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LAND USE AND PROFITABILITY IN WHEAT PRODUCTION: THE AUSTRALIAN WHEAT-SHEEP ZONE

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Abstract

The Australian wheat industry is an important contributor to the Australian economy and farm sector. This paper investigates the determinants of land use and profitability in wheat production for the Australian wheat-sheep zone. Wheat area supply response and its profitability were estimated across the wheat-sheep zone for the period 1990-2015. The results indicated that the growers in Western Australia are more (relative expected) price responsive than the growers in the South Eastern states. The current wheat area is highly depended on the previous year's wheat area, and the area adjustment is also not significantly different between the regions. Estimates for own-price (wheat-wheat) and cross-price (wheat-wool) elasticities are with the expected signs, and the cross-price elasticities are more inelastic compared to the own price elasticities. Wheat productivity influenced negatively by the area sown but showed the positive influence of locations and periods, which implies technological progress has been playing a significant role to improve wheat production. Ricardian approach for wheat profitability indicates the regional effect of minimum temperature on determining wheat net revenue in the Australian wheat-sheep zone.
Keywords: *Wheat production; Land use; Supply response; Relative prices; Ricardian approach; Profitability*
JEL Codes: *Q10, Q15*

1. Introduction

The Australian grain industry is an essential part of the Australian economy and farm sector. Within the industry, there are three distinct groups being wheat, coarse grains, and oilseeds. Wheat is the largest of three with production exceeding that of the other two. The total world consumption of wheat is around six hundred million tonnes per year, and this figure is expected to rise in the coming years (AWB, 2006).).Wheat is a major winter crop in Australia produced mainly in the States such as Western Australia, New South Wales, Victoria, South Australia, and Queensland which having more revealed comparative advantage (RCA) to trade with China and Association of Southeast Asian Nations (ASEAN) compared to the world average (DAWR, 2016; Culas and Timsina, 2019). Australia had produced 25303 kt of wheat in 2013-14, which is 3.5% of total world production (ABARE, 2015). Australia's wheat exported to over thirty-one different countries around the world, and Australia is the fourth largest exporter of cereal grains (ABARE, 2015). Due to Australia's small population, the export market is the most profitable as there is less demand for wheat in the domestic market.

About 25 million tonnes of wheat is produced annually in Australia (ABARE, 2007) and the domestic market uses about five to six million tonnes of wheat while the remaining being exported mainly to the Middle East and the South East Asian countries. Grain yields in Australia are subject to variations in rainfall and seasonal conditions. This demonstrated in production figures that range from 1.14-2.14 tonnes per hectare over the last decade (AWB, 2006). Since the deregulation of the wheat industry, the growers have the choice to sell directly to consumers and domestic traders utilizing cash contracts or wheat pools.

The wheat trends reflect the increased area of wheat sown in recent years as well as some improvement in the productivity (ABARE, 2007). The Australian wheat industry is expected to become much stronger in the coming years because of new technologies, increases in global population, high-quality products, and refined markets.

There is a wide geographical spread of wheat growing areas in Australia with different climatic conditions and soil types. These features act to minimize the adverse effects of climatic conditions on national production, though there is still some volatility from year to year. Over the last 20 years, Australian wheat production has increased with a significant increase in the area harvested for wheat. This is mainly due to growers switching from wool to wheat production following decreases in the price of wool, as well as increases in the price of wheat because of the recent drought with a fall in export quantities. The successful long-term future of the Australian wheat industry will be subject to many challenges such as resource sustainability, infrastructure development, climate change, international price distortion, and disease risks. Based on past performance, the wheat industry should be able to overcome these challenges and continue to make an essential contribution to the Australian economy and global food markets (ABARE, 2007).

The world wheat market has been significantly affected by drought in some of the world's largest production and exporting countries. This has resulted in the world wheat price increase to the highest price in ten years (ABARE, 2007). During the drought in the 2006-2007 world wheat production fell by 61 percent. Climate conditions play a large part in the fluctuations in the supply of wheat products in the Australian economy. Cline (2007) reported that crop productivity is affected by possible changes in the distribution of rainfall during the year. Droughts can seriously affect wheat quality and production. The development of the Australian wheat industry in the last few years has seen a change in management practices and the balance between stock and cropping enterprises. Over the coming years, the climate will be a major consideration for growers and their intended plantings. Further, uncertainties in the international wool market combined with poor returns have prompted some producers to change the focus of their enterprise from sheep production towards cereal production (ABARE, 2007).

