90119	1.0000
SLBFAU	0.25709	0.25440	0.23737	0.10683
PFBFAUTSR	-0.057242	0.30341	-0.68263	-0.60574
PFBFAUCR	-0.090292	0.42861	-0.72605	-0.67194
PFBFAUHSR	-0.050145	0.37720	-0.75642	-0.68394
RAINANONAU	-0.048649	-0.21891	0.44523	0.33104
	SLBFAU	PFBFAUTSR	PFBFAUCR	PFBFAUHSR
SLBFAU	1.00000			
PFBFAUTSR	-0.71968	1.00000		
PFBFAUCR	-0.65101	0.97204	1.00000	
PFBFAUHSR	-0.63800	0.98147	0.98151	1.00000
RAINANONAU	-0.26357	-0.17926	-0.17938	-0.25559
	RAINANONAU			
RAINANONAU	1.00000			

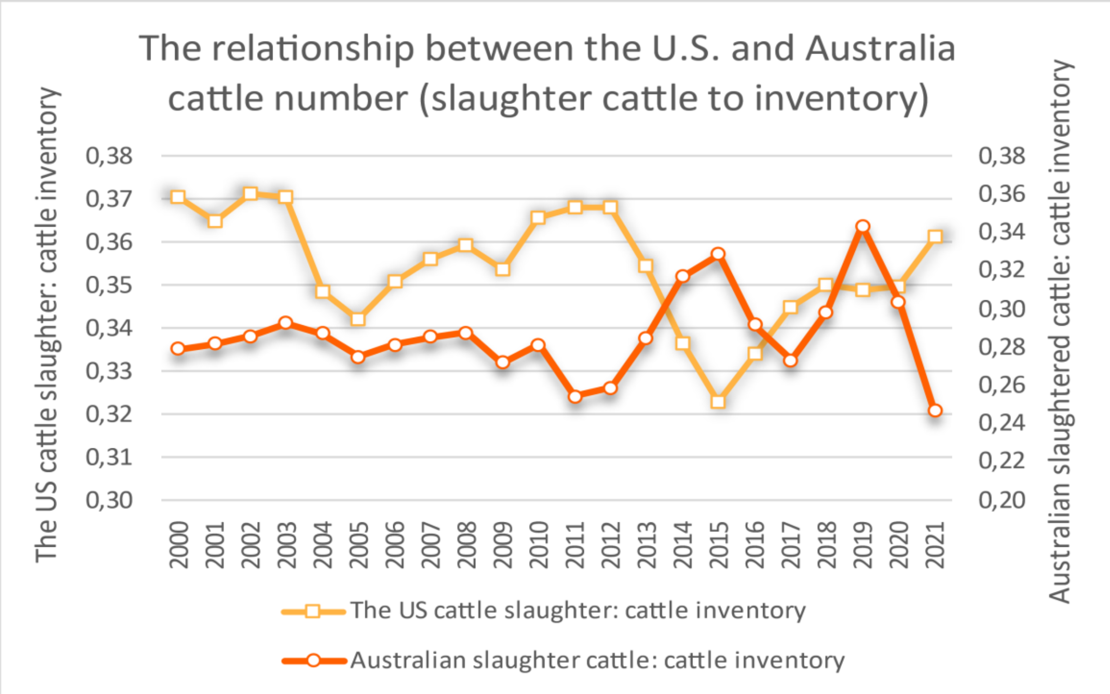
The Australian beef inventory variables are strongly positively correlated with each other (0.90) but there is a relatively weak relationship between inventories and slaughterings (0.11 to 0.24). This is a much weaker relationship than shown in the US data. The weaker correlation between slaughterings and inventories reflects the significance of the pasture-based finishing sector in Australia, the wider range of environmental conditions faced by beef producers in Australia and the increasing variability of climate especially in these production systems. Australian cattle prices are strongly positively correlated with each other (around 0.98) and negatively correlated with both the inventory and slaughterings series (-0.64 to -0.75). Also included in Table 2 is the variable representing variations in rainfall Australia-wide from long-run averages. The results suggest that Australia-wide rainfall is moderately positively related to beef numbers (0.45) and negatively related to beef slaughterings and prices, but at lower levels of association (-0.18 to -0.26).

The US beef inventory and slaughterings variables are all strongly positively correlated (all above 0.84). The strong correlation between slaughterings and inventories reflects the dominance of the feedlot sector in the US. The US prices of cattle are strongly negatively correlated with the inventory and slaughterings series (about -0.80 and greater), and as the futures price has only a moderate positive relationship with the auction price (0.42), the relationship between the futures price and the inventory and slaughterings variables is positive but much weaker.

When comparing the two industries across this whole data set, US and Australian cattle inventories show very weak positive or very weak negative correlations (ranging from -0.02 to 0.06), US and

Australian slaughterings show a very weak negative correlation (-0.02), and US and Australian prices show very weak negative correlations (-0.05 for the heavy steer categories). While not conclusive statistical evidence, this is strongly suggestive that economic activity in the US and Australian beef industries follow different paths.

Figure 8 The relationship between the US and Australian slaughter to inventory ratio, 2000 to 2021



Source: USDA (2022) and MLA (2022)

This is confirmed by looking at the relationship between the slaughter-to-inventory ratios in the two countries (Figure 8, taken from Helmi and Griffith (2023)). While only representing the latter part of the full data set, the graph clearly shows that these ratios are moving in different directions from around 2010. This is further evidence that the two industries are now uncoupled.

The main point from this simple graphical and correlation analysis is that contrary to the analysis and advice provided some 20 years ago, the US cattle cycle if it exists now, does not determine outcomes in the Australian beef industry. However, this speculation needs to be tested in the following more formal statistical analyses. The results for the unit root tests are provided in Table 3 and Table 4, for the US and Australian data respectively.

In Table 3, the important results are the p-values. All the test statistics except one confirm that the hypothesis of a unit root cannot be rejected. That is, non-stationarity is indicated and using these data in their current form in statistical procedures would produce misleading results. Given these results, further transformations of the US data series, such as first differencing, are required before any credible statistical analysis can proceed. The same is true for the Australian data series shown in Table 4. Again, for all the test statistics except two, non-stationarity is indicated so further transformation will be required. This is the same result as found by Longmire and Rutherford (1992).

The other interesting result has to do with the lag length. For the US series in Table 3, the optimal lag lengths for the influence of past values in the calculation of the test statistics are in general larger than those for the Australian data in Table 4. This says that in the US there is in general a longer period of time over which past values of these series are related to current values. Again, this is not conclusive but is suggestive of a shorter 'cycle' length in the Australian data, if such a cycle is confirmed in the following analyses.

Table 3 Unit root tests, US beef data series, 1970-2022

	Test Statistics			
	INALLUS	INCOWUS	INOTHUS	SLALLUS
Wtd.Sym.	-0.78965	-0.87470	-1.16407	-1.21193
Dickey-F	-1.35705	-4.49801	-1.53990	-3.09355
Phillips	-2.31673	-2.31753	-2.81600	-2.71959
	PFBFUSR	FUTBFUSR		
Wtd.Sym.	-1.96856	-2.14485		
Dickey-F	-2.74139	-2.13637		
Phillips	-3.78688	-6.02676		
	P-values			
	INALLUS	INCOWUS	INOTHUS	SLALLUS
Wtd.Sym.	0.98565	0.98158	0.95734	0.95109
Dickey-F	0.87308	0.0015209	0.81508	0.10777
Phillips	0.96140	0.96138	0.94424	0.94788
	PFBFUSR	FUTBFUSR		
Wtd.Sym.	0.66958	0.54472		
Dickey-F	0.21930	0.52568		
Phillips	0.89873	0.74330		
	Number of lags			
	INALLUS	INCOWUS	INOTHUS	SLALLUS
Wtd.Sym.	2.00000	7.00000	2.00000	3.00000
Dickey-F	7.00000	7.00000	7.00000	7.00000
Phillips	7.00000	7.00000	7.00000	7.00000
	PFBFUSR	FUTBFUSR		
Wtd.Sym.	2.00000	3.00000		
Dickey-F	7.00000	3.00000		
Phillips	7.00000	3.00000		

Note: SLALLUS commences 2000, PFBFUSR commences 1990, FUTBFUSR commences 1998

Table 4 Unit root tests, Australian beef and sheep data series, 1974-2022

	Test Statistics				
	INALLBFAU	SLBFAU	INCOWAU	PFBFAUTSR	PFBFAUCR
Wtd.Sym.	-1.30575	-1.56484	-1.38523	-0.82749	-1.43732
Dickey-F	-0.51039	-0.59749	-0.58041	-1.06518	-1.03814
Phillips	-2.81344	-12.93308	-5.12241	-1.69119	-4.38659
	PFBFAUHSR	INSHAU	PFLBAUR	PFMUAUR	RAINANONAU
Wtd.Sym.	-1.03936	-1.15042	-3.06937	-2.15374	-3.23693
Dickey-F	-0.80070	-2.20464	-2.40575	-3.09666	-1.65849
Phillips	-3.90345	-8.61647	-10.66458	-7.07694	-16.81864
	P-values				
	INALLBFAU	SLBFAU	INCOWAU	PFBFAUTSR	PFBFAUCR
Wtd.Sym.	0.93627	0.87135	0.92054	0.98396	0.90839
Dickey-F	0.98302	0.97908	0.97992	0.93468	0.93876
Phillips	0.94433	0.26958	0.81250	0.97729	0.86299
	PFBFAUHSR	INSHAU	PFLBAUR	PFMUAUR	RAINANONAU
Wtd.Sym.	0.97022	0.95897	0.070182	0.53813	0.043742
Dickey-F	0.96562	0.48724	0.37657	0.10703	0.76870
Phillips	0.89221	0.53573	0.39302	0.65825	0.13164
	Number of lags				
	INALLBFAU	SLBFAU	INCOWAU	PFBFAUTSR	PFBFAUCR
Wtd.Sym.	2.00000	6.00000	2.00000	6.00000	4.00000
Dickey-F	2.00000	3.00000	2.00000	6.00000	3.00000
Phillips	2.00000	3.00000	2.00000	6.00000	3.00000
	PFBFAUHSR	INSHAU	PFLBAUR	PFMUAUR	RAINANONAU
Wtd.Sym.	2.00000	7.00000	3.00000	3.00000	2.00000
Dickey-F	2.00000	2.00000	5.00000	8.00000	10.00000
Phillips	2.00000	2.00000	5.00000	8.00000	10.00000

The first stage of the ARIMA modelling process is presented in **Figure 9** for US beef industry variables and in **Figure 10** for Australian beef industry variables. In **Figure 5**, given the very high correlations between all the US inventory variables, just one is chosen for illustrative purposes (numbers of cows and heifers, 'incowus'), as well as slaughterings ('slbfus') and the real farm price ('pfbfusr'). First differencing is performed as required from the results of the unit root tests (denoted by

(1-B) in the copy of the printout). The graphs shown are the ‘correlograms’, which are the correlations of each data point of the series with its own lagged values, up to a lag of 10. While the ‘optimal’ number of lags selected in the unit root tests in Table 3 and Table 4 all showed lags shorter than 10, this value was chosen because it is the typical length of the beef cycle reported in previous research and in media commentary, and it is also a double check on the other test results.

Changes in US beef cow numbers (‘incowus’) are positively and significantly related to changes in beef cow numbers in the previous year (the ‘R’ outside the standard error band at lag 1), and negatively and significantly related to changes in beef cow numbers four years ago. The correlation at the lag of 5 is also close to the significance boundary. These results suggest a statistically significant regular pattern, where a current increase in cow numbers is related to a decrease in cow numbers some 4-5 years ago, or put another way, a cycle in cow numbers of some 8-10 years. No such patterns are shown for US beef slaughterings (‘slbfus’). There is no statistical evidence of cyclical behaviour in this variable. For farm prices (‘pfbfusr’), changes in real US beef prices are negatively and significantly related to changes in US beef prices five years ago. As with cow numbers, this suggests a significant regular pattern of a cycle in beef prices of some 8 to 10 years.

