To what extent has climate change impacted the Total Factor Productivity of the Australian beef industry by state and as a country?

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Patrick Walter Harris

Is TFP of beef production by state negatively influenced by changes in climate?

Patrick Walter Harris

Abstract

The societal and climatic pressures towards agriculture and specifically the beef industry is increasingly prevalent in recent years. This paper has identified and evaluated the impact of climate on the TFP of the beef sector by state and as a country, which was found to be negative on balance. Additionally, it was found that Victoria was the most susceptible to changes in climate on average, complimenting previous literature that the southern regions of Australia (NSW, VIC, SA, TAS) are more susceptible to changes in climate compared to northern regions on average. Moreover, this paper addressed the current and prospective initiatives and management practices to mitigate the impact of adverse climate aberations, which found that feed additives, the breed of cattle, government subsidised insurance markets and education will assist the productivity of the beef sector in Australia and develop the resilience of farmers during extreme climate aberations.

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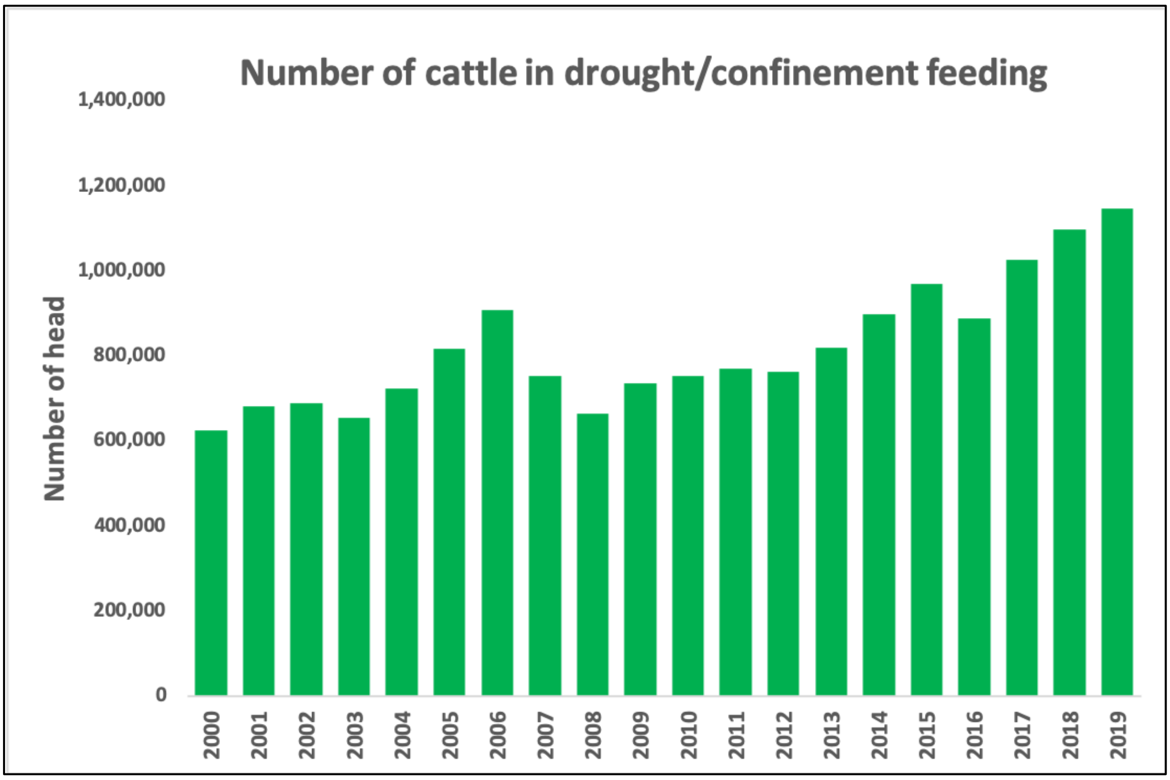
Research Question:

To what extent has climate change impacted the total factor productivity of the Australian beef industry by state and as a country? An empirical study covering the years 1995-2017, utilising the Cobb-Douglas production function as an empirical framework.

Introduction

The Australian beef cattle industry accounts for 23% of total agricultural production in Australia in 2016/17 and is the country's largest commodity export accounting for circa 27% in 2018/19 (Zammit, et al., 2019). Department of Agriculture (2018, pp 1) states "around 57% of all Australian farms carry beef cattle, making it the most common agricultural activity in Australia". Hence, it is critical to identify and understand the key drivers behind beef cattle production due to its economic importance, extreme variability and spatially diverse Australian climate, affecting the availability of water and other commodities as such grains for drought/confinement feeding (Department of Agriculture, 2018). Confinement feeding is defined by Meat and Livestock Australia (2018, pp 1) as "a drought feeding practice to promote animal health and welfare while preserving ground cover and land condition across the property".

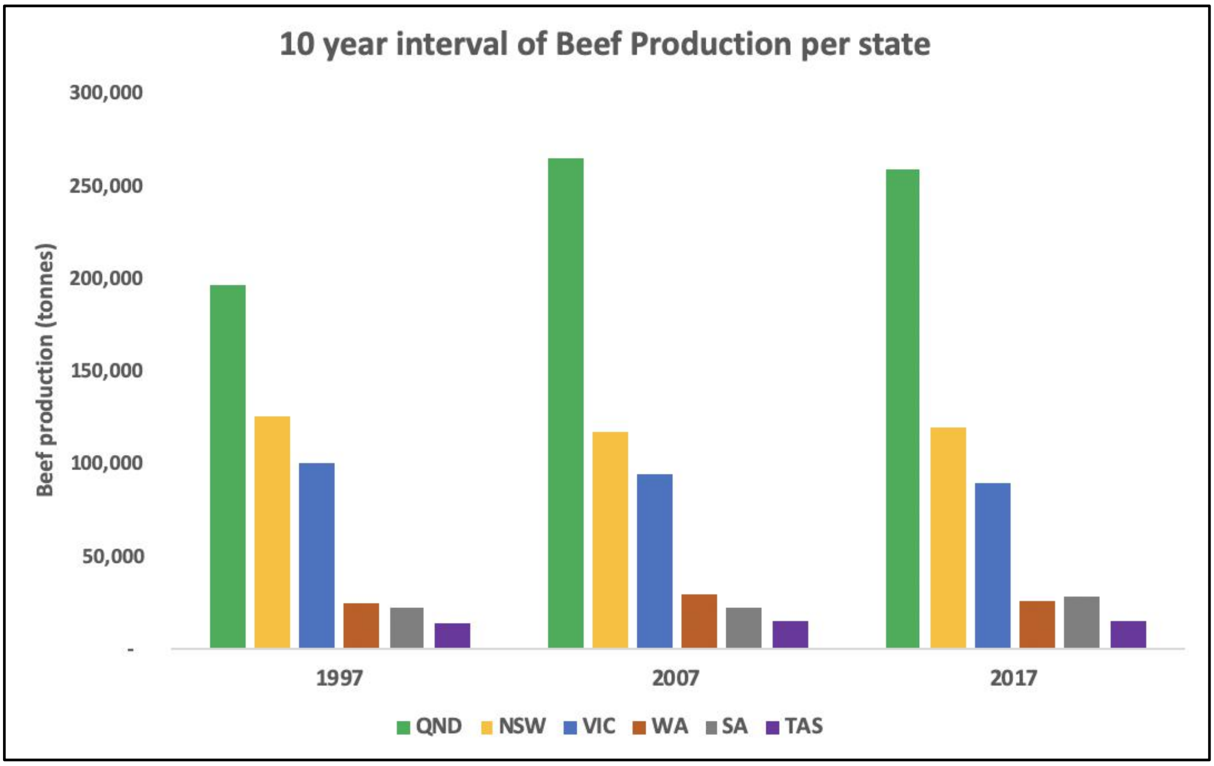
Figure 1 Number of Cattle in drought feeding (Authors own: Source MLA)