The impact of lowering demand for wool, which decreases the price received by Australian wool producers, has reduced the national flock numbers of sheep. And combined with higher prices of lamb, lowering demand for wool has caused many producers to shift their enterprise focus to meat and crop production and decreasing the wool supply. Supply and demand of wool are not only affected by the global economy but also by trade barriers since many countries have trade barriers (restricted trade flows) which distort free trade in wool and wool products, reducing world demand for wool (Garnaut *et al.*, 1993). The climatic and price uncertainties have caused the farmers to diversify their activities and the land allocated (area responses) between the wheat and the wool enterprises (Kingwell, 2012).

Economists have employed econometric models to analyze the responses of Australian farmers to the various factors thought to drive decision making in land use and enterprise mix. An early study by Fisher (1975) estimated supply response equations for several regions in South Eastern Australia using the area sown to wheat as the response variable for the period 1949/50-1971/72. Sanderson *et al.* (1980) have in particular studied the area responses of Australian wheat growers in four statistical divisions of New South Wales, namely, Central

Tablelands, Central Western Slopes, South Western Slopes and the Riverina for the period 1945/46-1974/75.

Some comparisons of early day estimates of agricultural supply elasticities for the Australian economy are given in Adams (1988). Fisher and Wall (1990) estimated the supply response in Australian sheep industry using a normalized quadratic profit function approach for the three major zones (the pastoral, the wheat-sheep and the high rainfall zones) for the period1967/68-1980/81.The same profit function approach has also used for estimating the production responses (elasticities) for the broadacre farms in Western Australia (Xayavong *et al.*, 2011). A more recent study by Oczkowski and Bandara (2013) highlights the role of prices, total land holdings and the effect of climate (rainfall) on the land use in regional Australia within a profit-maximizing theoretical framework.

Australian broadacre agriculture involves major grazing and cropping enterprises. They account for 65 percent of commercial farms in Australia and also 60 percent of the total value of agricultural output (Hall *et al.,* 1988). Broadacre agriculture is, however, subject to the greatest change in product mix due to the multi-product nature of these enterprises. For this reason, most studies disaggregate broadacre agriculture into three major agricultural/agro-ecological regions, namely, the pastoral zone, the wheat-sheep zone, and the high rainfall zone. The three major zones are geographically defined and aggregate farms with similar climatic and technological conditions (Fisher and Wall 1990; Griffith *et al.*, 2001). Accordingly, each zone has a comparative advantage in the production of certain products.

The objective of this paper is therefore to investigate the determinants of land use and its profitability in wheat production for the wheat-sheep zone. The land allocation between the wheat and the wool enterprises are mainly considered in view of maximizing the expected farm profit, following Culas (2014). Wheat area supply response is estimated across the wheat-sheep zone using data for the period 1990-2015. Further to the area response function, a physical relationship between the wheat production and the area of wheat grown is specified. Moreover, wheat profitability analysis using the Ricardian approach is discussed. The empirical results are presented in view of guiding the decision on land use.

The paper is organized as follows. Section 2 provides an overview of the Australian wheat and sheep/wool industries covering the study period. Section 3 details the empirical models. Data and sources are detailed in Section 4. Results and discussion are given in section 5, following with the conclusion in section 6.

2. An Overview of the Australian Wheat and Sheep/Wool Industries

In terms of the Australian Outlook average yield and production areas for wheat as a commodity are destined to remain stable or increase (ABARE, 2005). Despite the attractiveness of diversification into areas such as sheep and prime lamb production, the area sown to wheat is expected to maintain at current levels or increase. This trend hints that the cross-price elasticities of wheat in relation to other crops or livestock enterprises are relatively stable or slightly increased (Fisher and Wall, 1990; Griffith *et al.,* 2001).

The very slight increase in production of wheat over the past years has met with a fall in barley and feed sorghum, two of the more competitive substitutes in Australia. This demonstrates to some extent the willingness of Australian producers to continue with wheat in the short term, as well as the inability of many areas to diversify away from wheat since wheat is the most profitable crop. Responses in the area, production, average yield (productivity) and prices (in terms of the unit value of production) for the Australian wheat industry during the study period 1990-2015 are given in Table 1.