Figure 9 Identification tests, first differenced US data series, 1970-2022

```
Autocorrelation Function of: (1-B) INCOWUS

         -1.00     -0.60     -0.20     0.20      0.60      1.00
         |-+---------+---------+----0----+---------+---------+-|
 1       |                   +      |      +       R           | 0.59089
 2       |                 +        |   R    +                 | 0.15021
 3       |                 +  R     |        +                 | -0.23077
 4       |               R +        |        +                 | -0.42113
 5       |                +R        |         +                | -0.35521
 6       |               +         R|          +               | -0.042346
 7       |               +          |  R       +               | 0.10153
 8       |               +          | R        +               | 0.071450
 9       |               +          |R         +               | 0.054156
 10      |               +         R|          +               | -0.047476
         |-+---------+---------+----0----+---------+---------+-|
         -1.00     -0.60     -0.20     0.20      0.60      1.00
```

```
Autocorrelation Function of: (1-B) SLALLUS

         -1.00     -0.60     -0.20     0.20      0.60      1.00
         |-+---------+---------+----0----+---------+---------+-|
 1       |               +          |       R  +               | 0.32002
 2       |              +     R     |           +              | -0.23132
 3       |              +     R     |           +              | -0.25921
 4       |             +          R |            +             | -0.096515
 5       |             +            |R           +             | 0.046732
 6       |             +         R  |            +             | -0.13581
 7       |             +      R     |            +             | -0.23692
 8       |            +           R |             +            | -0.089118
 9       |            +             |  R          +            | 0.11307
 10      |            +             |       R     +            | 0.33384
         |-+---------+---------+----0----+---------+---------+-|
         -1.00     -0.60     -0.20     0.20      0.60      1.00
```

```
Autocorrelation Function of: (1-B) PFBFUSR

         -1.00     -0.60     -0.20     0.20      0.60      1.00
         |-+---------+---------+----0----+---------+---------+-|
 1       |                 +        R        +                 | 0.018030
 2       |                 +     R  |        +                 | -0.11902
 3       |                 +        |   R    +                 | 0.16547
 4       |                 +        |   R    +                 | 0.15369
 5       |               R +        |        +                 | -0.43013
 6       |               +   R      |          +               | -0.26741
 7       |               +          |     R    +               | 0.24176
 8       |              +           R           +              | 0.014127
 9       |              +       R   |           +              | -0.16447
 10      |              +           | R         +              | 0.062306
         |-+---------+---------+----0----+---------+---------+-|
         -1.00     -0.60     -0.20     0.20      0.60      1.00
```

Figure 10 Identification tests, first differenced Australian beef data series, 1974-2022

```
Autocorrelation Function of: (1-B) INCOWAU

         -1.00     -0.60     -0.20     0.20      0.60      1.00
         |-+---------+---------+----0----+---------+---------+-|
 1       |                  + R     |       +                  | -0.24160
 2       |                 +       R|        +                 | -0.046423
 3       |                 +      R |        +                 | -0.067952
 4       |                 +        |      R +                 | 0.28940
 5       |                 +   R    |        +                 | -0.18736
 6       |                +         |    R    +                | 0.20953
 7       |                +     R   |         +                | -0.14977
 8       |                +         |R        +                | 0.022392
 9       |                +         R         +                | -0.013453
 10      |                +         R         +                | -0.0081106
         |-+---------+---------+----0----+---------+---------+-|
         -1.00     -0.60     -0.20     0.20      0.60      1.00
```

```
Autocorrelation Function of: (1-B) SLBFAU

         -1.00     -0.60     -0.20     0.20      0.60      1.00
         |-+---------+---------+----0----+---------+---------+-|
 1       |                   +      |     R+                   | 0.23917
 2       |                  R+      |      +                   | -0.30499
 3       |                R +       |       +                  | -0.41844
 4       |                 +        | R      +                 | 0.069215
 5       |                 +        |      R +                 | 0.26462
 6       |                 +      R |        +                 | -0.065834
 7       |                +    R    |         +                | -0.20180
 8       |                +     R   |         +                | -0.17500
 9       |                +         |R        +                | 0.047573
 10      |                +         |R        +                | 0.059475
         |-+---------+---------+----0----+---------+---------+-|
         -1.00     -0.60     -0.20     0.20      0.60      1.00
```

```
Autocorrelation Function of: (1-B) PFBFAUHSR

         -1.00     -0.60     -0.20     0.20      0.60      1.00
         |-+---------+---------+----0----+---------+---------+-|
 1       |                   +      | R    +                   | 0.083792
 2       |                   R      |      +                   | -0.26363
 3       |                  +  R    |       +                  | -0.18286
 4       |                  +     R |       +                  | -0.083410
 5       |                  +       |  R    +                  | 0.10657
 6       |                  +       | R     +                  | 0.095394
 7       |                  +       |R      +                  | 0.041122
 8       |                  +     R |       +                  | -0.095220
 9       |                  +       R       +                  | -0.014711
 10      |                  +       R       +                  | 0.0035365
         |-+---------+---------+----0----+---------+---------+-|
         -1.00     -0.60     -0.20     0.20      0.60      1.00
```

The patterns for the equivalent first differenced Australian beef series shown in **Figure 10** are quite different to those shown in the US data. In none of the three series analysed is there any significant statistical evidence of the 8-10 year cycle that was found in US beef industry inventories and prices. None of the correlations for the Australian cow numbers variable ('incowau') lie outside of the standard error bands – there are no significant correlations of current changes in cow numbers with any previous change in cow numbers. There is no regular medium-term cycle in Australian cow numbers.

There are significant negative correlations shown in the slaughterings series ('slbfau') at lags 2 and 3, and there is a significant negative correlation shown in the farm price series ('pfbfauhsr') at lag 2. These results are both indicative of much shorter-term beef industry variability in Australia, which are more likely to be caused by changes in world market conditions on the demand side or environmental conditions on the supply side than by the decisions of uninformed, myopic beef cattle producers.

Sheep

Given the outcomes of the literature review, we are sceptical of the existence of a sheep cycle in Australia, but we have completed the analysis regardless.

Figure 11 shows Australian sheep numbers (the series labelled as 'inshau'), the real lamb price (labelled as 'pflbaur') and the real mutton price (labelled as 'pfmuaur') from 1974 to 2022. Sheep numbers were rising slowly up until 1989 in response to the incentives provided by the then-regulated wool market, but following deregulation the next year, numbers have continued falling and are now less than half of what they were 30 years ago. This is a very steady decline with little evidence of any cyclical activity. Real lamb and mutton prices move closely together, and following the historic lows immediately following deregulation, have been trending up over the years, albeit with significant shorter-term variability. Patterns in the sheep meat price series seem to match those in the beef price series (**Figure 5**) to some extent.

The correlation coefficients shown in **Table 5** confirm these patterns. The correlations suggest a very high level of association between the two sheep price series (0.97), and both prices have relatively high negative associations with sheep numbers (-0.76). Contrary to the situation in the beef industry, the rainfall variable has very little relationship to any of the sheep industry series. Also of interest is the moderately positive relationship between sheepmeat prices and beef prices (around the 0.5 mark). The unit root tests for the sheep industry variables reported in **Table 4** tell the same story as for the beef industry variables – all the series are non-stationary and require a first difference transformation before any statistical procedures are undertaken.

Figure 11 Australian sheep numbers and prices, 1974 to 2022

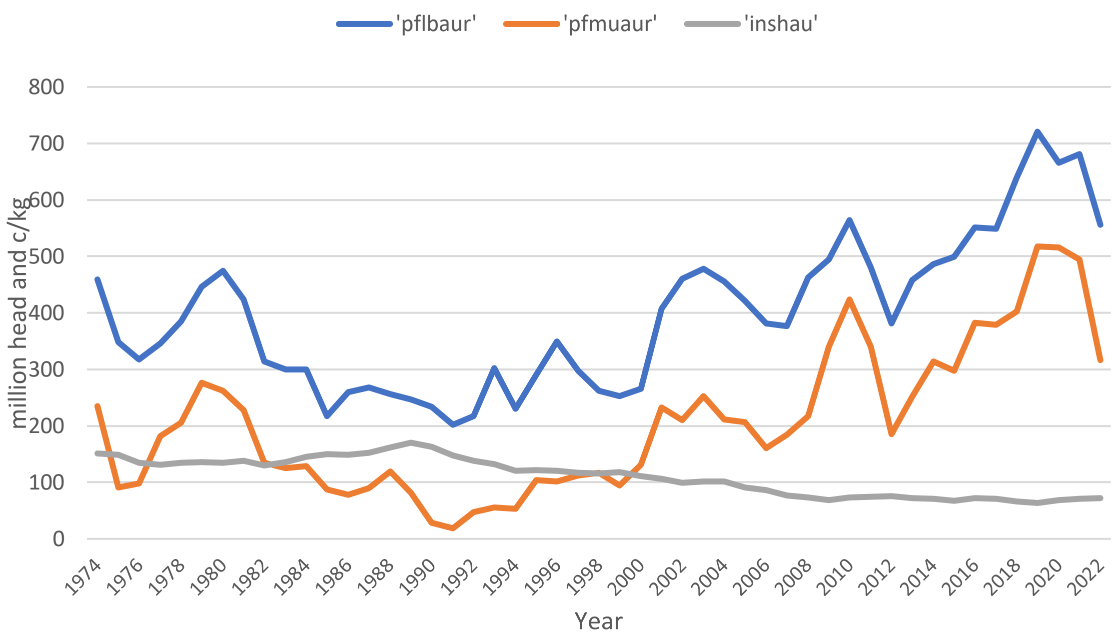


Table 5 Correlation coefficients, Australian sheep data series, 1974-2022

	INSHAU	PFLBAUR	PFMUAUR	PFBFAUTSR
INSHAU	1.00000			
PFLBAUR	-0.76621	1.00000		
PFMUAUR	-0.76160	0.96670	1.00000	
PFBFAUTSR	-0.15761	0.47510	0.52766	1.00000
PFBFAUCR	-0.13966	0.45343	0.51276	0.96651
PFBFAUHSR	-0.18186	0.47339	0.51778	0.97368
RAINANONAU	0.040850	-0.023772	0.036783	-0.16362

	PFBFAUCR	PFBFAUHSR	RAINANONAU
PFBFAUCR	1.00000		
PFBFAUHSR	0.98013	1.00000	
RAINANONAU	-0.18807	-0.24131	1.00000

The first stage of the ARIMA modelling process is presented in Figure 12 for the Australian sheep industry variables.

Figure 12 Identification tests, first differenced Australian sheep data series, 1974-2022

```
Autocorrelation Function of: (1-B) INSHAU

        -1.00     -0.60     -0.20     0.20      0.60      1.00
        |-+---------+---------+----0----+---------+---------+-|
1       |                   +      |      + R                 | 0.37728
2       |                  +       |R      +                  | 0.027537
3       |                  +      R|       +                  | -0.050283
4       |                  +       | R     +                  | 0.075873
5       |                  +      R|       +                  | -0.041380
6       |                  +       R       +                  | -0.019220
7       |                  +  R    |       +                  | -0.18986
8       |                  +   R   |       +                  | -0.14822
9       |                  +     R |       +                  | -0.079793
10      |                  +       R       +                  | 0.0031280
        |-+---------+---------+----0----+---------+---------+-|
        -1.00     -0.60     -0.20     0.20      0.60      1.00
```

```
Autocorrelation Function of: (1-B) PFLBAU

        -1.00     -0.60     -0.20     0.20      0.60      1.00
        |-+---------+---------+----0----+---------+---------+-|
1       |                   +      R      +                   | 0.019136
2       |                   +    R |      +                   | -0.071264
3       |                   +   R  |      +                   | -0.10237
4       |                 R +      |      +                   | -0.37484
5       |                  +       |  R    +                  | 0.11606
6       |                  +       | R     +                  | 0.085170
7       |                  +     R |       +                  | -0.061314
8       |                  +       |   R   +                  | 0.17939
9       |                  +       |R      +                  | 0.046443
10      |                  +      R|       +                  | -0.044318
        |-+---------+---------+----0----+---------+---------+-|
        -1.00     -0.60     -0.20     0.20      0.60      1.00
```

```
Autocorrelation Function of: (1-B) PFMUAU

        -1.00     -0.60     -0.20     0.20      0.60      1.00
        |-+---------+---------+----0----+---------+---------+-|
1       |                   +      | R    +                   | 0.096081
2       |                   + R    |      +                   | -0.19221
3       |                   +R     |      +                   | -0.22694
4       |                  +    R  |       +                  | -0.12372
5       |                  +       |R      +                  | 0.030436
6       |                  +       |R      +                  | 0.031767
7       |                  +      R|       +                  | -0.024072
8       |                  +     R |       +                  | -0.065963
9       |                  +       |R      +                  | 0.051685
10      |                  +       |      R+                  | 0.27209
        |-+---------+---------+----0----+---------+---------+-|
        -1.00     -0.60     -0.20     0.20      0.60      1.00
```

In the sheep numbers variable ('inshau'), there is a significant positive autocorrelation between the current value and the value last year, but none of the other lags showed any evidence of significant autocorrelations. There is no evidence of a medium-term sheep cycle in this data set.

There is evidence of a significant autocorrelation in real lamb prices at lag 4 but no evidence of any significant autocorrelation in mutton prices at any lag. The lamb price result does not appear to be output-based, given the lack of cyclic activity in sheep numbers, but could be caused by the strong interrelationships between lamb prices and beef prices. These two products are both substitutes in demand and competitors in supply, where lamb production and beef production often coexist on the same farm and the enterprise mix can change quickly due to relative profitability. In **Table 5** the correlation coefficients indicate a moderately strong positive relationship between lamb and beef prices (around 0.5), so changes in beef prices due to cyclical tendencies in that industry would be transferred across to similar changes in lamb prices in the same year.

6.2 Short-term analysis of market cycles

Data for market cycle analysis

The data required for this part of the project is outlined in **Table 6**.

Table 6 Data definitions for short-term analysis

Variable name used in the Figures and in the software outputs	Definitions
SLSBAU	Slaughterings of steers and bulls, Australia, thousands/quarter
SLCHAU	Slaughterings of cows and heifers, Australia, thousands/quarter
SLACAU	Slaughterings of adult cattle, Australia, thousands/quarter
SLVLAU	Slaughterings of calves, Australia, thousands/quarter
PDBFAU	Production of beef, Australia, tonnes/quarter
PDVLAU	Production of veal, Australia, tonnes/quarter
SLSHAU	Slaughterings of sheep, Australia, thousands/quarter
SLLBAU	Slaughterings of lambs, Australia, thousands/quarter
PDMTAU	Production of mutton, Australia, tonnes/quarter
PDLBAU	Production of lamb, Australia, tonnes/quarter
PABFAUR	The real farm price of beef, Australia, cents/kg DCW, average/quarter
PALBAUR	The real farm price of lamb, Australia, cents/kg DCW, average/quarter
PAMTAUR	The real farm price of mutton, Australia, cents/kg DCW, average/quarter
CPIAU	Australian Consumer Price Index, all groups, all capitals, base 2010/11=100

These data are consistent with the type of data used in previous studies of livestock cycles (see for example Longmire and Rutherford, 1992; Griffith, 1977), and with the data used in the Final Report on the first stage of the project, with four notable differences:

- First, it is quarterly data, so that a more detailed examination of the shorter-term cycles revealed in the annual analysis can be undertaken.
- Second, it does not include livestock numbers, as in Australia that information is only collected once a year at the March 31 agricultural census.
- Third, it does not include data on the United States beef industry, as it has already been established that the two industries no longer move in tandem. However, the influence of the United States beef industry will again be examined as part of the short-term price transmission part of the project.
- Fourth, it does not include data on seasonal conditions. There are no publicly available aggregated time series data on seasonal conditions on a quarterly basis outside of the data associated with specific weather stations. However, the influence of environmental conditions will again be examined as part of the short-term processor-specific and regional analysis part of the project.