The proportion of beef cattle in confinement feeding equates to approximately 40% of total beef production in Australia, exposing the Australian beef industry to the costs and availability of grains, especially in extreme drought conditions where pasture for cattle is scarce (Future Beef, 2018). Figure 1, illustrates the number of cattle in drought feeding from 2000-2019, showing increased numbers during the years of the Millennium Drought, particularly in the year of 2006 and the current drought 2017-2019.

Beef production in Australia is heavily reliant on Queensland, New South Wales and Victoria who have consistently been the largest producing states of beef in Australia over the 20 years illustrated in figure 2. However, data for Northern Territory beef production was either incomplete or missing from the Meat and Livestock Australia database, therefore, we are unable to draw a holistic representation to beef production performance per state. This is significant as the Northern Territory has a well recognised beef sector with established logistic chains that are located to capitalise on demand from Asian markets (The Territory, 2020). Moreover, Jackson, et al., (2015) suggest changes in climate, impacts the productivity of the beef sector less in the northern region when compared to the southern region of Australia. Figure 2 indicates Queensland as the leading state in beef production (excluding Northern Territory), however, it is hard to identify as to whether climate is the sole confounding factor to Queensland's dominance over other states or is it due to changes in management practices and geographical proximity to overseas markets.

Figure 2 Beef production per state (Authors own illustration: source MLA, 2019)

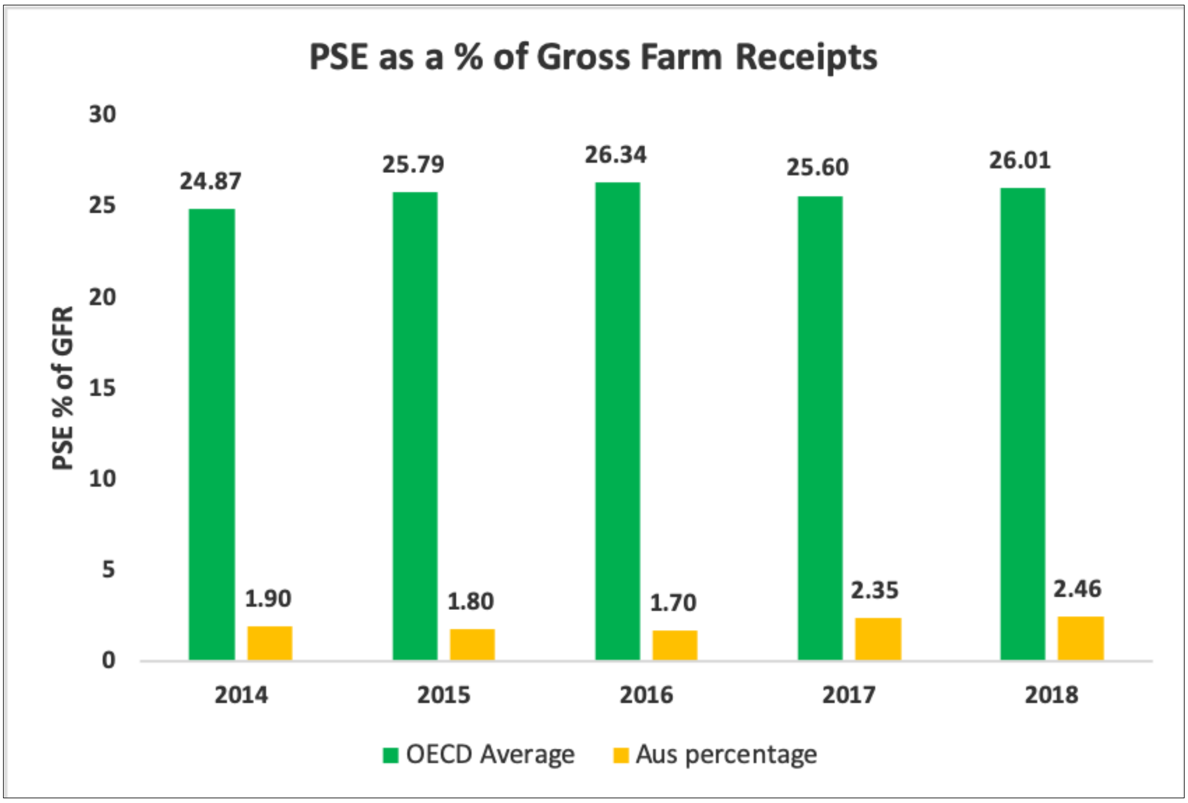


Zammit, et al. (2019) identifies volume and value of agricultural production and exports respectively, are expected to decline below long-term production averages due to the ongoing drought in south-eastern Australia. Although, this effect is to be limited due to favourable seasonal conditions in both Western Australia and Victoria where crop production has been above average, suggesting that climate impacts on agricultural production are spatially diverse (Zammit, et al., 2019). The 'Millennium Drought' from the late 1996-2009 of Australia's rural southern and south west regions suffered from significant drying of soils and lowering of water tables (Australian Bureau of Meteorology, 2015). This led to the decrease in irrigation farming, resulting in a large decrease in both crop and livestock production (Heberger, 2012).

During the worst years of the Millennium Drought (2001-2006) farm debt tripled, resulting in circa 10,600 families leaving the agricultural industry in search of other sources of income (Heberger, 2012). The effects of drought on beef production in the subsequent years saw doubling in paddock death rates from 3% to 6%, poorer branding rates and finishing of cattle at lower weights from 478kg lwt down to 463kg lwt (MLA, 2015). This added significant stress on farmers ability to service debt (MLA, 2015). Surprisingly, given Australia's importance in global agricultural trade, the country is the second lowest receiver of direct/indirect government support. In Australia, the OECD Producer Support Estimates (2018) constitutes for 2.46% of gross farm income, well below the OECD average of 26%, illustrated in figure 3.