The data presented in Table 1 evidenced that there are fluctuations in the area sown during the period. The data also reveals that Australian wheat production is notably variable so that the annual variations in the average yields and the wheat prices are considerable. As with most grains grown throughout Australia, wheat prices are volatile and change frequently (Kingwell, 2012).

Table 1. Area, Production, Productivity and Prices for Australian Wheat (1990-2015)

Year	Area ('000 ha)	Production ('000 t)	Average yield (Productivity) (t/ha)	Price (unit value of production) (A$/t)
1990-91	9,218	15,066	1.63	132.0
1991-92	7,183	10,577	1.47	200.2
1992-93	9,101	16,184	1.78	165.9
1993-94	8,383	16,479	1.97	174.0
1994-95	7,891	8,972	1.14	237.1
1995-96	9,221	16,504	1.79	260.8
1996-97	10,936	22,924	2.10	212.8
1997-98	10,439	19,224	1.84	197.7
1998-99	11,543	21,464	1.86	186.9
1999-00	12,168	24,758	2.03	195.1
2000-01	12,141	22,108	1.82	232.1
2001-02	11,529	24,298	2.11	261.6
2002-03	11,170	10,132	0.91	265.7
2003-04	13,067	26,132	2.00	225.7
2004-05	13,399	21,905	1.63	197.1
2005-06	12,443	25,150	2.02	202.7
2006-07	11,798	10,822	0.92	242.0
2007-08	12,578	13,569	1.08	390.0
2008-09	13,530	21,420	1.58	281.1
2009-10	13,881	21,834	1.57	218.3
2010-11	13,502	27,410	2.03	257.3
2011-12	13,902	29,905	2.15	226.6
2012-13	12,979	22,855	1.76	313.0
2013-14	12,613	25,303	2.01	316.1
2014-15	12,384	23,743	1.92	300.1

Source: ABARE, 2016

Further, rising crude oil prices and the greenhouse gas emissions encouraged countries to expand the land allocated to oilseed production to produce biofuels as an alternative fuel source. This has also affected the wheat production worldwide including Australia. Thus the supply of grains such as wheat is influenced not only by the uncertain climatic conditions and the price variations in domestic and international markets but also by the technological, biological, economic, social and institutional factors.

Wool is generally traded and exported from Australia in either raw form or processed to different degrees (AWEX, 2009). The reserve price scheme for wool was abandoned by 1990 and after that, the wool price, which stayed flat over the 1990s, has made wheat as an attractive crop than the alternatives. The impact of lowering demand for wool, which also decreases the price received by Australian wool producers, has reduced the national flock numbers of sheep.

Table 2 shows the sheep numbers, total wool production and average prices for wool (Eastern Market Indicator) for the period 1990-2016. The data presented in Table 2 reveals that there is a decline in sheep numbers and consequently for the area allocated to sheep (wool) production. The data also shows that total wool production has declined over the years as a result of the decline in sheep numbers. The variation in the prices indicates that the wool price has not improved over the period until 2009/2010 (though some improvement can be seen in 2002-03), but the price has started to improve since 2010/2011. Combined with higher prices of lamb, lowering demand for wool has caused many producers to shift their enterprise focus to meat and crop production.

Table 2. Sheep Numbers, Wool Production and Average Prices for Wool (1990-2015)

Year	Sheep numbers (million)	Wool Production ('000 t)	Average price (Eastern Market Indicator) (c/kg)
1990/01	163.2	989.2	699.6
1991-92	148.2	801.2	592.6
1992-93	138.1	815.1	519.2
1993-94	132.6	828.3	547.0
1994-95	120.9	727.9	788.0
1995-96	121.1	684.9	658.1
1996-97	120.2	731.4	669.8
1997-98	117.5	689.6	733.2
1998-99	115.5	687.6	550.2
1999-00	118.6	666.0	627.0
2000-01	110.9	645.1	764.0
2001-02	106.2	587.2	841.0
2002-03	99.3	551.1	1049.0
2003-04	101.3	509.5	820.0
2004-05	101.1	519.7	766.6
2005-06	91.0	519.9	713.3
2006-07	85.7	502.3	864.1
2007-08	76.9	458.7	945.0
2008-09	72.7	420.3	793.8
2009-10	68.1	422.5	871.7
2010-11	73.1	429.1	1131.5
2011-12	74.7	410.8	1202.9
2012-13	75.5	435.1	1034.6
2013-14	72.6	419.1	1069.9
2014-15	70.3	428.0	1101.5
2015-16	68.4	404.1	1253.5

Source: ABARE, 2016

Opportunities over the coming years will provide a higher demand for Australian wheat growers. This includes the increased importance of the use of grains for feeding the world, industrial purposes globally and the growth in grain consumption and import requirements from other countries.