All the data required was able to be obtained from public sources. The time period covered in the data set was from 1970:1 to 2024:2, the most recent data available in the public databases. The number of quarterly observations is 218 prior to any required data transformations. The period covered is actually slightly longer than that used in the earlier study using annual data.

The livestock slaughterings and meat production variables were available directly from the electronic databases in the ABS publication*, 7215 Livestock Products, Australia, June 2024*. These databases covered the period 1972:3 to 2024:2, except for the variables SLSBAU and SLCHAU which were only reported from 1976:3. Comparable earlier data for 1970:1 to 1972:2, and to 1976:2 for SLSBAU and SLCHAU, were accessed from the TSP database maintained by the author which underpins a quarterly econometric model of the Australian livestock section (*GRAZMOD*) as reported in a number of publications (see for example Vere and Griffith, 2004, 2005; Griffith et al., 2007). These data were accessed at the time from ABS and ABARES. The livestock slaughterings and meat production series have been consistently defined over the whole period and reported by the same sources, so there are no problems with simply adding the two data sets together.

It is different for the price series, however, where there have been a number of changes in the series reported over this almost 55-year period. MLA currently provide quarterly saleyard price averages for a range of different types of cattle, lambs and sheep, which are available from 2000:1 to 2024:2.

The quarterly GRAZMOD database mentioned above contains average saleyard prices for cattle, lambs and sheep for the period 1970:1 to 1998:2. To fill in the gaps between these two data sets, data for 1999 was constructed from the monthly data provided in the 2000 issue of ABARES's *Australian Commodity Statistics*, but data for the last two quarters of 1998 could not be accessed as the meat and livestock data tables are missing from the online copy of the 1999 issue. The two missing values for each series were interpolated given adjoining data points and evident seasonal patterns.

To splice together the early (1970-1999) quarterly ABARES data and the later (2000-2024) quarterly MLA data, the closest matches were trade lamb for lamb and young cattle for beef. For the mutton price, there was only one option. However, to take some account of any possible irregularities caused by the series construction method, a dummy variable splitting the period into two, 1970:1 to 1999:4, and then 2000:1 to 2024:2, was developed and used as an exogenous weighting factor in the estimated autocorrelation models reported below.

Note again that all prices are in 'real' terms – they have been deflated by the CPI – to remove the impacts of changes in costs in the rest of the economy on farm prices over the data period.

Methods

The objective of this analysis is to examine whether short-term and medium-term cycles in output and prices of cattle and sheep in Australia, of regular length and magnitude, exist, with a high standard of proof. Very short-run, within-year, seasonal patterns are also accounted for, but they are not the primary focus of the analysis. Time series econometrics tools are used to see if there is any statistical evidence of cyclical activity in these markets, and if so, what is the nature of this activity. The methods used are in the class of methods called 'time domain', as they are simpler to implement and interpret and do not require sophisticated software packages. The more sophisticated 'frequency domain' methods, such as spectral analysis (Griffith, 1975,1977; Hinchy, 1978; Longmire and Rutherford, 1992) could be applied in future if required to confirm the time domain results.

Several steps are required:

First, the relevant data series are graphed and reported to provide a visual representation of the trends and patterns. Simple correlation coefficients are also calculated and reported in the results below.

Second, the relevant series are checked for ‘stationarity’. Even though real prices are used, some of the graphs suggest strong trends, so it is necessary to test for stationarity before proceeding further. Most econometric estimation techniques assume that the time series being examined are stationary, that is “the mean and variance are constant over time and the covariance between two values from the series depends only on the length of time separating the two values and not on the actual time at which the variables are observed” (Hill et al., 2001, p.335). If the series are non-stationary, ‘spurious’ regressions may result, where significant relationships are found when there are none.

The stationarity of a time series can be tested by using a ‘unit root’ test. Three different test statistics are available in the TSP 4.5 software package (Hall and Cummins, 2003) and are used here – the augmented Dickey-Fuller test, the Weighted Symmetric test, and the Phillips-Perron test. All allow the addition of constant and trend variables, and where appropriate, other exogenous variables such as dummy variables (Hall and Cummins, 2003, pp.42-48). ‘Augmenting’ lags can be specified to control for additional serial correlation. Here, for the cattle series, lags up to 40 are included, given the common perception that the cattle cycle if it exists will show peak-to-peak or trough-to-trough of about 10 years apart. For sheep and lamb, lags up to 16 are specified (so up to a 4-year cycle, if it exists). For the various series to be considered stationary, the selected test statistics should be significantly different from zero (p values less than 0.05). The results of applying these tests are shown in the results.

Third, AutoRegressive Integrated Moving Average (ARIMA), or Box-Jenkins (1976), models are applied to the stationary time series variables. These models use only a series’ own lagged values to forecast its future values. The lagged values can be either moving average terms, autoregressive terms, or both, which statistically best describe the patterns in the past data. These methods are preferable to the full structural econometric approach where in addition to the information on the dependent variable, all the values of all the other explanatory variables that ‘cause’ future supplies, demands and prices must be either known or be reliably estimated (such as in Vere and Griffith, 2004, 2005). As mentioned earlier, ARIMA models are also easier to implement and interpret than ‘time domain’ methods such as spectral analysis.

For the purposes of the project, the key results from the ARIMA output are the autocorrelation functions and partial autocorrelation functions. Autocorrelation is the correlation or degree of association between two observations at different points in the same time series. For example, current values are associated with the immediately previous values (this quarter and last quarter, a lag of 1), current values are associated with the values two observations back (this quarter and two quarters ago, a lag of 2), and so on. When these correlations are statistically significant, they indicate that these past values are closely associated with the current value. The correlations may be positive or negative. The autocorrelation function is a plot of these correlations for the different specified lag lengths. The partial autocorrelation function is similar to the autocorrelation function except that it displays only the correlation between two observations that the shorter lags between those observations do not explain. For example, the partial autocorrelation for lag 3 is only the correlation that lags 1 and 2 do not explain. Autocorrelation functions and partial autocorrelation functions are reported for each of the key variables.

Fourth, if there are statistically significant autocorrelations (cyclical characteristics) of the variable of interest, that is values showing as outside the standard error bands, steps can be taken to:

- *identify* the type of statistically significant characteristics of the variable of interest (moving average, autoregressive, or both); and then if needed

- *estimate* the parameters of the model specified based on what was found in the identification phase (the actual empirical relationships between past and current values); and then
- *forecast* into the future the variable of interest based on the estimated model parameters.

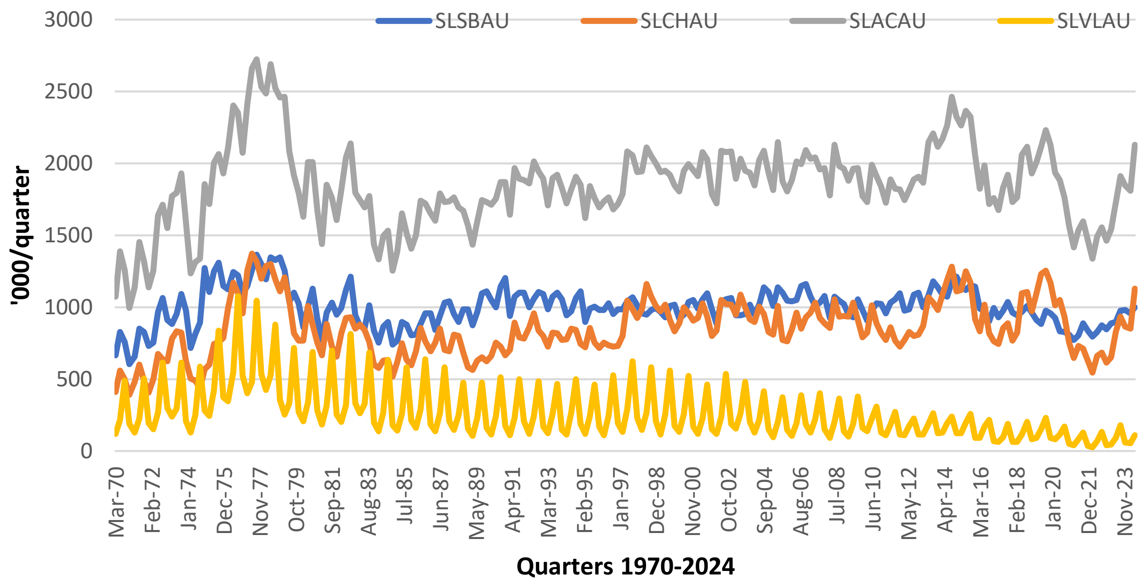
The consequent question is how this information could be used by industry. That is taken up in the discussion.

7.1.2 Results

Beef

Slaughterings of steers and bulls (the blue series labelled 'slsbau'), cows and heifers (the orange series labelled 'slchau'), total adult cattle (the grey series labelled 'slacau') and calves (the yellow series labelled 'slvlau'), for Australia in total, are shown in **Figure 13** on a quarterly basis for the period 1970:1 to 2024:2. The variable definitions were provided in **Table 6**.

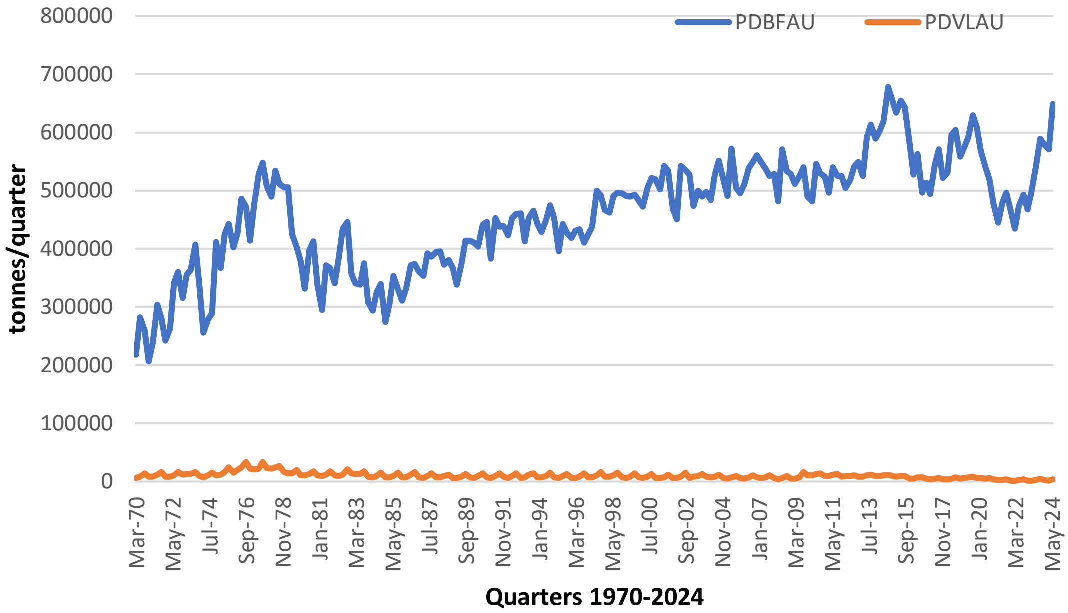
Figure 13 Slaughterings of different types of beef cattle ('000 head/quarter), Australia, 1970:1 - 2024:2



The export-led industry expansion in the early 1970s followed by the long, drawn-out decrease in the beef herd following the 1974/75 Japanese import quota restriction is clearly shown. This was followed by the slow and partial rebuilding through to the mid-2000s, and then a period of increased variability, especially in the breeding herd ('slchau'), together with a decline in all types of slaughterings over the past decade. It is evident that changes in cow and heifer slaughterings ('slchau') have a much greater influence on total adult cattle slaughterings ('slacau') than do slaughterings of steers and bulls ('slsbau'). There are very distinct seasonal patterns in all the beef slaughterings series, and while there are periods of rises and falls in these data, there is little indication of any regular, longer-term cyclical activity in the slaughterings of any of these types of Australian cattle, at least on a similar scale as in the United States cattle herd as mentioned in previous analyses. The possible exception is the first 10 years or so of the data set, but as indicated above, this boom and bust was primarily related to trade-related events.