This paper will critically assess the extent the variability in climate has had on Total Factor Productivity (TFP) on the Australian beef industry by state, specifically looking at the impacts of climate variability by modelling a proxy temperature for each state and evaluating its impact against beef TFP.

Figure 3 Producer Support Estimate as % of Gross Farm Receipts (Authors own illustration: sourced from OECD stat, 2019)



Research Objectives:

- To study the latest trends of the Australian beef industry
- To determine the key factors of beef production in Australia.
- To understand climate change and its implications on the Australian beef industry.
- To critically evaluate the impact climate change has had on beef production in Australia by state and as a country using panel data.
- To make policy recommendations to improve the operational efficiency of beef production in Australia.

Rationale:

The societal and climatic pressures towards agriculture and specifically the beef industry is increasingly prevalent in recent years. This study aims to achieve a critically balanced and up to date assessment of the cyclical climatic pressures on total factor productivity of the beef industry in Australia. Additionally, the study will evaluate current government policies that support Australian farmers directly/indirectly as well providing comprehensive insight into an industry esoteric in nature for the general public.

Literature Review

Theoretical background:

Economic growth theory has evolved since the work by Roy Harrod, Evsey Domar, and Arthur Lewis of the 1950's, that suggested that an economy can balance its stock of plant and equipment with the supply of labour, enabling stable growth even with short-term aberrations in labour supply (Solow, 1988). These findings assumed that all three key inputs (rate of saving, labour force growth, and capital-output ratio) were all constants. Solow (1988) criticised that these key input variables to be capable of change over time, independently. Sheng, et al, (2011) supports Solow's critique in their research suggesting that there are structural adjustments of the key inputs of land, labour and capital as a result from shifts in economic policy, physical and social factors associated with farming in Australia. Sheng's findings are significant because they represent a shift from the prior research of Harrod, Domar and Lewis' assumptions of constant rate of saving, labour force growth and capital-output ratio to the variability of those parameters.

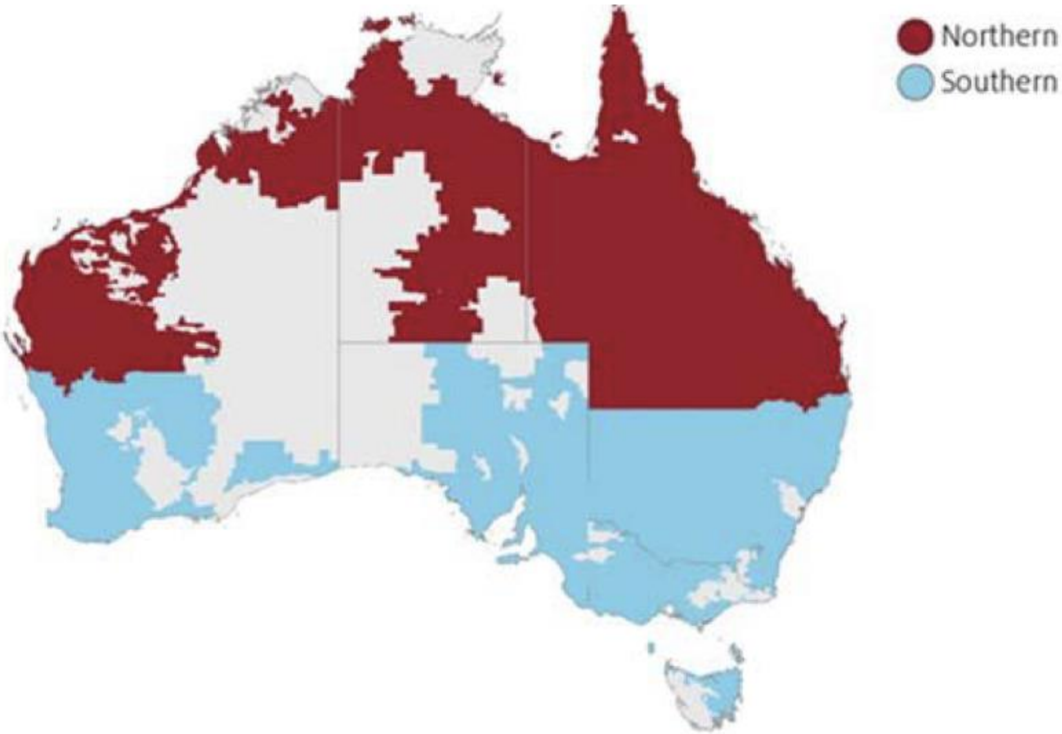
Existing literature in conceptual economics measures TFP of Australian agriculture using two distinct approaches, the 'bottom up' and the 'top down' approach (Jackson, et al., 2017). The former approach entails the gathering of farm level data. Data is gathered from farm surveys may not be comparable to other countries for cross-country analysis or have the historical depth suitable for econometric analysis inhibiting the statistical significance of the determinates of agricultural production (Jackson, et al., 2017). Although, farm level data collected in the form of surveys can be beneficial as you are able to gain a more holistic insight into the different microeconomic factors that may influence the determinates of agricultural production (Jackson, et al., 2017).

This data will be used where feasible. Leading works in this topic area suggest that the Tornqvist index is the ubiquitous method of measuring Australian agricultural TFP as exhibited by (Coelli, 1996; Mullen & Cox, 1996; Mullen, 2007) as this approach can be broken down into the individual components of technological change or returns to scale. The 'top down' approach is favoured by government bodies as the data is derived from national accounts which allows for better cross-country or cross-sector analysis (Jackson, et al., 2017). However, as the data is compiled together from national accounts, there is a lack of specification as agriculture will include other sectors such as forestry and fishing which may lead to overestimation in the results when analysing a particular subsector within Agriculture (Jackson, et al., 2017).

This study will use a combination of these approaches to gain greater insight into and evaluate TFP of the Australian beef industry by state. The Solow Growth model identifies that technological change is an exogenous variable that increases productivity from the result of better institutions (Pack, 1994). In contrast, neoclassical economists theorised what is known as 'Endogenous Growth Theory' in the 1980's suggesting that increased productivity is directly influenced and achieved by persistent rates of internal growth factors of production such as human capital, innovation and investment capital (Pack, 1994).