3. Empirical Models

3.1 Model Specifications for Land Use and Production of Wheat

Given the characteristics of wheat and wool production discussed above as well as following the conceptual model described in Culas (2014), an area response function for wheat can be specified by the empirical model in Equation 1 (*Model 1*)

$$Y_t = \beta_0 + \beta_1 D + \beta_2 N_t + \beta_3 N_t D + \beta_4 Y_{t-1} + \beta_5 Y_{t-1} D + \beta_6 T + u_t \quad (1)$$

Where Y_t is area of wheat grown, D is a dummy (1 for wheat-sheep zone of Western Australia; 0 for South Eastern wheat-sheep zone of Australia), N_t is expected relative price between wheat and wool, Y_{t-1} is a lag variable of the wheat area grown, T is time-trend, and u_t is an error term with classical properties.

The estimated coefficients from the *Model 1* can be interpreted, both statistically and economically, as the farmers' decision parameters for the area responses to wheat.

Further to the area response function, a physical relationship between wheat production and the area of wheat grown is specified by a cubic equation (Griffin *et al.*, 1987). Average annual rainfall and rainfall for the period from March to October during which wheat is grown are included in *Model 2* (see Equation 2) to assess the impacts of droughts on the wheat production during the study period following Kingwell (2006).

$$Q_t = \lambda_0 + \lambda_1 D + \lambda_2 Y_t + \lambda_3 Y_t^2 + \lambda_4 Y_t^3 + \lambda_5 F_t + \lambda_6 M_1 + \lambda_7 M_2 + \lambda_8 M_3 + \lambda_9 M_4 + \lambda_{10} M_5 + \lambda_{11} M_6 + \lambda_{12} M_7 + \lambda_{13} M_8 + \lambda_{14} T + w_t \quad (2)$$

Where Q_t is wheat production, F_t is average rainfall (mm), M_1 is average monthly rainfall in March (mm), M_2 is average monthly rainfall in April (mm), M_3 is average monthly rainfall in May (mm), M_4 is average monthly rainfall in June (mm), M_5 is average monthly rainfall in July (mm), M_6 is average monthly rainfall in August (mm), M_7 is average monthly rainfall in September (mm), M_8 is average monthly rainfall in October (mm) and w_t.is an error term with the classical properties.

3.2 Ricardian Approach and Wheat Profitability

Ricardian methods suggested that farmland prices estimated agricultural land productivity in the long run (Ricardo, 1817). Mendelsohn *et al.* (1994) used this approach first to study the impact of climate change on farmland value or net farm income in US agriculture. They used the Ricardian method to overcome the main limitation of the production function approach, which fails to estimate adaptation strategies used by farmers to cope with climate change effects. Production function approach can be used for the modeling of the agronomic data based on a controlled experiment to see the impact of climate change on agricultural net revenue. However, the Ricardian approach would be best to model the link between crop production and farmers' economic management decisions (Ouedraogo *et al.*, 2006). The Ricardian approach, recompenses for the bias in the production function approach (Bello and Maman, 2015). It is the most applied econometric approach to measure the economic impact of climate change on agriculture because it captures adaptation, provides geographically precise value and is easy to estimate (Salvo *et al.*, 2013; Mendelsohn *et al.*, 2010; Niggol Seo *et al.*, 2005).

The original Ricardian study has used land value. However, information on land value is not always possible. Kurukulasuriya and Ajwad (2007) reported that net revenue is a more appropriate measure of land value compared to land price because land price does not assume about the discount rate of future revenues. Annual net revenue per hectare can be used instead, since land values are based on the discounted stream of future net revenues (Kurkurlasuriya and Ajwad, 2006; Kumar and Parikh, 1998). The Ricardian approach has been applied in different continents including developed and developing countries to study the impact of climatic factors on net revenue of different crops, for example, in the United States of America (Mendelsohn *et al.*, 1994), Africa (Deressa, 2007; Jain, 2007; Kabubo-Mariara and Karanja, 2007), and Asia (Niggol Seo *et al.*, 2005; Wang *et al.*, 2008; Thapa and Joshi, 2010; Kumar and Parikh 1998).