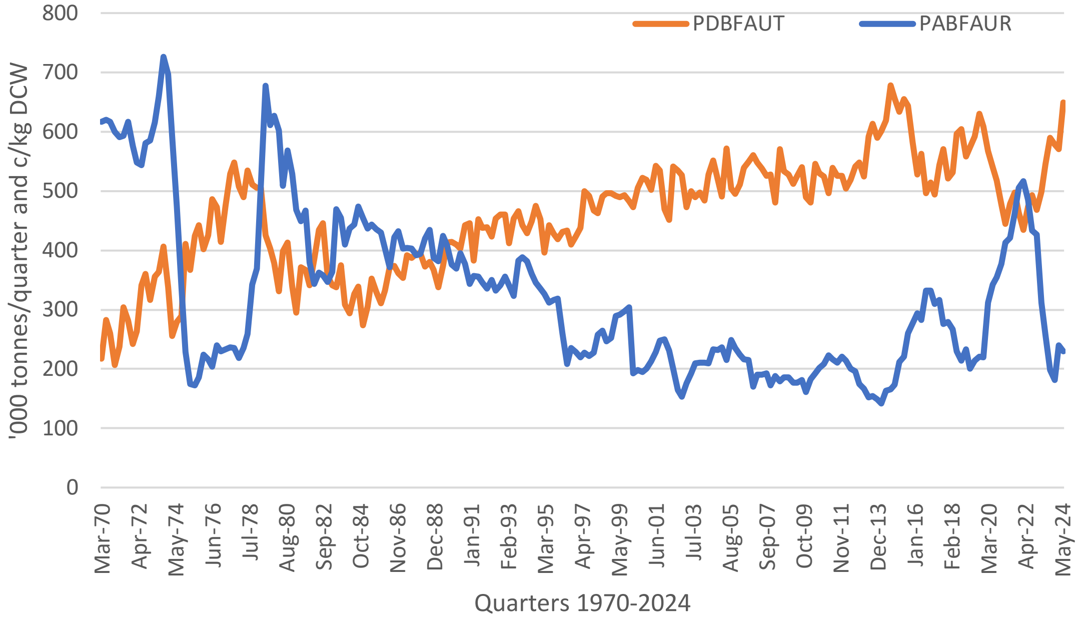
Production of beef (the blue series labelled 'pdbfau') and veal (the orange series labelled 'pdvlau') is shown in **Figure 14** for the same time period. The production of beef series closely matches that of the slaughtering of adult cattle, but with an upward trend reflecting the increase in carcase weights over this time period. As for the slaughterings series, there is no indication of longer-term cyclical activity in beef production, again with the possible exception of the first 10 years or so of the data set. Production of veal is minor and declining in importance over time.

Figure 14 Production of beef and veal (tonnes/quarter), Australia, 1970:1 - 2024:2



The real price of cattle at the farm gate (the blue series labelled as 'pabfaur') and beef production (the grey series labelled 'pdbfau') is graphed in **Figure 15** for the same period. The bust and boom in prices from 1975 through to about 1980 is due to the trade restrictions imposed in 1974 and the diversion of surplus export beef onto the domestic market, and then the subsequent shortage of stock as herd rebuilding occurred. Likewise, the boom in prices since the mid-2000s is due to herd liquidation and shortages of stock. Both these periods of large price changes inversely match the periods of quantity changes as shown in the 'pdbfau' series. In between however is a period of steadily declining real prices, with minor downturns evident and probably associated with the widespread 1982 drought, the 1990s extended drought and the droughts of the early 2000s and 2018-2019.

Figure 15 **Production of beef ('000 tonnes/quarter) and real saleyard price of cattle (c/kg DCW), Australia, 1970:1 – 2024:2**



The results of the correlation analyses are provided in **Table 7** (copied directly from the software output file to prevent any transcription errors).

Table 7 **Correlation coefficients, Australian beef data series, 1970:1-2024:2**

	SLSBAU	SLCHAU	SLACAU	SLVLAU
SLSBAU	1.00000			
SLCHAU	0.58409	1.0000		
SLACAU	0.84155	0.92919	1.00000	
SLVLAU	0.44895	0.16556	0.31964	1.00000
PDBFAU	0.52577	0.76510	0.74117	-0.14840
PDVLAU	0.53393	0.29496	0.44713	0.89745
PABFAUR	-0.45821	-0.57495	-0.58348	0.11133

	PDBFAU	PDVLAU	PABFAUR
PDBFAU	1.0000		
PDVLAU	-0.11567	1.0000	
PABFAUR	-0.75298	0.039275	1.0000

Slaughterings of cows and heifers and slaughterings of steers and bulls are both strongly correlated with total adult slaughterings (0.84 and 0.93), more so the 'slchau' variable as indicated in **Table 7**. Male and female slaughterings are only moderately related (0.58) and adult and calf slaughterings are generally weakly related in the current quarter. These associations flow over into the production variables, with the production of beef most closely related to female slaughterings (0.77) and of course, veal production is closely related to calf slaughterings (0.90). The real farm price of beef is moderately negatively related to adult slaughterings (-0.46 to -0.58) and strongly negatively correlated with beef production (-0.75). These are about the same degrees of correlation as found in the annual data.

The results for the unit root tests for the beef series are provided in **Table 8**. Three alternative test statistics are provided by the software package. While the literature suggests that one of the alternatives may be preferred in some circumstances (the Weighted Symmetric), there does not appear to be any general consensus on which one would be preferred in all circumstances, so here all are reported.

In **Table 8** the important results are the p-values. The majority of the test statistics confirm that the hypothesis of a unit root cannot be rejected. That is, non-stationarity is indicated and using these data in their current form in statistical procedures would produce misleading results. Given these results, further transformations of the series, such as first differencing, are required before any credible statistical analysis can proceed. This is the same result as found by Longmire and Rutherford (1992) and as found when analysing the annual data.

Table 8 Unit root tests, Australian beef data series, 1970:1-2024:2

		Test Statistics		
	SLSBAU	SLCHAU	SLACAU	SLVLAU
Wtd.Sym.	-2.35178	-2.52736	-2.35778	-2.38176
Dickey-F	-2.46680	-2.33881	-2.06050	-2.07633
Phillips	-24.97421	-26.00438	-19.76316	-272.50010
	PDBFAU	PDVLAU	PABFAUR	
Wtd.Sym.	-2.77503	-2.18759	-3.20478	
Dickey-F	-2.16503	-2.02876	-3.81278	
Phillips	-22.77639	-119.08341	-20.29279	
		P-values		
	SLSBAU	SLCHAU	SLACAU	SLVLAU
Wtd.Sym.	0.39195	0.27610	0.38769	0.37081
Dickey-F	0.34475	0.41261	0.56813	0.55932
Phillips	0.025463	0.020506	0.073984	9.62082D-28
	PDBFAU	PDVLAU	PABFAUR	
Wtd.Sym.	0.15392	0.51290	0.047943	
Dickey-F	0.50954	0.58568	0.015925	
Phillips	0.040178	6.59262D-12	0.066548	
		Number of lags		
	SLSBAU	SLCHAU	SLACAU	SLVLAU
Wtd.Sym.	8.00000	20.00000	18.00000	10.00000
Dickey-F	19.00000	20.00000	19.00000	11.00000
Phillips	19.00000	20.00000	19.00000	11.00000
	PDBFAU	PDVLAU	PABFAUR	
Wtd.Sym.	8.00000	14.00000	5.00000	
Dickey-F	19.00000	14.00000	5.00000	
Phillips	19.00000	14.00000	5.00000	

The first stage of the ARIMA modelling process is presented in the following figures for selected Australian beef industry variables. The vealer component of the industry is ignored, given the small and declining share of output as shown in **Figure 13** and **Figure 14**, and similarly, total adult slaughterings are ignored as it is simply the sum of slaughterings of steers and bulls, and cows and heifers. First differencing is performed as required from the results of the unit root tests (denoted by (1-B) in the graphs copied from the output file). The graphs shown are the ‘correlograms’, which are the autocorrelations of each data point of the series with its own lagged values, up to a lag of 40. While the ‘optimal’ number of lags selected in the unit root tests in **Table 8** all showed lags of 20 or shorter, the value of 40 was chosen because it is the typical length of the beef cycle reported in previous research and in media commentary, and it is also a double check on the other test results. Also reported are the partial correlograms, which indicate the significance of the correlations of the series with its own past values after the correlations with shorter lags are removed.

For the ‘slsbau’ series shown in **Figure 16**, the autocorrelation function shows statistically significant positive correlations at lags of 4, 8, 12, then for most of the other 4-period lags all the way to a lag of 36.

Figure 16 Identification tests, first differenced steer and bull slaughterings, Australia, 1970:4 – 2024:2

Autocorrelation Function of: (1-B) SLSBAU

```
        -1.00     -0.60     -0.20     0.20      0.60      1.00
        |-+---------+---------+----0----+---------+---------+-|
1       |                       R  |  +                       | -0.11323
2       |              R        +  |  +                       | -0.46428
3       |                      +  R|   +                      | -0.035232
4       |                      +   |   +     R                | 0.40003
5       |                      +   R   +                      | 0.010876
6       |                 R    +   |   +                      | -0.35865
7       |                     +   R|    +                     | -0.050958
8       |                     +    |    +  R                  | 0.32817
9       |                     +    |R   +                     | 0.033641
10      |                  R  +    |    +                     | -0.31749
11      |                     +   R|    +                     | -0.029641
12      |                     +    |    +   R                 | 0.34978
13      |                     +   R|    +                     | -0.028682
14      |                    R+    |    +                     | -0.25727
15      |                    +    R|     +                    | -0.054670
16      |                    +     |     +   R                | 0.39890
17      |                    +     R     +                    | 0.0054320
18      |               R    +     |     +                    | -0.42039
19      |                    +    R|     +                    | -0.042988
20      |                    +     |     +  R                 | 0.35777
21      |                    +     |R    +                    | 0.043202
22      |                   R+     |     +                    | -0.27727
23      |                   +   R  |      +                   | -0.10263
24      |                   +      |      R                   | 0.29911
25      |                   +      |R     +                   | 0.048507
26      |                  R+      |      +                   | -0.30504
27      |                   +    R |      +                   | -0.089123
28      |                   +      |      +R                  | 0.30058
29      |                   +      | R    +                   | 0.079912
30      |                  R+      |      +                   | -0.30889
31      |                   +    R |      +                   | -0.086399
32      |                   +      |      R                   | 0.27406
33      |                   +      | R    +                   | 0.075905
34      |                 R +      |      +                   | -0.36246
35      |                  +      R|       +                  | -0.058882
36      |                  +       |       +R                 | 0.35969
37      |                  +       | R     +                  | 0.086419
38      |                  R       |       +                  | -0.32517
39      |                  +     R |       +                  | -0.087079
40      |                  +       |       R                  | 0.30319
        |-+---------+---------+----0----+---------+---------+-|
        -1.00     -0.60     -0.20     0.20      0.60      1.00
```

Partial Autocorrelation Function of: (1-B) SLSBAU

```
        -1.00     -0.60     -0.20     0.20      0.60      1.00
        |-+---------+---------+----0----+---------+---------+-|
1       |                       R  |  +                       | -0.11343
2       |              R        +  |  +                       | -0.48831
3       |                    R  +  |  +                       | -0.22972
4       |                       +  |  +R                      | 0.17991
5       |                       +  |R +                       | 0.052985
6       |                      R+  |  +                       | -0.14961
7       |                       R  |  +                       | -0.11048
8       |                       +  | R+                       | 0.074121
9       |                       +  |R +                       | 0.034712
10      |                       R  |  +                       | -0.10553
11      |                       + R|  +                       | -0.047497
12      |                       +  |  R                       | 0.13868
13      |                       +  R  +                       | -0.019459
14      |                       +  R  +                       | 0.0031657
15      |                       R  |  +                       | -0.10366
16      |                       +  |  + R                     | 0.21245
17      |                       +  | R+                       | 0.094185
18      |                      R+  |  +                       | -0.14814
19      |                       R  |  +                       | -0.12820
20      |                       + R|  +                       | -0.041415
21      |                       +  |R +                       | 0.050353
22      |                       +  | R+                       | 0.093235
23      |                       R  |  +                       | -0.10116
24      |                       +  R  +                       | -0.010857
25      |                       + R|  +                       | -0.045448
26      |                       +R |  +                       | -0.092558
27      |                       +R |  +                       | -0.091887
28      |                       +R |  +                       | -0.076117
29      |                       +  |R +                       | 0.042375
30      |                       +R |  +                       | -0.073745
31      |                       +R |  +                       | -0.079992
32      |                       +R |  +                       | -0.082027
33      |                       +R |  +                       | -0.078782
34      |                     R +  |  +                       | -0.21630
35      |                       +R |  +                       | -0.062529
36      |                       +  R  +                       | -0.0060175
37      |                       +  |R +                       | 0.038380
38      |                       + R|  +                       | -0.057181
39      |                       + R|  +                       | -0.036625
40      |                       +  R  +                       | 0.014333
        |-+---------+---------+----0----+---------+---------+-|
        -1.00     -0.60     -0.20     0.20      0.60      1.00
```

This is strongly suggestive of an annual seasonal cycle, with the significant correlations at lags of 8, 12 etc just being repeats of the annual seasonal pattern (known as 'harmonics'). This is confirmed by an examination of the related partial autocorrelation function, which shows the same significant correlation at lag 4, but then only one other significant correlation at a lag of 16. All other positive correlations are insignificant. This shows that once the strength of the initial annual seasonal cycle is accounted for, there are no other patterns that show up, apart from the lag of 16.

Also shown in the autocorrelation function for the 'slsbau' series are a series of significant negative correlations at lags of 2, 6, 10 etc up to a lag of 38. Again, inspection of the partial autocorrelation function shows that most of these lose significance once the effects of the lower lag lengths are accounted for. There is again primarily evidence of a simple seasonal pattern. Beyond the seasonal pattern, the only remaining significant negative correlation is at a lag of 18, and again at a lag of 34.

The strongly significant positive autocorrelation at a lag of 16 backed up by the significant partial autocorrelations at that lag length, suggests a consistent 4-year cycle in Australian steers and bulls slaughterings. The strongly significant negative autocorrelation at lag 18, and the significant partial autocorrelation at the same lag length and at lag 34, are difficult to rationalise. Because it is a negative correlation it implies a peak and a trough 4-5 years apart but there are no positive autocorrelations outside of the recurring seasonal pattern that confirm any lag of that magnitude.