Jackson, et al. (2015) measured TFP, output and input growth of the beef industry by comparing the northern regions to the southern regions of Australia. The northern and southern regions are graphically defined by a horizontal cross-section of Australia shown in figure 4. Jackson, et al. (2015) found that productivity growth was notably different between the two regions and suggested that this was due to differences in climate. Beef farms in the southern region faced more volatile climatic conditions and were more sensitive to drought conditions than the northern region. This exposes the southern region farms to be susceptible to increased feed costs and stocking cycles (Jackson, et al., 2015). These findings do not specifically measure changes in climate to validate their suggestions, as well as the assumptions of variability in climate across the entire southern region. Hence, this study is estimating TFP of beef production per state and changes in mean maximum temperature per state using panel data to develop a more holistic analysis and understanding on how climate variations impact beef production.

Figure 4 Beef regions as defined by ABARES (ABARES, 2019)



Empirical review:

The estimation of TFP is derived from the inputs and outputs of production. Hence, previous literature has been found to use the Cobb-Douglas production function due to its simplicity (Echevarria, 1998; Sheng, et al., 2011; Hatirli, et al., 2005; Bravo-Ortega & Lederman, 2004). Echevarria, (1998); Sheng, et al., (2011); Hatirli, et al., (2005); Bravo-Ortega & Lederman, (2004) explore variables contributing to agricultural output, some more specific than others. Bravo-Ortega & Lederman (2004) include specific variables such as livestock, pasture lands, crop lands, tractors, fertilisers and education level. The specific use of pastureland is beneficial as it is assumed that land for pasture is used for livestock production, providing a more specific analysis and appropriate for this study. In Australia, circa 60% of beef cattle are fed on pasture land, realising the importance of pastureland as an input variable for beef production in Australia. Employment in agriculture is subject to diminishing marginal rate of productivity, meaning as an increase in the number of employees may not increase output at the same rate of production when not scaled appropriately.

Advancements in technology and management practices improve the efficiency of transforming inputs into outputs (Roberts, et al., 2009). Highlighting the importance of these labour and capital inputs in the production process of beef. Battese and Corra (1977) estimated land, labour and capital to have positive elasticities (0.2471, 0.0881, 0.0769) respectively, indicating a positive impact on agricultural production. An upto date comparison with recent results obtained by Sheng, et al. (2011) identified increases in labour and capital elasticities and a decrease in land elasticity (0.124, 0.361, 0.039) respectively. Interpreting the reduction of the land elasticity in Sheng, et al., (2011) findings may be due to the growing number of cattle in confinement feeding during periods where drought was prevalent, perhaps indicating the growing scarcity of water and pastureland illustrated in figure 1.

Analysis of existing literature indicates that TFP has been negatively affected by extreme climate conditions such as drought (Mullen & Cox, 1996; Mullen, 2007). Due to the irregularity of extreme climate conditions Mullen & Cox (1996) produced a TFP index over three sub-periods (1953-68, 1969-84, 1985-94) to examine the impact before and after the Eastern Australian Drought shown in table 1. Their results show a slight decrease in TFP from 1953-68 to 1969-84 from 2 to 1.8 respectively. Although the results still indicate a reduction in productivity during the time of the Eastern Australian Drought, productivity was measured over a circa 15 year interval, providing doubt as to whether drought was captured accurately since the Eastern Australian Drought occurred over a period of 4 years 1979-1983.

Mullen (2007) revisited productivity growth in Australian agriculture and provided an up-to date review capturing part of 'Millennium Drought' of the early 2000's. The reduction of the time interval to specifically capture periods of extreme drought appears to exhibit the affect on productivity perhaps more precisely. Interpreting Mullen's results indicate a reduction in TFP during the Eastern Australian Drought and the Millennium Drought by 0.4 and 1.6 for each respective event. The gap identified in the former and latter is that there was no specific measure that climate was the sole contributing factor to the decrease in TFP where shifts in economic policy and other public events may have contributed to the reduction in TFP. Moreover, reiterating the consistent gap in the literature identified previously by Jackson, et al. (2015) and that this study will specifically test how climate variability influences TFP of the beef industry and whether the result is consistent across the states of Australia.

Table 1 TFP results from Mullen & Cox (1996)

Mullen & Cox (1996) TFP results	**1953-68 (ex-ante)**	**1969-84 (during)**	**1985-94 (ex-post)**
Output %	4.5	2.4	2.6
Input %	2.5	0.6	0.1
Productivity (TFP)	2	1.8	2.5

Table 2 Results from Mullen (2007)

Mullen (2007)	**1975-82**	**1982-85**	**1994-1999**	**2000-2005**
Productivity TFP	1.6	1.1	4.3	2.7

Methodology:

Data:

Data collected for this study is secondary and publicly available. This is beneficial, as it generally allows for greater degrees of freedom (greater number of observations) increasing the efficiency of the results. This is known as the Central Limit Theorem (Ganti, 2019) where the distribution of the sample means approximates to a normal distribution with the greater number of observations. Data for state beef production (carcase weight) is collected from Meat and Livestock Australia data library (MLA). The number of people employed in agriculture per state is collected from Australian Bureau of Statistics (ABS). Data on capital inputs is collected from the Australian Bureau of Agricultural and Resource Economics Statistics (ABARES) survey data which has been adjusted to 2012 prices using state level CPI index. Mean maximum temperature per state data was collected and adjusted from over 150 individual weather stations across various regions of each state accessed via the Australian Bureau of Meteorology (ABM). Exchange rate (AUD/USD) data was collected from the Federal Reserve Economic Data (FRED). Limitations include the frequency of the data which is annually. If quarterly or monthly data were available this would improve the efficiency of the model due to the greater number of observations. Additionally, if the data was in quarterly or monthly frequency this would improve the ability to identify seasonal trends through other modelling techniques such as the Autoregressive Distributed Lag model.

Moreover, data for employment is the whole of agriculture and is not specific to employment in beef production farms only. Therefore, our results may not provide a complete representation of labour on beef production by state. If this type of intricate data was available, the results of this study would provide a more holistic representation of the impact of labour on beef production. Finally, data concerning the Northern Territory is not found for beef production. Therefore, Northern Territory will not be included in this study.