Although there is a broader application of the Ricardian approach, several studies have also criticized this approach. Darwin (1999) reported this model ignores the technology effects that may be available in the future. Similarly, it assumes the price will remain constant (Darwin, 1999; Cline, 1996). The inclusion of price effects is problematic in the Ricardian approach, which makes the model weaker but the bias is less than 7% (Kurukulasuriya and Rosenthal, 2003). Mendelsohn (2000) also reported that this problem is significant but not fatal. The assumption of constant prices in the Ricardian approach leads to bias in the welfare calculations (Cline, 1996). Reilly *et al.* (1994) reported that global markets determine the price of food crops and the effect of climate change on the price of crops is expected to be small. However, if supplies of individual crops are altered by the climate change, their prices are likely to Change (Niggol Seo *et al.*, 2005).

3.2.1 Model Specification for Estimating Wheat Profitability in Australia

The Ricardian approach followed by Mendelsohn *et al.* (1994, 1999) is suggested to study the impact of climate and other socioeconomic variables on wheat profitability (the net revenue of wheat) in Australia. The net revenue function of the form is presented in Equation (3):

$$\text{Max NR} = \Sigma P_i Q_i (X, C, Z) - \Sigma P_x X \qquad (3)$$

Where NR is the net revenue per hectare, P_i is the market price of crop *i*, Q_i refers to the output of Crop *i*, X is the vector of purchased inputs, C is a vector of climate variables, Z is a set of socioeconomic characteristics, and P_x is a vector of input prices.

This model is based on the assumption that farmer will maximize net farm revenue by choosing inputs (X) subject to climate and other socio-economic variables. It is based on the assumption of a direct cause and effect relationship between climate events and socioeconomic variables to the farm value (net revenue). Net revenue per unit area can be calculated following Niggol Seo *et al.* (2005) that the net revenue per unit area is equal to the total net revenue of the district divided by the area of cropland in hectares of the district.

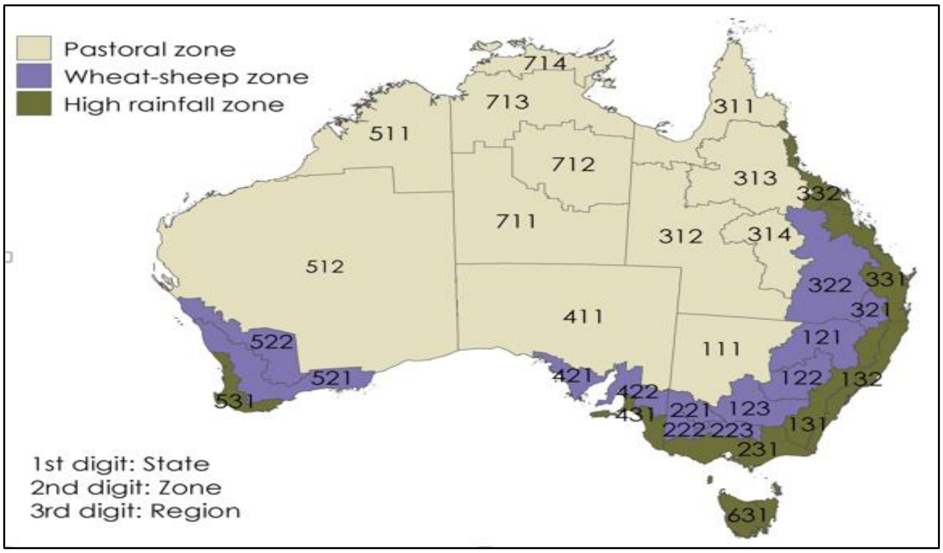
Several year average of net revenue can be used to provide a long-term measure of net revenue (Mendelsohn *et al.*, 2007). They also suggested that the Ricardian approach can be used to estimate the relationship between profits and climate. Several past studies explain that farm revenues will have U-shaped or hill-shaped relationship with climatic data due to non-linear form of response between them (for example, Mendelsohn *et al.*,1994; Kumar and Parikh, 1998; Deressa *et al.*, 2005; Wang *et al.*, 2008; Mendelsohn *et al.*, 2010; De Salvo *et al.*, 2013). Therefore, a quadratic formulation of climate variables is essential in the standard Ricardian model *(Model 3*).

$$NR = \beta_0 + \beta_1 C + \beta_2 C^2 + \beta_3 Z + \mu \qquad (4)$$

Where, C and C^2 capture the levels and quadratic terms for climate variables (i.e., temperature and precipitation) respectively, Z capture the effects of socioeconomic variables and μ is an error term. Mendelsohn and Dinar (2009) reported that farmers always want to maximize their revenue from a specific combination of input and output and, given the values of different exogenous variables.