For the 'slchau' series shown in **Figure 17**, a very similar pattern is evident as for steers and bulls. The autocorrelation function shows statistically significant positive correlations at lags of 4, 8, and 12, then for most of the other 4-period lags all the way to a lag of 40. The related partial autocorrelation function shows the same significant correlation at lag 4, but then only one other significant correlation at a lag of 16. Again, this is strongly suggestive of an annual seasonal cycle. Further, the significant partial autocorrelation at lag 16 coincides with what was found in the 'slsbau' series. There are some differences at longer lag lengths, however. There are significant autocorrelations and partial autocorrelations at lags of 20 which may indicate a weak 5-year cycle. The significant negative partials at lag 10 match the positive partial at 20. As in the steer and bull series, there are some anomalous longer-term negative patterns (at lag 34) that are difficult to explain.

Figure 17 Identification tests, first differenced cow and heifer slaughterings, Australia, 1970:4 – 2024:2

Autocorrelation Function of: (1-B) SLCHAU

```
        -1.00     -0.60     -0.20      0.20      0.60      1.00
        |-+---------+---------+----0----+---------+---------+-|
1       |                       +  R  +                       | -0.0085852
2       |                R      +  |  +                       | -0.41848
3       |                      +   R   +                      | -0.0061295
4       |                      +   |   +         R            | 0.55991
5       |                     +   R|    +                     | -0.056734
6       |               R     +    |    +                     | -0.44675
7       |                     +  R |    +                     | -0.086509
8       |                     +    |    +     R               | 0.43278
9       |                    +   R |     +                    | -0.064908
10      |              R     +     |     +                    | -0.48418
11      |                    +  R  |     +                    | -0.12610
12      |                    +     |     +    R               | 0.43202
13      |                    +    R|     +                    | -0.046265
14      |               R    +     |     +                    | -0.45739
15      |                   +    R |      +                   | -0.096179
16      |                   +      |      +     R             | 0.52705
17      |                   +      |R     +                   | 0.047676
18      |                R  +      |      +                   | -0.40533
19      |                   +    R |      +                   | -0.075481
20      |                   +      |      +       R           | 0.58746
21      |                  +       |R      +                  | 0.034743
22      |                 R+       |       +                  | -0.35172
23      |                  +     R |       +                  | -0.094797
24      |                  +       |       +    R             | 0.52745
25      |                 +       R|        +                 | -0.021160
26      |                R+        |        +                 | -0.40617
27      |                 +     R  |        +                 | -0.10935
28      |                 +        |        +R                | 0.39910
29      |                 +        R        +                 | -0.0091494
30      |                R+        |        +                 | -0.39138
31      |                 +    R   |        +                 | -0.14184
32      |                 +        |        +R                | 0.41948
33      |                 +        R        +                 | -0.016940
34      |               R +        |        +                 | -0.42735
35      |                +      R  |         +                | -0.10935
36      |                +         |         +R               | 0.43528
37      |                +         |  R      +                | 0.10636
38      |                +R        |         +                | -0.34110
39      |                +      R  |         +                | -0.11402
40      |                +         |         +R               | 0.45912
        |-+---------+---------+----0----+---------+---------+-|
        -1.00     -0.60     -0.20      0.20      0.60      1.00
```

Partial Autocorrelation Function of: (1-B) SLCHAU

```
        -1.00     -0.60     -0.20      0.20      0.60      1.00
        |-+---------+---------+----0----+---------+---------+-|
1       |                       +  R  +                       | -0.0087239
2       |               R       +  |  +                       | -0.42647
3       |                       +  R  +                       | -0.017736
4       |                       +  |  +        R              | 0.48149
5       |                       +R |  +                       | -0.090787
6       |                     R +  |  +                       | -0.21550
7       |                      R+  |  +                       | -0.16798
8       |                       +  |  R                       | 0.10417
9       |                       +R |  +                       | -0.063781
10      |                    R  +  |  +                       | -0.23448
11      |                     R +  |  +                       | -0.18019
12      |                       +  | R+                       | 0.078660
13      |                       +R |  +                       | -0.097905
14      |                      R+  |  +                       | -0.17823
15      |                      R+  |  +                       | -0.16036
16      |                       +  |  + R                     | 0.19581
17      |                       +  | R+                       | 0.086174
18      |                       + R|  +                       | -0.054765
19      |                       R  |  +                       | -0.10885
20      |                       +  |  +  R                    | 0.22805
21      |                       + R|  +                       | -0.035797
22      |                       +  | R+                       | 0.065304
23      |                       R  |  +                       | -0.10641
24      |                       +  |  R                       | 0.13442
25      |                       R  |  +                       | -0.10890
26      |                       R  |  +                       | -0.12848
27      |                       +  R  +                       | -0.0016450
28      |                       +R |  +                       | -0.065613
29      |                       + R|  +                       | -0.029014
30      |                       + R|  +                       | -0.024664
31      |                       + R|  +                       | -0.051252
32      |                       +  | R+                       | 0.077339
33      |                      R+  |  +                       | -0.15566
34      |                     R +  |  +                       | -0.21946
35      |                       + R|  +                       | -0.029092
36      |                       +  R  +                       | 0.0056483
37      |                       +  |  +R                      | 0.14389
38      |                       + R|  +                       | -0.050480
39      |                      R+  |  +                       | -0.14004
40      |                       +  |  R                       | 0.11326
        |-+---------+---------+----0----+---------+---------+-|
        -1.00     -0.60     -0.20      0.20      0.60      1.00
```

The beef production series ‘pdbfau’ (**Figure 18**) is very similar to the slaughterings of steers and bulls series ‘slsbau’ – a distinct seasonal pattern which tails off quickly, significant positive autocorrelations at lags of 16 and 20 which suggests a 4-5 year cycle, and some anomalous longer term negative associations.

Finally, for beef, there is no evidence of any cyclical activity in the real cattle price (**Figure 19**) apart from some very short-term sawtooth-like movements at lags of 1 and 3. These results are indicative of much shorter-term beef industry variability in Australia, which is more likely to be caused by market reactions to changes in world market conditions on the demand side or environmental conditions on the supply side than by the decisions of uninformed, myopic beef cattle producers.

Figure 18 Figure 6. Identification tests, first differenced beef production, Australia, 1970:4 – 2024:2

Autocorrelation Function of: (1-B) PDBFAU

```
        -1.00     -0.60     -0.20     0.20      0.60      1.00
        |-+---------+---------+----0----+---------+---------+-|
1       |                       R  |  +                       | -0.11374
2       |                  R    +  |  +                       | -0.32292
3       |                      +   R   +                      | -0.010499
4       |                      +   |   +   R                  | 0.31889
5       |                      +   R   +                      | -0.0073504
6       |                   R  +   |   +                      | -0.27573
7       |                      +   R   +                      | -0.019585
8       |                      +   |   + R                    | 0.25422
9       |                      +  R|   +                      | -0.047101
10      |                    R +   |   +                      | -0.25918
11      |                     +  R |    +                     | -0.060113
12      |                     +    |    +R                    | 0.25813
13      |                     +  R |    +                     | -0.087751
14      |                     R    |    +                     | -0.21378
15      |                     +   R|    +                     | -0.037218
16      |                     +    |    +  R                  | 0.33998
17      |                     +    R    +                     | 0.00083175
18      |                   R +    |    +                     | -0.28458
19      |                     +   R|    +                     | -0.043682
20      |                     +    |    +   R                 | 0.37105
21      |                    +    R|     +                    | -0.026930
22      |                    + R   |     +                    | -0.17585
23      |                    +  R  |     +                    | -0.10907
24      |                    +     |     + R                  | 0.31607
25      |                    +    R|     +                    | -0.024103
26      |                    R     |     +                    | -0.25524
27      |                    +    R|     +                    | -0.047832
28      |                    +     |    R+                    | 0.21683
29      |                    +     R     +                    | -0.0098470
30      |                    R     |     +                    | -0.22718
31      |                    +   R |     +                    | -0.089474
32      |                    +     |     +R                   | 0.26647
33      |                    +    R|     +                    | -0.024393
34      |                   R+     |     +                    | -0.29390
35      |                    +    R|     +                    | -0.025144
36      |                    +     |     + R                  | 0.30917
37      |                   +      |R     +                   | 0.050558
38      |                   +R     |      +                   | -0.24755
39      |                   +     R|      +                   | -0.059786
40      |                   +      |      R                   | 0.29096
        |-+---------+---------+----0----+---------+---------+-|
        -1.00     -0.60     -0.20     0.20      0.60      1.00
```

Partial Autocorrelation Function of: (1-B) PDBFAU

```
        -1.00     -0.60     -0.20     0.20      0.60      1.00
        |-+---------+---------+----0----+---------+---------+-|
1       |                       R  |  +                       | -0.11499
2       |                 R     +  |  +                       | -0.34661
3       |                       R  |  +                       | -0.11677
4       |                       +  |  +  R                    | 0.22675
5       |                       +  |R +                       | 0.056276
6       |                      R+  |  +                       | -0.14783
7       |                       +R |  +                       | -0.075298
8       |                       +  | R+                       | 0.099931
9       |                       + R|  +                       | -0.030280
10      |                      R+  |  +                       | -0.14415
11      |                      R+  |  +                       | -0.14692
12      |                       +  |R +                       | 0.058681
13      |                       R  |  +                       | -0.11375
14      |                       R  |  +                       | -0.10586
15      |                      R+  |  +                       | -0.14310
16      |                       +  |  +R                      | 0.17390
17      |                       +  |  R                       | 0.10649
18      |                       + R|  +                       | -0.059000
19      |                       R  |  +                       | -0.12817
20      |                       +  |  +R                      | 0.14550
21      |                       +  |R +                       | 0.025372
22      |                       +  | R+                       | 0.098465
23      |                     R +  |  +                       | -0.18261
24      |                       +  | R+                       | 0.079527
25      |                       +  R  +                       | -0.016675
26      |                       +R |  +                       | -0.071359
27      |                       +R |  +                       | -0.073474
28      |                       +R |  +                       | -0.078161
29      |                       +  R  +                       | 0.0047314
30      |                       + R|  +                       | -0.041906
31      |                       R  |  +                       | -0.12842
32      |                       + R|  +                       | -0.021479
33      |                       + R|  +                       | -0.056125
34      |                    R  +  |  +                       | -0.22413
35      |                       + R|  +                       | -0.042535
36      |                       + R|  +                       | -0.031292
37      |                       +  |  R                       | 0.11404
38      |                       +R |  +                       | -0.073089
39      |                       +R |  +                       | -0.071405
40      |                       +  |R +                       | 0.032068
        |-+---------+---------+----0----+---------+---------+-|
        -1.00     -0.60     -0.20     0.20      0.60      1.00
```

Figure 19 Identification tests, first differenced real cattle prices, Australia, 1970:4 – 2024:2

Autocorrelation Function of: (1-B) PABFAUR

```
        -1.00     -0.60     -0.20     0.20      0.60      1.00
        |-+---------+---------+----0----+---------+---------+-|
1       |                       +  |  +    R                  | 0.31229
2       |                      +   |  R+                      | 0.12665
3       |                      +   |   +R                     | 0.19055
4       |                      + R |   +                      | -0.065612
5       |                      R   |   +                      | -0.15328
6       |                      +R  |   +                      | -0.13695
7       |                      +R  |   +                      | -0.13025
8       |                      + R |   +                      | -0.097834
9       |                      + R |   +                      | -0.069619
10      |                      + R |   +                      | -0.071589
11      |                      + R |   +                      | -0.089522
12      |                      +R  |   +                      | -0.12654
13      |                      +  R|   +                      | -0.051698
14      |                      +  R|   +                      | -0.027420
15      |                      + R |   +                      | -0.077287
16      |                      +   |R  +                      | 0.057836
17      |                      + R |   +                      | -0.072712
18      |                      R   |   +                      | -0.16418
19      |                      + R |   +                      | -0.092051
20      |                      +   R   +                      | 0.0055603
21      |                      +   | R +                      | 0.077492
22      |                      +   |  R+                      | 0.10797
23      |                      +   |  R+                      | 0.10109
24      |                      +   |   R                      | 0.16375
25      |                      +   | R +                      | 0.085213
26      |                      +  R|   +                      | -0.046820
27      |                      +   |R  +                      | 0.046914
28      |                      +   R   +                      | -0.0017773
29      |                      +  R|   +                      | -0.031186
30      |                      +   R   +                      | 0.0011900
31      |                      +   R   +                      | 0.0039413
32      |                      +  R|   +                      | -0.023533
33      |                      +R  |   +                      | -0.10629
34      |                      +R  |   +                      | -0.10164
35      |                      + R |   +                      | -0.072713
36      |                      +   R   +                      | -0.017228
37      |                      +   R   +                      | -0.0037341
38      |                      +   R   +                      | -0.0039754
39      |                      +   |R  +                      | 0.024726
40      |                      +   | R +                      | 0.061148
        |-+---------+---------+----0----+---------+---------+-|
        -1.00     -0.60     -0.20     0.20      0.60      1.00
```

Partial Autocorrelation Function of: (1-B) PABFAUR

```
        -1.00     -0.60     -0.20     0.20      0.60      1.00
        |-+---------+---------+----0----+---------+---------+-|
1       |                       +  |  +    R                  | 0.31233
2       |                       +  |R +                       | 0.031934
3       |                       +  |  +R                      | 0.15941
4       |                     R +  |  +                       | -0.19644
5       |                       R  |  +                       | -0.11753
6       |                       +R |  +                       | -0.098435
7       |                       +  R  +                       | -0.011951
8       |                       +  R  +                       | -0.0012512
9       |                       + R|  +                       | -0.030760
10      |                       +R |  +                       | -0.069137
11      |                       +R |  +                       | -0.094272
12      |                       R  |  +                       | -0.11807
13      |                       +  R  +                       | 0.014591
14      |                       +  R  +                       | -0.0073396
15      |                       +R |  +                       | -0.068684
16      |                       +  | R+                       | 0.070642
17      |                     R +  |  +                       | -0.20276
18      |                     R +  |  +                       | -0.18153
19      |                      R+  |  +                       | -0.14935
20      |                       +  | R+                       | 0.084817
21      |                       +  |  +R                      | 0.14578
22      |                       +  | R+                       | 0.076867
23      |                       + R|  +                       | -0.059654
24      |                       +  |R +                       | 0.030336
25      |                       + R|  +                       | -0.058664
26      |                       R  |  +                       | -0.11835
27      |                       +  | R+                       | 0.083027
28      |                       +  R  +                       | 0.014107
29      |                       +  R  +                       | 0.016657
30      |                       R  |  +                       | -0.10817
31      |                       +  R  +                       | -0.011320
32      |                       + R|  +                       | -0.039235
33      |                       +R |  +                       | -0.064643
34      |                       + R|  +                       | -0.029348
35      |                       +  R  +                       | -0.0018460
36      |                       +  |R +                       | 0.053831
37      |                       +R |  +                       | -0.068270
38      |                       + R|  +                       | -0.033943
39      |                       +  |R +                       | 0.047433
40      |                       +  |  R                       | 0.10006
        |-+---------+---------+----0----+---------+---------+-|
        -1.00     -0.60     -0.20     0.20      0.60      1.00
```

Sheep

Given the outcomes of the literature review and the results of the annual data analysis, we are sceptical of the existence of a sheep cycle in Australia, but we have completed the analysis regardless.