Table 3 Variables used in empirical analysis, definition and source

Variable	**Description**	**Source**
Q	Beef production for each state (NSW, VIC, WA, TAS, SA, QND) Continuous variable	MLA data library
L	Number of people employed in agriculture by state (Continuous variable)	ABS
K	Total estimated capital value of land, buildings, structures, livestock, plant and equipment including leased (Adjusted to 2012 CPI prices specific for each state)	ABARES
T	Mean Maximum temperature per state (continuous variable)	ABM

Specification of regression model:

Principles by which businesses make decisions are based on how much to produce and how much of each input element that it employs in order to reach the efficient level of production (Dorfman, 2016). The Cobb-Douglas Production function is ubiquitous in existing literature that defines the level of output (Q) as a multiplicative aggregation of input variables, Labour (L) and Capital (K) (Felipe & Adams, 2005). Hence, the equation for the Cobb-Douglas production function is defined as:

$$Q_{it} = A\left(L_{it}^{\alpha} K_{it}^{\beta}\right)$$

The level of output (Q) is expressed in units or value, (L) is the quantity of labour, (K) is the amount of land, machinery and equipment employed (Felipe & Adams, 2005). The addition of the output elasticities indicates whether the function has constant returns to scale ($\alpha + \beta = 1$), increasing returns to scale ($\alpha + \beta > 1$) or decreasing returns to scale ($\alpha + \beta < 1$) (Felipe & Adams, 2005). 'A' represents TFP and t indicates the time dimension of the panel. Productivity in Australian agriculture is an important measure of industry performance (Boult & Chancellor, 2019). TFP is the increase in total production that is more than the increased inputs that contribute to output and growth (Boult & Chancellor, 2019). Measuring TFP over the long-term is most advantageous as the measure can capture technological progress and other measures of efficiency (Boult & Chancellor, 2019). Therefore, TFP can be estimated by rearranging the Cobb-Douglas production function noted previously in terms of A.

$$TFP_{it} = A = \frac{Q_{it}}{\left(L_{it}^{\alpha} K_{it}^{\beta}\right)}$$

Due to data availability across 6 individual states of Australia (New South Wales, Victoria, Queensland, Tasmania, South Australia and Western Australia) the use of panel data allows us to model a two-dimensional analysis of beef production across states. The subscript i is used to identify the first dimension that is cross-sectional, which in this study, refers to the state in which that variable belongs to and the subscript t refers to the second-dimension time. However, the Cobb-Douglas production function inhibits elasticity substitution between capital and labour as they are assumed to be constant. Therefore, by applying the principles of the Cobb-Douglas production function to a 'Transcendental Logarithmic Production Function' (translog production function), that imposes no restriction on the elasticities of substitution between capital and labour, provides more flexibility in this analysis of beef TFP (Christensen, et al., 1973; Kim, 1992).

The Cobb-Douglas Production function can be estimated using Ordinary Least Squares by taking the natural log to both sides of the equation to help secure normality and homoscedasticity, noting only to variables that are not in the form of a rate, nor variables that can take on the value ≤ 0 (Wooldridge, 2015). The estimation of the Cobb-Douglas Production Function provides the regression model specification of Australian beef production by state.

$$ln(Q_{it}) = \beta_0 + \beta_1 ln\ (A) + \beta_2\ ln(L_{it}) + \beta_3\ ln(K_{it}) + \varepsilon_{it}$$

Where β_2 is the elasticity of output Q, with respect to labour input and β_3 is the elasticity of output Q, with respect to capital. After estimating the Cobb-Douglas production function, TFP is estimated by estimating the residuals and generating a new dependent variable. This will then be estimated against state mean maximum temperature and to determine the impact climate has had on TFP of beef production and whether this effect is specific to a particular state.

$$TFP_{it} = \beta_0 + \beta_1 ln\ (T_{it}) + \varepsilon_{it}$$

Hausman test (FE or RE) and Heteroscedasticity

Panel data analysis is subject to the effects of the unobserved heterogeneity of the error term. It is generally assumed that the random effects model is suitable, or alternatively the fixed effects model. The random effects model assumes in this study that the error term is not correlated with explanatory variables, this allows for time-invariant variables to act as an explanatory variable (Wooldridge, 2015). The fixed effect model removes the time-invariant characteristic and allows for the net effect of the explanatory variables on the output variable. Although the fixed effects model is less efficient than the random effects model. To compensate for the reduction in efficiency, robust standard errors will be used (Wooldridge, 2015). The use of robust standard errors will render the results valid, allowing for substantive significance to be drawn from the results. Robust standard errors essentially adjust the standard error figure that will then adjust the statistical significance of the model. To test which model is more appropriate a Hausman test is applied. The null hypothesis as briefly inferred above is that the random effects model is preferred:

H_0: Random Effects model is preferred **or H_A:** Fixed effects model

The Hausman test indicates whether the unique errors are correlated with the regressors, if the errors are not correlated the study will accept the null hypothesis that the random effects model is most suitable. If the result is statistically significant at the 5% level, we may reject the null hypothesis and therefore, accept the alternative that the fixed effects model is suitable.

Model fitness

This study is utilising time-series data and it is acknowledged that the problems of autocorrelation and non-stationarity are likely to be present. Autocorrelation, also known as serial correlation, is where a time-series variable (s) is highly correlated with the lagged version of itself (Wooldridge, 2015). If autocorrelation is present, this identifies that there is a time-trend present which violates one of the Gauss-Markov OLS assumptions of no autocorrelation, thus, rendering the results invalid. The data can be transformed via first differencing to try eradicating the problem of autocorrelation which may additionally help secure stationarity.
To determine whether autocorrelation is present, the Wooldridge test for serial correlation in panel data will be implemented (Wooldridge, 2015).

Stationarity in time-series is where a variable's mean and variance do not change with a shift in time (Carter Hill, et al., 2018). If the data is non-stationary, there is a possibility of identifying relationships between variables that are statistically significant but are not substantially correlated (Carter Hill, et al., 2018). To test for stationarity, the Im-Persaran-Shin (IPS) unit root test for panel data will be applied. If it is found that the data is non-stationary the data will be transformed by taking the first difference to try remove any time element. Eradicating the time element will be confirmed by repeating the unit root test.

Results:

Significance testing:

Table 4 Significance testing

Significance testing	**p-value**
Breusch-Pagan test for heteroscedasticity	0.7945
Breusch-Godfrey test for serial correlation	0.2109
Hausman Test (Prob>chi2)	0.0235

The Hausman test indicates that the model for random effects can be accepted at the 1% level or fixed effects at the 5 and 10% level. The study used fixed effects model as it controls for time-invariant differences, which in this study examines the causes of changes in beef productivity as a result from changes in climate. However, the random effects model may be better suited for alternative studies, that examine how different breeds of cattle adjust and perform to varying climates (Bell, et al., 2011). Inference tests for heteroscedasticity, autocorrelation, and stationarity helps quantify as to whether the results produced were of chance or of a causal nature (Wooldridge, 2015). Table 4 indicates the various testing applied to the regression model. The test for heteroscedasticity and serial correlation confirms that we can accept the null hypothesis that neither of these problems are contaminating the statistical significance of the results. Furthermore, the IPS test for unit roots in panel data was applied, that determined the data was stationary and no further action is required shown in table 5.

This is confirmed by the test statistic being greater than the critical value at the 5 and 10% critical values for Beef Production and at the 1, 5 and 10% critical values for TFP and Temperature. Therefore, the model for Beef TFP can be accepted and substantive significance can be drawn from the results.

Table 5 testing for stationarity

		Critical Value		
Stationarity Testing	**Test statistic**	**1%**	**5%**	**10%**
Beef Production	-2.2989	-2.32	-2.08	-1.95
TFP	-2.4584	-2.32	-2.08	-1.95
Temp	-3.0827	-2.32	-2.08	-1.95

Estimation of parameters:

The estimated Cobb-Douglas production function for Australian beef production, indicates that both labour and capital are positive and statistically significant at the 1 and 10% levels respectively, shown in Table 6. This suggests that a 1% increase in labour or capital will on average increase beef production by 0.24% and 0.14% respectively. However, the estimate for labour may not provide a holistic representation of its impact on beef production since labour includes employment in other sub-sectors of Australian agriculture such as fisheries and cropping (Australian Bureau of Statistics, 2019). The R_2 suggests that circa 64% of variation in beef production is explained in this production function. Leaving circa 36% of the variation in beef production unexplained but is captured in the error term (ε_{it}).

Other confounding factors such as interest rates, or credit to agriculture have not been included in this analysis that may have impacted the results. Moreover, the Cobb-Douglas production function is the empirical framework used to estimate the beef TFP and its interaction with mean maximum temperature.

*Table 6 Cobb-Douglas Production Function (*** = p<0.01, ** = p<0.05, * = p<0.1), '()'= t-score*

Beef Production	**Coefficients**
Labour	0.2408638*** (2.74)
Capital	0.1420186* (1.93)

R_2 = 0.6420 **Observations** = 138

After estimating the residuals from the Cobb-Douglas production function to get TFP, TFP was then regressed against temperature to determine its impact on beef TFP for Australia as a whole. Table 7 indicates that an increase in mean maximum temperature by 1 degree Celsius, on average beef TFP will fall by 0.14 units. This result is statistically significant at the 1% level. Additionally, this can be demonstrated in figure 5, representing a circa 35% decrease from 2017 TFP level ((0.4 - 0.14 / 0.4) -1). The R_2 suggests that changes mean maximum temperature explains circa 38% of variation in the TFP of beef in Australia. Figure 5 illustrates how beef TFP has changed over 21 years, showing a significant drop in TFP during 2002/2004 which highlights the severe impact of the millennium drought on beef production as suggested in previous literature (Heberger, 2012).

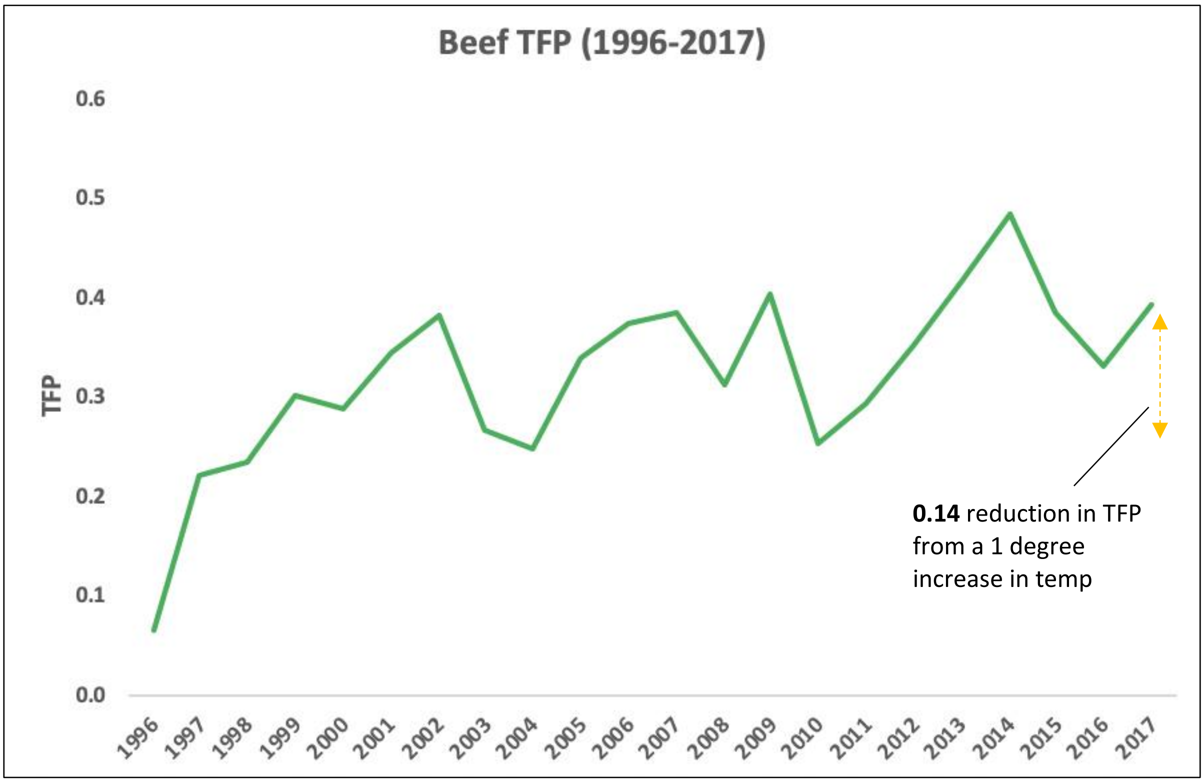
Additionally, the drop in beef TFP over the 2008/2010 period is likely to have been driven by the global financial crisis (GFC), as meat is seen as a luxury good (Dimova, et al., 2014). Dimova, et al. (2014) calculated the income elasticities of consumption and found that during the GFC, meat had an income elasticity greater than 1 across all income brackets, indicating that households reduce their proportion of expenditures on meat during economic crisis. Despite the high variability in TFP over the 21 year period, TFP for the beef sector has continued an upward trend, which supports the findings of (Sheng, et al., 2011). Other confounding factors such as extreme rainfall, exchange rates, or changes in politics have not been included in the study as this paper isolates the impact of temperature on beef TFP specifically.

*Table 7 TFP interaction with temperature (*** = p<0.01, ** = p<0.05, * = p<0.1), '()'= t-score*

TFP	**Coefficient**
Temperature	-0.1416605*** (-2.78)

R^2 = 0.3768 **Observations** = 138

Figure 5 Historical Beef TFP for Australia (Authors own illustration: Stata output)



The creation of indicative dummy variables for each state of Australia included in this study, multiplied by the temperature allows the model to capture the interaction between temperature and each individual state's TFP of beef. Using equation 4, TFP is regressed on each of these interaction variables as shown in table 8. It was expected to see that an increase in temperature would have a negative impact on TFP based on previous literature, however, this study's aim is to determine on average how different states are impacted by changes in temperature. Table 8 demonstrates how susceptible beef TFP is to changes in temperature per state, which found Victoria to be the most volatile at circa -0.23 that is statistically significant at the 1% level. This suggests that beef farms in Victoria are most exposed to the perils of the changing climate.