Figure 20 shows slaughterings of adult sheep (the blue series labelled as 'slshau'), and slaughterings of lambs (the orange labelled as 'sllbau') from 1970 to 2024. There is extreme variability in both series, both within and between years. Sheep slaughterings dropped dramatically in the early 1970s and were fairly stable during the later 1970s and 1980s in response to the incentives provided by the then-regulated wool market but following deregulation in 1990 numbers slaughtered have continued falling and are now less than a quarter of what they were 50 years ago. Lamb slaughterings were also fairly stable from the mid-1970s to the mid-1990s but have trended up since then. There is some indication of cyclical activity outside of seasonal patterns. The patterns of mutton and lamb production (Figure 21) are practically identical to those of the associated slaughterings series apart from the effect of increasing lamb carcase weight.

Figure 20 Slaughterings of sheep and lambs ('000 head/quarter), Australia, 1970:1 - 2024:2

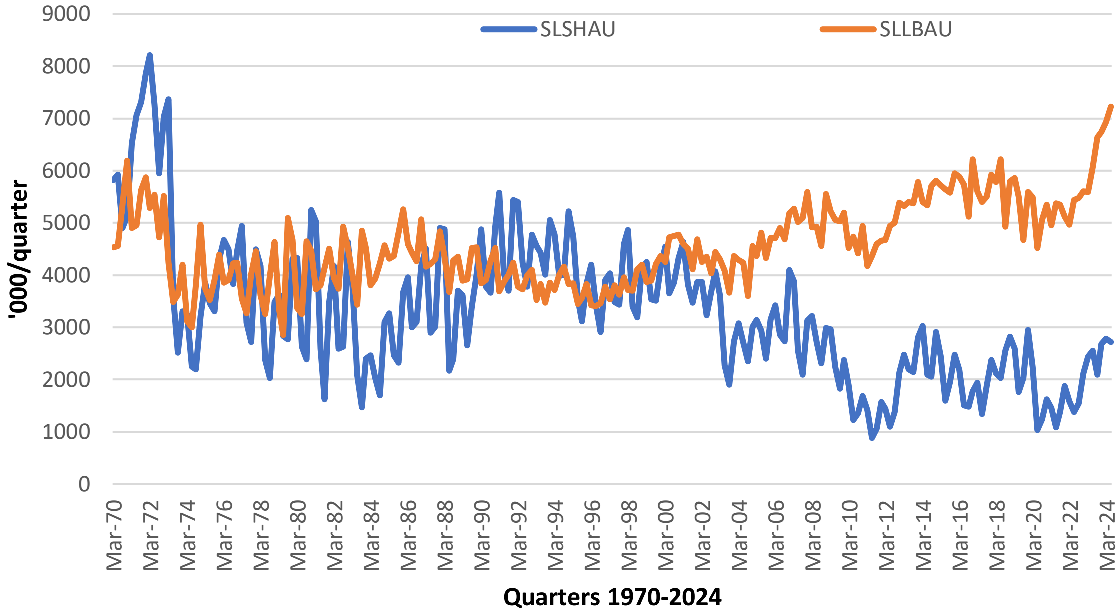


Figure 21 Production of mutton and lamb (tonnes/quarter), Australia, 1970:1 - 2024:2

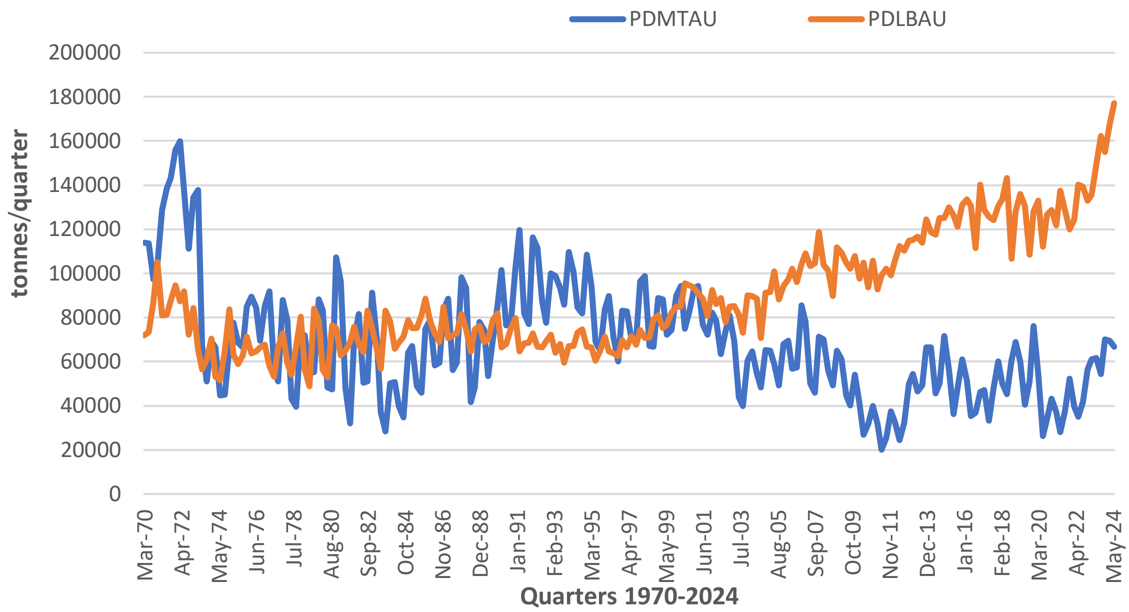


Figure 22 Production of lamb ('000 tonnes/quarter) and the real saleyard price of lamb (c/kg DCW), Australia, 1970:1 - 2024:2

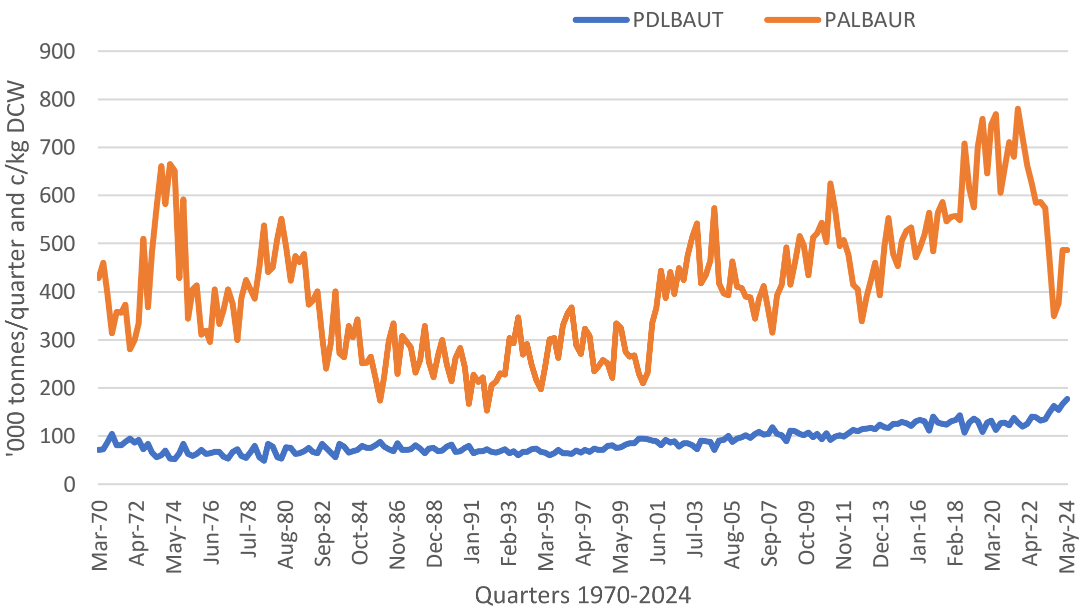
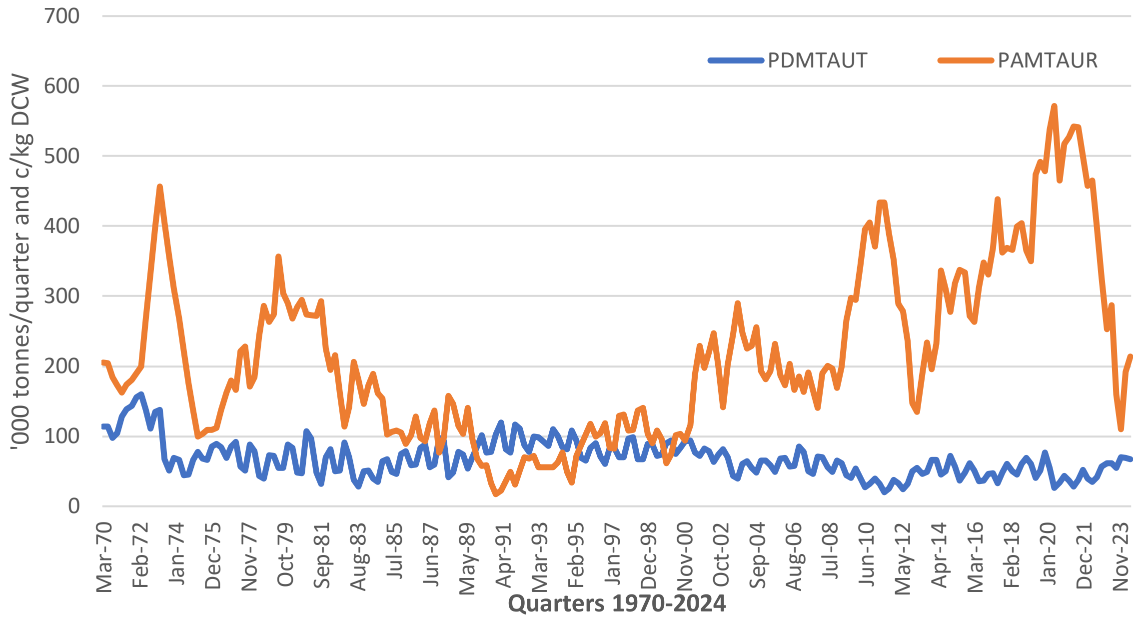


Figure 23 Production of mutton ('000 tonnes/quarter) and the real saleyard price of mutton (c/kg DCW), Australia, 1970:1 - 2024:2



The relationships between the output of sheepmeat and the associated prices are shown in **Figure 22** and **Figure 23**. The real prices of both lamb and mutton are highly variable, with the price of mutton being the more volatile. The broad patterns are similar, with a decline to historic lows in the early 1990s followed by a rising trend. Mutton production and price appear to have an inverse relationship, but the opposite is true for lamb, with both production and real price steadily increasing over the past 30 years.

The correlation coefficients shown in **Table 9** confirm these patterns. The correlations suggest a very high level of association between the related slaughterings and production series (0.99 and 0.91), but production decisions in the lamb sector are negatively related to production decisions in the mutton sector, in spite of the two prices being strongly positively correlated (0.90). As suggested from the graphs, the price of mutton is moderately negatively correlated with mutton production (-0.49), but the price of lamb is moderately positively correlated with lamb production (0.49).

Table 9 Correlation coefficients, Australian sheep data series, 1970:1 - 2024:2

	SLSHAU	SLLBAU	PDMTAU	PDLBAU
SLSHAU	1.00000			
SLLBAU	-0.20355	1.0000		
PDMTAU	0.98544	-0.11437	1.0000	
PDLBAU	-0.45347	0.91272	-0.34750	1.0000
PALBAUR	-0.54012	0.30571	-0.51568	0.49195
PAMTAUR	-0.50491	0.38025	-0.48779	0.52349

	PALBAUR	PAMTAUR
PALBAUR	1.00000	
PAMTAUR	0.89972	1.00000

The unit root tests for the sheep industry variables reported in **Table 10** tell the same story as for the beef industry variables – all the series are non-stationary and require a first difference transformation before any statistical procedures are undertaken.