New South Wales was found to be the least sensitive to changes in climate (disregarding Queensland) however, a 1 degree increase in mean maximum temperature still found to have a negative impact on beef TFP of circa -0.17 that is statistically significant at the 5% level. South Australia, Western Australia and Tasmania were found to show negative impacts on TFP (-0.188, -0.187, -0.193) respectively. The aforementioned were statistically significant at the 10% level.

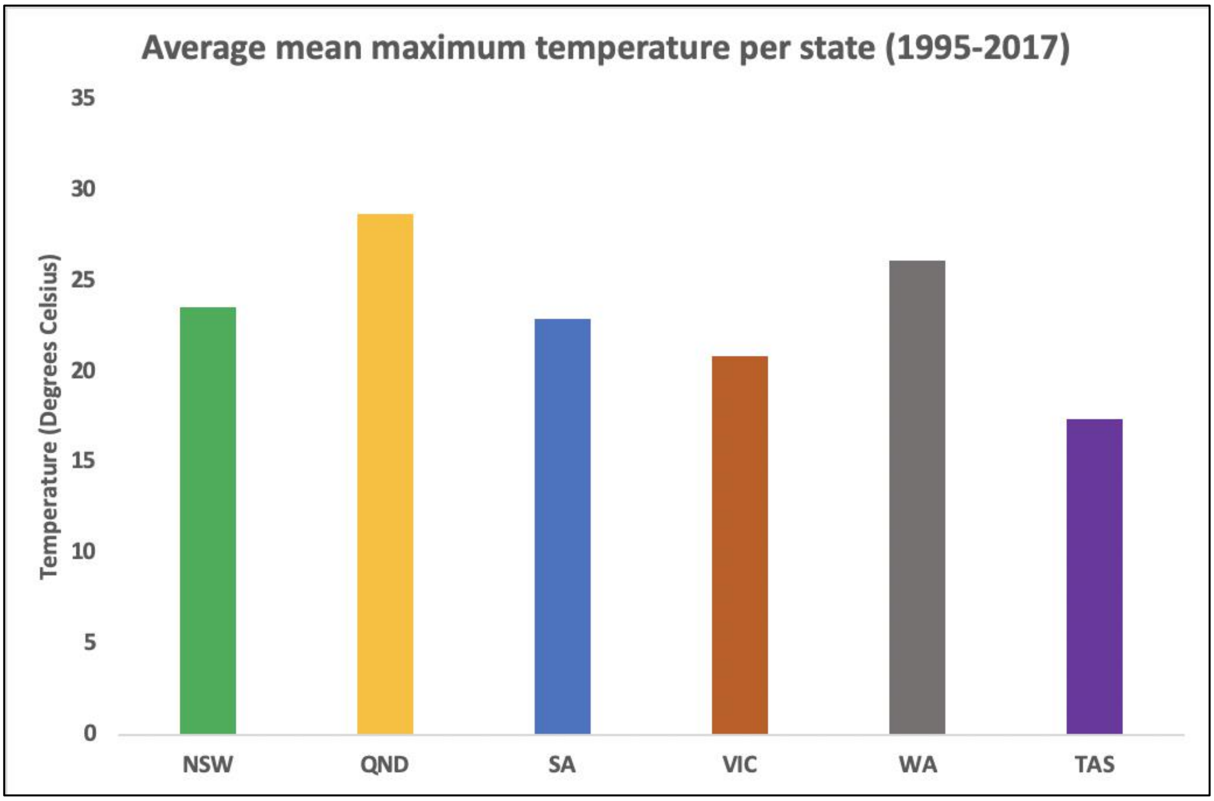
However, the results are restricted in terms of comparing with previous literature for Western Australia as this study has evaluated the impact on Western Australia as a whole rather than the results found by Jackson, et al., (2015), Mullen & Cox, (1996) in figure 4. Queensland was found to be statistically insignificant; this was surprising as Queensland is subject to a hotter climate in comparison to the other states, as shown in figure 6. The R_2 for the estimation of equation 4 is 0.68, therefore, on average explaining circa 68% of the variation in TFP with the remaining 32% captured in the error term.

*Table 8 TFP interaction with temperature for each state (*** = p<0.01, ** = p<0.05, * = p<0.1), '()'= t-score*

TFP	**Coefficient**
NSW *TFP interaction with Temperature*	-0.17551** (-2.87)
VIC *TFP interaction with Temperature*	-0.22796** (-3.12)
QND *TFP interaction with Temperature*	0.06981 (-0.98)
SA *TFP interaction with Temperature*	-0.18888*** (-4.23)
WA *TFP interaction with Temperature*	-0.18722*** (-4.19)
TAS *TFP interaction with Temperature*	-0.19362*** (-4.34)

R_2 = 0.6815 **Observations =** 138

Figure 6 Average mean maximum temperature per state (Authors own illustration: Australian Bureau of Meteorology 2019)



Discussion of results:

The results suggest that an increase in mean maximum temperature does have a negative and statistically significant impact on beef TFP, that indeed varies in terms of severity across states with the exception of Queensland. Hence, it is critical to explore the reasons as to why Queensland may be insignificant and what is currently being done to address the problem of climate change as it is in the best interest of both the farmer and government. Previously noted, the breed of cow that can adjust to the hotter climates will outperform a cow that cannot (Bell, et al., 2011). During the 20th century, beef productivity in northern Australia was constrained due to the inability of the British cattle breeds (Angus and Hereford) to adapt to the extreme heat and seasonal variations in feed whether that be the transition from pasture fed to grain fed cattle due to pastuer scarcity (Bell, et al., 2011; Department of Agriculture, 2018). The introduction of the American Brahman in the 1950's significantly increased beef productivtiy in Northern Australia as this breed was able to adapt to the environmental perils aforementioned (Bell, et al., 2011). British breeds, such as Angus and Hereford are popular amognst beef cattle farms in the southern region of Australia as they are able to gain weight with less feed, which is economically beneficial to the producer.

However, the former and latter breeds do not perform as well in the northern region due to the extreme temperatures that can impair the health of the animal, which will not be economically beneficial to the producer and distressing for the animal (Bell, et al., 2011).

This suggests that Queensland farmers have recognised the impact of climate and adapted their managerial decision making to the environment by implementing breeds that are suitable to its climate. This may have resulted in Queensland being insiginifcant identified in table 6. However, it is important to note as to the potential reason why not all states hold brahman cattle since they have qualities that make them better suited to the harsh environment. Brahman cattle have less fat compared to british bred cattle that do not allow them to overheat in the harsh conditions (Bell, et al., 2011). This ulitmately affects the quality of the meat from the cusumers eating experience. Thus, there is a tradeoff between quality and quantity that is directed by the impact of climate and management.