Table 10 Unit root tests, Australian sheep data series, 1970:1 to 2024:2

	SLSHAU	SLLBAU	PDMTAU	PDLBAU	PALBAUR	PAMTAUR
Test Statistics						
Wtd.Sym.	-1.91102	-1.73536	-1.98590	-1.09749	-1.51001	-1.65314
Dickey-F	-2.19148	-2.11813	-2.38268	-1.56968	-2.75959	-1.89291
Phillips	-51.39056	-29.18530	-62.27135	-30.60739	-23.63024	-11.72808
P-values						
Wtd.Sym.	0.70646	0.80270	0.65801	0.96476	0.88863	0.83876
Dickey-F	.49465	0.53593	0.38887	0.80408	0.21218	0.65834
Phillips	0.000070383	0.010409	5.51381D-06	0.0076550	0.033687	0.33072
Number of lags						
Wtd.Sym.	16.00000	14.00000	16.00000	14.00000	16.00000	16.00000
Dickey-F	16.00000	14.00000	16.00000	14.00000	16.00000	16.00000
Phillips	16.00000	14.00000	16.00000	14.00000	16.00000	16.00000

The first stage of the ARIMA modelling process is presented in **Figure 24** to **Figure 29** for the Australian sheep industry variables.

Figure 24 Identification tests, first differenced Australian sheep slaughterings, 1970:1 - 2024:2

```
Autocorrelation Function of:  (1-B)  SLSHAU
         -1.00     -0.60     -0.20     0.20      0.60      1.00
         |-+---------+---------+----0----+---------+---------+-|
1        |                       +  R  +                       | 0.014076
2        |       R               +  |  +                       | -0.76910
3        |                     +    |R   +                     | 0.026192
4        |                     +    |    +            R        | 0.73777
5        |                    +   R |     +                    | -0.062635
6        |         R          +     |     +                    | -0.67961
7        |                   +      R      +                   | 0.00070830
8        |                   +      |      +        R          | 0.65405
9        |                  +     R |       +                  | -0.081211
10       |         R        +       |       +                  | -0.69574
11       |                  +       R       +                  | 0.019461
12       |                  +       |       +        R         | 0.66002
13       |                 +       R|        +                 | -0.020468
14       |         R       +        |        +                 | -0.66596
15       |                 +        |R       +                 | 0.033588
16       |                 +        |        +       R         | 0.67263
         |-+---------+---------+----0----+---------+---------+-|
         -1.00     -0.60     -0.20     0.20      0.60      1.00
```

```
Partial Autocorrelation Function of:  (1-B)  SLSHAU
         -1.00     -0.60     -0.20     0.20      0.60      1.00
         |-+---------+---------+----0----+---------+---------+-|
1        |                       +  R  +                       | 0.014122
2        |       R               +  |  +                       | -0.77223
3        |                       +  |  +R                      | 0.14099
4        |                       +  |  +     R                 | 0.36004
5        |                       R  |  +                       | -0.12292
6        |                       +R |  +                       | -0.080374
7        |                     R +  |  +                       | -0.20691
8        |                       +  |  +R                      | 0.15108
9        |                    R  +  |  +                       | -0.22899
10       |                   R   +  |  +                       | -0.28327
11       |                       +R |  +                       | -0.090579
12       |                       +  R  +                       | 0.0073591
13       |                       +  | R+                       | 0.072039
14       |                    R  +  |  +                       | -0.24047
15       |                       +  |R +                       | 0.053029
16       |                       +  | R+                       | 0.068438
         |-+---------+---------+----0----+---------+---------+-|
         -1.00     -0.60     -0.20     0.20      0.60      1.00
```

Figure 25 Identification tests, first differenced Australian lamb slaughterings, 1970:1 - 2024:2

Autocorrelation Function of: (1-B) SLLBAU

```
        -1.00     -0.60     -0.20     0.20      0.60      1.00
        |-+---------+---------+----0----+---------+---------+-|
1       |                   R   +  |  +                       | -0.26287
2       |                R     +   |   +                      | -0.38349
3       |                      +  R|   +                      | -0.036677
4       |                      +   |   +          R           | 0.59173
5       |                     R    |    +                     | -0.18476
6       |                   R +    |    +                     | -0.29963
7       |                     +  R |    +                     | -0.061479
8       |                     +    |    +      R              | 0.47277
9       |                    +  R  |     +                    | -0.11808
10      |                   R+     |     +                    | -0.29009
11      |                    +  R  |     +                    | -0.13291
12      |                    +     |     +      R             | 0.52754
13      |                    +  R  |     +                    | -0.12522
14      |                  R +     |     +                    | -0.32933
15      |                   +     R|      +                   | -0.036809
16      |                   +      |      +   R               | 0.44942
        |-+---------+---------+----0----+---------+---------+-|
        -1.00     -0.60     -0.20     0.20      0.60      1.00
```

Partial Autocorrelation Function of: (1-B) SLLBAU

```
        -1.00     -0.60     -0.20     0.20      0.60      1.00
        |-+---------+---------+----0----+---------+---------+-|
1       |                   R   +  |  +                       | -0.26437
2       |              R        +  |  +                       | -0.49882
3       |              R        +  |  +                       | -0.46239
4       |                       +  |  +     R                 | 0.35470
5       |                       +  |  +R                      | 0.15882
6       |                       +  | R+                       | 0.072433
7       |                     R +  |  +                       | -0.21481
8       |                       +  R  +                       | -0.0091673
9       |                       +  |R +                       | 0.058102
10      |                       +  |R +                       | 0.040083
11      |                   R   +  |  +                       | -0.28947
12      |                       +  |  R                       | 0.10728
13      |                       +  |R +                       | 0.048828
14      |                       + R|  +                       | -0.058191
15      |                       + R|  +                       | -0.053934
16      |                       + R|  +                       | -0.045274
        |-+---------+---------+----0----+---------+---------+-|
        -1.00     -0.60     -0.20     0.20      0.60      1.00
```

Figure 26 Identification tests, first differenced Australian mutton production, 1970:1 - 2024:2

Autocorrelation Function of: (1-B) PDMTAU

```
         -1.00     -0.60     -0.20     0.20      0.60      1.00
         |-+---------+---------+----0----+---------+---------+-|
1        |                       +  R  +                       | -0.00069172
2        |      R                +  |  +                       | -0.79533
3        |                     +    |R   +                     | 0.021154
4        |                     +    |    +             R       | 0.77750
5        |                    +    R|     +                    | -0.054739
6        |        R           +     |     +                    | -0.71213
7        |                   +      R      +                   | 0.00010323
8        |                   +      |      +          R        | 0.70136
9        |                  +     R |       +                  | -0.070970
10       |        R         +       |       +                  | -0.72264
11       |                 +        R        +                 | 0.015944
12       |                 +        |        +       R         | 0.69657
13       |                 +       R|        +                 | -0.026638
14       |         R       +        |        +                 | -0.69877
15       |                +         |R        +                | 0.033689
16       |                +         |         +       R        | 0.70188
         |-+---------+---------+----0----+---------+---------+-|
         -1.00     -0.60     -0.20     0.20      0.60      1.00
```

Partial Autocorrelation Function of: (1-B) PDMTAU

```
         -1.00     -0.60     -0.20     0.20      0.60      1.00
         |-+---------+---------+----0----+---------+---------+-|
1        |                       +  R  +                       | -0.00069301
2        |      R                +  |  +                       | -0.79708
3        |                       +  |R +                       | 0.055178
4        |                       +  |  +      R                | 0.40632
5        |                       +R |  +                       | -0.093971
6        |                       + R|  +                       | -0.059141
7        |                     R +  |  +                       | -0.20640
8        |                       +  |  +R                      | 0.15474
9        |                     R +  |  +                       | -0.20372
10       |                   R   +  |  +                       | -0.27694
11       |                       R  |  +                       | -0.11986
12       |                       +  R  +                       | 0.0098108
13       |                       +  | R+                       | 0.067495
14       |                     R +  |  +                       | -0.20934
15       |                       +  |R +                       | 0.051512
16       |                       +  | R+                       | 0.072125
         |-+---------+---------+----0----+---------+---------+-|
         -1.00     -0.60     -0.20     0.20      0.60      1.00
```

Figure 27 Identification tests, first differenced Australian lamb production, 1970:1 - 2024:2

```
Autocorrelation Function of: (1-B) PDLBAU

         -1.00     -0.60     -0.20     0.20      0.60      1.00
         |-+---------+---------+----0----+---------+---------+-|
 1       |                  R    +  |    +                     | -0.30354
 2       |                  R   +   |     +                    | -0.31370
 3       |                      +  R|     +                    | -0.043123
 4       |                      +   |     +     R              | 0.48980
 5       |                     +R   |    +                     | -0.15426
 6       |                     +R   |    +                     | -0.17757
 7       |                     +  R |    +                     | -0.081505
 8       |                     +    |    +   R                 | 0.35462
 9       |                     +  R |    +                     | -0.098521
 10      |                     +R   |    +                     | -0.14495
 11      |                     R    |    +                     | -0.18594
 12      |                     +    |    +     R               | 0.44131
 13      |                    +  R  |     +                    | -0.11063
 14      |                    +R    |     +                    | -0.20969
 15      |                    +    R|     +                    | -0.040289
 16      |                    +     |     + R                  | 0.30060
         |-+---------+---------+----0----+---------+---------+-|
         -1.00     -0.60     -0.20     0.20      0.60      1.00
```

```
Partial Autocorrelation Function of: (1-B) PDLBAU


         -1.00     -0.60     -0.20     0.20      0.60      1.00
         |-+---------+---------+----0----+---------+---------+-|
 1       |                  R    +  |  +                       | -0.30532
 2       |              R        +  |  +                       | -0.46426
 3       |              R        +  |  +                       | -0.46211
 4       |                       +  |  + R                     | 0.20565
 5       |                       +  |  R                       | 0.11030
 6       |                       +  |  +R                      | 0.14562
 7       |                       +R |  +                       | -0.079886
 8       |                       +  | R+                       | 0.078602
 9       |                       +  |R +                       | 0.041777
 10      |                       +  |R +                       | 0.051238
 11      |                   R   +  |  +                       | -0.28639
 12      |                       +  |  R                       | 0.12664
 13      |                       +  |R +                       | 0.026057
 14      |                       + R|  +                       | -0.054493
 15      |                       +  |R +                       | 0.024582
 16      |                       + R|  +                       | -0.052979
         |-+---------+---------+----0----+---------+---------+-|
         -1.00     -0.60     -0.20     0.20      0.60      1.00
```

Figure 28 Identification tests, first differenced real price of lamb, Australia, 1970:1 - 2024:2

```
Autocorrelation Function of: (1-B) PALBAUR

         -1.00     -0.60     -0.20     0.20      0.60      1.00
         |-+---------+---------+----0----+---------+---------+-|
 1       |                   R   +  |  +                       | -0.27626
 2       |                      R   |   +                      | -0.14934
 3       |                      +   |R  +                      | 0.040711
 4       |                      +   |   +R                     | 0.21941
 5       |                      + R |   +                      | -0.090751
 6       |                      +R  |   +                      | -0.12853
 7       |                      +  R|   +                      | -0.022358
 8       |                      +   | R +                      | 0.061920
 9       |                      +   R   +                      | 0.0051888
 10      |                      +R  |   +                      | -0.13077
 11      |                      +R  |   +                      | -0.11722
 12      |                      +   |   +   R                  | 0.30013
 13      |                      + R |   +                      | -0.078657
 14      |                     R+   |   +                      | -0.18330
 15      |                      +   R   +                      | -0.015475
 16      |                      +   |   +R                     | 0.19082
         |-+---------+---------+----0----+---------+---------+-|
         -1.00     -0.60     -0.20     0.20      0.60      1.00
```

```
Partial Autocorrelation Function of: (1-B) PALBAUR

         -1.00     -0.60     -0.20     0.20      0.60      1.00
         |-+---------+---------+----0----+---------+---------+-|
 1       |                   R   +  |  +                       | -0.27681
 2       |                    R  +  |  +                       | -0.25004
 3       |                       +R |  +                       | -0.096081
 4       |                       +  |  + R                     | 0.20170
 5       |                       +  | R+                       | 0.071842
 6       |                       +R |  +                       | -0.078692
 7       |                      R+  |  +                       | -0.15315
 8       |                       R  |  +                       | -0.10368
 9       |                       +  R  +                       | 0.015813
 10      |                       +R |  +                       | -0.063738
 11      |                     R +  |  +                       | -0.21317
 12      |                       +  |  +R                      | 0.17328
 13      |                       +  |R +                       | 0.048681
 14      |                       R  |  +                       | -0.10888
 15      |                      R+  |  +                       | -0.16208
 16      |                       + R|  +                       | -0.030717
         |-+---------+---------+----0----+---------+---------+-|
         -1.00     -0.60     -0.20     0.20      0.60      1.00
```

Figure 29 Identification tests, first differenced real price of mutton, Australia, 1970:1 - 2024:2

```
Autocorrelation Function of: (1-B) PAMTAUR

         -1.00     -0.60     -0.20     0.20      0.60      1.00
         |-+---------+---------+----0----+---------+---------+-|
 1       |                       +  |  R                       | 0.10634
 2       |                     R +  |  +                       | -0.21503
 3       |                      +   |   R                      | 0.17061
 4       |                      +   |   +  R                   | 0.29241
 5       |                      +R  |   +                      | -0.11439
 6       |                   R  +   |   +                      | -0.29566
 7       |                      +  R|   +                      | -0.053648
 8       |                      +   |  R+                      | 0.12251
 9       |                      + R |   +                      | -0.077530
 10      |                   R  +   |   +                      | -0.28793
 11      |                      +R  |   +                      | -0.10194
 12      |                      +   |   +   R                  | 0.30210
 13      |                     +   R|    +                     | -0.048128
 14      |                  R  +    |    +                     | -0.33924
 15      |                     +    R    +                     | 0.0065550
 16      |                     +    |    +R                    | 0.22633
         |-+---------+---------+----0----+---------+---------+-|
         -1.00     -0.60     -0.20     0.20      0.60      1.00
```

```
Partial Autocorrelation Function of: (1-B) PAMTAUR

         -1.00     -0.60     -0.20     0.20      0.60      1.00
         |-+---------+---------+----0----+---------+---------+-|
 1       |                       +  |  R                       | 0.10648
 2       |                    R  +  |  +                       | -0.23096
 3       |                       +  |  +  R                    | 0.24394
 4       |                       +  |  +  R                    | 0.22120
 5       |                       R  |  +                       | -0.12844
 6       |                    R  +  |  +                       | -0.23843
 7       |                      R+  |  +                       | -0.15716
 8       |                       +  |R +                       | 0.044910
 9       |                       +  |R +                       | 0.030168
 10      |                      R+  |  +                       | -0.15828
 11      |                      R+  |  +                       | -0.17159
 12      |                       +  |  +  R                    | 0.22847
 13      |                       +R |  +                       | -0.079810
 14      |                     R +  |  +                       | -0.18091
 15      |                       +R |  +                       | -0.095149
 16      |                       +  R  +                       | -0.014215
         |-+---------+---------+----0----+---------+---------+-|
         -1.00     -0.60     -0.20     0.20      0.60      1.00
```

In the four sheep and lamb slaughterings and production series (**Figure 24**-**Figure 27**), very similar patterns are evident. There are strong seasonal cycles, but no other significant autocorrelations at longer lag lengths. In the lamb series, in addition there is a significant negative autocorrelation between the current value and the value last quarter, a common sawtooth pattern, but there is no evidence of a medium-term sheep cycle in this data set.

In the two real price series for sheepmeat (**Figure 28** and **Figure 29**) The patterns in the data are again remarkably similar. There is evidence of a significant seasonal pattern in both real lamb prices and real mutton prices, as well as a significant positive autocorrelation at lag 12. As with lamb slaughterings and production, in addition to lamb prices, there is a significant negative autocorrelation between the current value and the value last quarter. Also, in both series, there is a significant negative autocorrelation at a lag of 14, which infers some longer-term (about 7 years) pattern. There is no confirming evidence of this in the annual data analysis.

7 Discussion

Literature points to consistent cyclical activity in the US cattle industry for almost 180 years. Rosen and colleagues (1994, p.468) referred to the US cattle cycle as '… among the most periodic time series in economics.' It was also established that these regular fluctuations in US beef numbers and prices have significant spill-over effects worldwide via variations in US traded quantities since the US has a large beef industry and traditionally has been both a major exporter of beef and a major importer of beef. Considerable previous research has shown the impact of the US cattle cycle on the beef market globally (Rosen et al., 1994; Mundlak and Huang, 1996; Mathews, et al., 1999; Aadland and Bailey, 2001). The statistical analysis reported in this study confirms this cyclical behaviour is still a major factor in the US cattle industry.

For at least 70 years, the conventional wisdom in the Australian beef industry has been that there is similar and closely related cyclical activity in Australia, that is predetermined by what occurs in the US industry. This idea has been supported by both theoretical arguments and empirical evidence (Gutman, 1950; Reynolds, 1977; Hinchy, 1978; Longmire and Rutherford, 1992; Alford and Griffith, 2002).

Alford and Griffith (2002) pointed to several other external influences as impacting the cycles in both countries (human- and animal-health-related disruptions, exchange rates, climate influences and the growing pattern of the industrialisation of production), but none of these influences were formally tested at the time. It should also be noted that some of these influences have been raised in the past. Reynolds (1977) argued that the Australian cattle cycle was likely to be sizeably shocked by random external factors; while Longmire and Rutherford (1992) found that a cattle cycle still existed in Australia, despite the restructuring of the cattle industry that had occurred.

The latest study of the Australian and US cattle cycles was by Helmi and Griffith (2023). Using graphical and correlation analyses, these authors found that in the last decade, the US and Australian cattle cycles had become uncoupled. Prices in both countries and cattle numbers in both countries have moved in opposite directions in recent years. This major change was put down to the growing importance of the external influences mentioned above, and a call was made for a more formal examination of the role played by these influences.

The initial analysis of annual data in this study found there was no evidence of the typical 8-10-year cycle found in the United States beef industry and in previous studies in Australia. The only significant correlations between current and lagged values were found in the beef slaughterings series (negative at lags 2 and 3 (cycles of around 4 years)) and in the cattle price series (negative at lag 2 (cycle of 4 years)).

The above patterns were confirmed in analysis of quarterly slaughterings and production data series. In addition, there were found to be significant annual cycles in all these series. However, for the beef price series, the 4-year cycle found in the annual data was not confirmed in this analysis using quarterly data. Nor was there any significant seasonal cycle, although there was some evidence of other significant very short-term regular patterns.

These results are indicative of much shorter-term beef industry variability in Australia, which are more likely to be caused by changes in world market conditions on the demand side, or by changes in environmental conditions on the supply side, than by the decisions of beef cattle producers making decisions based on belief that the past will continue into the present and the future.

While the real price of beef is moderately negatively correlated with beef production, the fact that beef prices do not follow the same cyclical patterns as domestic production variables suggests a much greater influence of world market conditions on domestic beef prices. This seems logical given the high proportion of Australian beef production that is exported. These interesting relationships can be examined in more depth in the regional and processor-specific pricing studies.

The initial analysis of annual data for the sheep industry found no evidence of cyclical behaviour apart from cross-linkages with the beef industry through prices. The subsequent analysis using quarterly data confirms these findings for the lamb sector, however, finds significant 2-3-year cycles in the mutton sector prices and quantities. In addition, there were found to be significant annual cycles in all these series.

While there may still be ‘cyclical tendencies’ evident in industry data such as a graph showing an apparent regular movement of prices of a farm product up and down over a previous time period, these tendencies are not statistically significant. Such tendencies should not be called a ‘cycle’. It should not be presumed that such patterns will happen in the future, and it should not be the information on which to base decisions about future production levels.

In relation to the other major extensive livestock industry, the sheep industry, a formal search of the Google Scholar database of published articles and reports did not find one mention of the term ‘sheep cycle’, or of any of several alternative phrases with the same meaning, anywhere in the world. In the unpublished literature, only one study was found that even mentioned a sheep cycle. Longmire and Rutherford (1992) included sheep numbers and slaughterings in their study of Australian cattle and pig cycles. Using autocorrelation analysis for sheep numbers, they found no evidence of a regular cycle, while using spectral analysis they found a weak but insignificant cycle in sheep numbers with length ranging between 4-6 years. The statistical analysis reported in this study confirms these findings in that in none of the Australian sheep industry series modelled is there any evidence of a 4-6 year cycle.

The broad implication is that other external influences on world and Australian red meat markets (human- and animal-health-related disruptions, exchange rates, trade disruptions, political instability, market access, drought and flood and the growing industrialisation of production), have become increasingly significant and relevant in recent years, and have effectively outweighed the cyclical tendencies embedded in expectations processes and biological lags. The result of this analysis suggests the need for more attention to be paid to risk management in light of uncertainties in the future about these external influences.

While no formal testing of these significant external influences has been done, a broad-brush variable representing variations in rainfall Australia-wide from long-run averages was obtained from the Bureau of Meteorology. Keeping in mind that at any time across Australia, regional differences in rainfall and environmental conditions are most often quite marked, the results suggest that Australia-wide rainfall is moderately positively related to beef numbers (0.45), and negatively related to beef slaughterings and prices, but at lower levels of association (-0.18 to -0.26). With these levels of association Australia-wide, it would seem sensible to examine the linkage between numbers, output, and prices on a more localised level, such as by state or even by major saleyard. The rainfall variable has little relationship to any of the sheep industry series. The result of this analysis suggests the need for more attention to be paid to risk management in the light of uncertainty.

The results for the beef and sheep industry variables are respectively summarised in Table 11 and Table 12 below.

Table 11 Summary of the beef results

Definitions	Indications from graphical analysis	Evidence from correlation analysis	Evidence from autocorrelation analysis	Relation to annual data results
Slaughterings of steers and bulls, Australia, thousands/quarter	Distinct seasonal pattern, trending down in recent years, weak suggestion of 4-year cycle	Moderately related to beef production (0.53)	Significant seasonal cycle, significant 4-year cycle, significant unexplained longer-term negative correlations	Confirm 4-year cycle
Slaughterings of cows and heifers, Australia, thousands/quarter	Distinct seasonal pattern, trending down in recent years, strong suggestion of 4-year cycle	Strongly related to beef production (0.77)	Significant seasonal cycle, significant 4-year cycle	Confirm 4-year cycle
Slaughterings of adult cattle, Australia, thousands/quarter	Distinct seasonal pattern, trending down in recent years, strong suggestion of 4-year cycle			
Slaughterings of calves, Australia, thousands/quarter	Distinct seasonal pattern, trending down in recent years, strong suggestion of 4-year cycle			
Production of beef, Australia, tonnes/quarter	Distinct seasonal pattern, trending up over time but down in recent years, strong suggestion of 4-year cycle		Significant seasonal cycle, significant 4-year cycle, significant 5-year cycle	Confirm 4-year cycle
Production of veal, Australia, tonnes/quarter	Distinct seasonal pattern, trending down in recent years, strong suggestion of 4-year cycle			
The real farm price of beef, Australia, cents/kg DCW, average/quarter	Weak seasonal pattern, trending down over time but sharply up in recent years, strong suggestion of 4-year cycle	Strongly related to beef production (-0.75)	No significant seasonal cycle, no significant 4-year cycle, significant within-year correlations	4-year cycle is not confirmed

Table 12 Summary of the sheep results

Definitions	Indications from graphical analysis	Evidence from correlation analysis	Evidence from autocorrelation analysis	Relation to annual data results
Slaughterings of sheep, Australia, thousands/quarter	Distinct seasonal pattern, trending down over time, weak suggestion of short-term cycle	Strongly related to mutton production (0.99)	Significant seasonal cycle, significant 2-year cycle, significant unexplained longer-term negative correlations	No cycles found
Slaughterings of lambs, Australia, thousands/quarter	Distinct seasonal pattern, trending up in recent years, weak suggestion of short-term cycle	Strongly related to lamb production (0.91)	Significant seasonal cycle, significant negative correlation at lag 1	No cycles found
Production of mutton, Australia, tonnes/quarter	Distinct seasonal pattern, trending down over time, weak suggestion of short-term cycle		Significant seasonal cycle, significant 2-year cycle, significant unexplained longer-term negative correlations	No cycles found
Production of lamb, Australia, tonnes/quarter	Distinct seasonal pattern, trending up in recent years, weak suggestion of short-term cycle		Significant seasonal cycle, significant negative correlation at lag 1	No cycles found
The real farm price of mutton, Australia, cents/kg dcw, average/quarter	Distinct seasonal pattern, trending up over time, highly volatile, some suggestion of cycle behaviour	Moderately related to mutton production (-0.49)	Significant seasonal cycle, significant 3-year cycle, significant unexplained longer-term negative correlations	
The real farm price of lamb, Australia, cents/kg dcw, average/quarter	Distinct seasonal pattern, trending up over time, highly volatile, some suggestion of cycle behaviour	Moderately but positively related to lamb production (0.49)	Significant seasonal cycle, significant 3-year cycle, significant negative correlation at lag 1	

8 Conclusions and recommendations

The analysis found no statistical evidence of the often-mentioned 8–10-year cycle in the Australian beef industry, which has been found to exist in the United States beef industry. Further, the analysis found the Australian and US markets have become uncoupled, moving independently based on external factors.

The only significant correlations between current and lagged annual values are found in the beef slaughterings and prices (around 4 years peak to peak), however, the 4-year cycle in prices is not confirmed in the quarterly data analysis. The short-term analysis found significant 2-3-year cycles in mutton sector prices and quantities. These results are indicative of much shorter-term red meat industry variability in Australia, more likely to be caused by changes in world market conditions on the demand side, and by changes in environmental conditions on the supply side, than by the decisions of beef cattle producers making decisions based on belief that the past will continue into the present and the future.

While there may still be 'cyclical tendencies' evident in industry data such as a graph showing an apparent regular movement of prices of a farm product up and down over a previous time period, these tendencies are not statistically significant. Such tendencies should not be called a 'cycle'. It should not be presumed that such patterns will happen in the future, and it should not be the information on which to base decisions about future production levels.

The findings within this report lead to the following recommendations:

- The findings of the existence of much shorter-term market ups and downs in the Australian beef industry rather than the longer-term cycles evident in the US industry, and similar patterns of shorter-term cyclical behaviour in the sheep industry, should be brought to the attention of meat and livestock industry stakeholders.
- The meat and livestock industries should consider undertaking a collaborative research and engagement initiative to examine the implications of this finding for the industry's supply chain.
- The collaboration should explore the risk management options currently available to supply chain participants, and the potential for future development of risk management approaches and instruments, in order to better address the inherent volatility and uncertainty associated with the short-term ups and downs and hence to ensure mutually beneficial outcomes for chain participants in terms of productivity, profitability and long-term industry growth.

The above recommendations are in addition to the following recommendations from Part 2 of the project (analysis of price transmission).

- The findings indicating the absence of market power should be brought to the attention of meat and livestock industry stakeholders.
- The findings should in particular be brought to the attention of the authorities undertaking reviews of competition in relevant inquiries, including that relating to the grocery sector of which the meat processing industry is a part.
- The collaboration should explore the risk management options currently available to supply chain participants, and the potential for future development of risk management approaches and instruments, in order to better address the inherent volatility and uncertainty associated with the short-term ups and downs and hence to ensure mutually beneficial outcomes for chain participants in terms of productivity, profitability and long term industry growth.

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