It is imperative for Australian farmers irrespective of their geographic location to recognise the impact of climate on beef production and to address this problem. The Commonwealth Scientific and Indiustrial Research Organisation (CSIRO) attempts to improve the economic and social impact of an industry for the benefit of the commonwealth through its research and implementation (CSIRO, 2020). Cattle contribute 10% of the total greenhouse gas emissions in Australia and 20% globally, highlighting the critical importance of addressing the problem of climate change as well as still being alble to fulfil the food demand of the world (CSIRO, 2019).

FutureFeed is a seaweed supplement that can be included into an already established feed ration, that reduces/inhibits methane production by the cow by upwards of 80% (CSIRO, 2019). It is hypothesised that methane is wasted energy by the animal that is exerted. However, if the animal were able to reduce its methane production via the addition of aspragopsis (seaweed species) in its ration then the animal would be able to convert this otherwise wasted energy, metabolically. This may potentially lead to an economic benefit for the producer from increased beef productivity and metabolic benefit for the animal (CSIRO, 2019). Additionally, CSIRO (2019) estimate that if only 10% of beef cattle producers globally, implement FutureFeed into their current ration, its impact to the climate would be the same as removing 50 million cars from the roads as well as feed an additional 23 million people from increased livestock productivity (CSIRO, 2019). However, despite the reduction in emissions, if FutureFeed is implemented, it is unlikely this will automatically translate into more stable climate conditions for Australia.

It is recognised that FutureFeed is just one part of a larger ongoing solution that needs to be addressed and supported by all other industries and individuals that will aid in reducing the severity and recurrentness of extreme climate shocks, fostering a more propitious economic and social environment.

Australia's agricultural industry is well resourced to combat climate change in comparison to some OECD and developing countries, however, Australia does not have the government support that other OECD countries relish, illustrated in figure 3 (Kingwell, 2006; OECD, 2019). Kingwell, (2006) suggest that Australian government is unlikely to provide support on climate-change related assistance, apart from natural disaster relief. Recently, the Deparment of Agriculture announced the development of the Future Drought Fund that aims to provide AUD$100 million per year to help farmers and communities prepare for, and alleviate the effects of droughts in the future (ABARES, 2019). Rather than the fund providing capital to farmers directly the fund will invest in natural resource management, education and training in financial, climate risk and business management to improve the resilience of farmers and their ability to support their business during times of climate distress such as drought (ABARES, 2019). This government initiative is the first step in recognising the ongoing impact of extreme climate instead of a one off event but indeed a recurring issue that agriculture is particularly prone to. If successful, this initiative may reduce the impact of the perils associated with farming and improve confidence in the industry that may increase the availability of affordable funds or insurance from financial institutions.

Agricultural insurance is a particular grey area when applied it to extreme climate like drought. This is because drought is often widespread and the risk of drought occurring in Australia is prominent (Bardsley, et al., 1984; Chambers, 1989). Additionally, it is likely the risks are highly correlated, therefore, the profit incentive from the seller of insurance is reduced as gains diminish with an increase in the risk correlation (Bardsley, et al., 1984). Furthermore, as the likelihood of drought in Australia is high, policy premiums are extortionate, making insurance a less attractive or financially not a viable option for the farmer, where the capital paid for insurance could be invested into profitable projects (Chambers, 1989). However, if the seller of insurance is able to diversify across other insurable markets, the insurer may be able to reduce their risk exposure and still make monetary benefit (Bardsley, et al., 1984; Chambers, 1989). Therefore, the development of insurance markets is imperative in order to facilitate affordable and sustainable insurance against climate risks. This will improve farmers working capital management during climate distress that will support the productivity of their operations (Hughs, et al., 2019). Hughs, et al. (2019) suggest parametric insurance as an alternative approach that bases insurance policies on weather data rather than actual damages.

This approach would reduce the costs of information in regard to moral hazard and adverse selection that are common problems associated with the insurance market, supporting the profitability of the beef industry in climate distress (Bardsley, et al., 1984; Hughs, et al., 2019).

Conclusion

This paper has identified and evaluated the impact of climate on the TFP of the beef sector by state and as a country, which was found to be negative on balance. Additionally, it was found that Victoria was the most susceptible to changes in climate on average, complimenting previous literature that the southern regions of Australia (NSW, VIC, SA, TAS) are more susceptible to changes in climate on average. Although, the data used to calculate the average temperature per state proxy variable was limited in historical depth for some individual weather stations comprised within a particular region. However, the geographical locations of each individual weather station with sufficient historical data were spatially diverse, enabling the study to estimate of the avergae temperature per state given the relative data constraints. Furthermore, this paper discussed the various management techniques to address climate that states like Queensland have adopted such as the adjustment to climate through selective bred cattle. The governments 'Futrue Drought Fund' is a recent development in government support for farmers in Australia, with a focus on educating and training farmers on financial management during climate distress. This inititive will develop the resilience of farmers and increase the longevity of farms that will improve job retention in agriculture, supporting the overall economy. The results from this study are statistically and substantively significant and draw upon various implications and recommendations that is dependent from the view of the stakeholder.

It is recommended to the government to subsidise the insurance market for drought and other climate related risks, as this will develop the foundation needed for farmers to access attractive insurance. If successfully implemented farmers will benefit from higher profitability in bad years that will allow them to manage production efficiently and reduce the possibility of financial distress from extreme climate aberrations. Additionally, the development of insurance markets for climate variability will result in the industry as a whole being more attractive to institutional investors and perhaps result in the farmers benefiting from lower interest rates, fostering the potential growth and profitability of the agricultural industry. Furthermore, it is recommended that the government should implement tax incentives for climate mitigating schemes such as the implementation of FutureFeed to reduce methane emissions from cattle.

This tax incentive will stimulate the curiosity and eagerness for beef farmers to take action on climate change, that is likely to benefit the productivity of the beef sector long-term. From the perspective of the farmer, it is recommended to invest and implement climate risk mitigating initiatives in order to reduce carbon emissions.

The government should actively assist farmers implement clean energy projects and practices in the form of subsidies, education and training. Successful implementation of initiatives such as FutureFeed will benefit the future generations in Australia as well as the global agricultural community from a potential reduction in the number of extreme climate events as global emissions fall. Additionally, if the insurance market for agriculture benefited from government subsidies, farmers would be encouraged to take out insurance for adverse climate events. This would improve farmer creditability as they actively take steps to mitigate climate risk exposure in the form of insurance which may improve farmers access to finance that is sustainable in regard to serviceability.

It is recognised that these initiatives and recommendations may not resolve the issues associated with climate change, however, these initiatives will be part of a larger transition from carbon pollutants to cleaner energy sources and climate mitigating practices. Future studies should estimate how different breeds of cattle perform in different states to assess the level productivity given the variability of climate. On balance, the issue of climate change needs to be addressed in order to sustain and increase productivity of not only the beef and agricultural sector but the wider economy as a whole.

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