4. Data and Sources

The sample consists of South Eastern states wheat-sheep zone of Australia and Western states wheat-sheep zone of Australia for the period 1990-2015 as described in http://apps.daff.gov.au/agsurf/ and www.grdc.com.au. These two zones are distinguished with respect to their agro-ecological characters. The agro-ecological characteristics of the South Eastern states include temperate climate, relatively infertile soils, yield dependent upon reliable spring rainfall, smaller enterprise size, phase farming innovator, a shift in intensive livestock production and demand for feed grains in this region, diverse production patterns and opportunities, and large and diverse domestic market. Whereas the agro-ecological characteristics of Western Australia include Mediterranean climate, low soil fertility, yield dependent upon good winter rains as spring rainfall is generally unreliable, large enterprise size, narrower range of crop options, export market dominant and domestic market smaller, and leader in grain storage practice and transport advantage to South East Asian countries (Figure 1).



Source: http://apps.daff.gov.au/agsurf/

Figure 1. South Eastern (Right) and Western Australia (Left) Wheat-Sheep Zones of Australia

The samples for both regional wheat-sheep zones were collected from 1990 to 2015. The South Eastern wheat-sheep zone consists of 260 observations from the areas of NSW wheat-sheep zone (NSW North West Slopes and Plains; NSW Central West; NSW Riverina), VIC wheat-sheep zone (VIC Mallee; VIC Wimmera; VIC Central North), QLD wheat-sheep zone (QLD Eastern Darling Downs; QLD Darling Downs and Central Highlands of QLD) and SA wheat-sheep zone (SA Eyre Peninsula; SA Murray Lands and York Peninsula). Similarly, the Western Australia wheat-sheep zone consists of 52 observations from the areas of Western

Australia (WA Central and South Wheat Belt and WA North and East Wheat Belt). There were altogether 312 observations. The details of the study locations are presented in Figure 1.

Data for wheat area grown (hectare), wheat production (tonne), price of wheat ($/tonne) and price of wool (cents/kg) and socioeconomic variables were obtained from ABARE *AgSurf* data base (ABARE, 2016). The price of wheat estimated from the gross receipts for wheat sold during the year, and the price of wool estimated from the gross receipts for total wool sold during the year. Data on annual average rainfall (mm) and average rainfall (mm) for the period from March to October, and average minimum and maximum temperature were obtained from the Australian Government Bureau of Meteorology (BOM, 2016).

5. Results and Discussion

5.1 Wheat Area Response

The regression results for *Model 1* (area response) is presented in Table 3. The model was estimated by OLS for the fitness to the data and the statistical significance of the relevant variables. The regression results were also checked and corrected for the first-order autocorrelation (AR1) following Greene (1993).

Table 3. Estimates for the Area Response Model (*Model 1*)

Dependent variable: Y_t (wheat area in ha)				
Explanatory variables	*Model 1(a)*	*Model 1(b)*	*Model 1(c)*	*Model 1(d)*
Constant term (South Eastern states)	11.208 (701.154) *	48.103 (694.395)	-8.800 (7.659)	-9.791 (7.356)
D (dummy for Western Australia)	-44.606 (34.356)	-41.811 (33.569)	-45.004 (34.254)	-42.257 (33.493)
N_t (expected relative price)	245.793 (129.642) *	244.477 (129.324)*	246.939 (126.525)*	247 (126.263)**
N_t * D	1108.980. (643.942) *	1134.83 (641.606)*	1117.309 (640.548)*	1147.110 (637.773)*
Y_{t-1} (lagged wheat area)	1.003 (0.013) ***	1.008 (0.009)***	1.003 (0.013)***	1.008 (0.008)***
Y_{t-1} * D	0.008 (0.018)		0.008 (0.017)	
T (time trend 1991-2015)	-0.009 (0.349)	-0.288 (0.346)		
Durbin-Watson statistic	2.029	2.026	2.026	2.024
degrees of freedom	299	299	299	299
Adjusted-R^2	0.988	0.988	0.988	0.988
Prob > F	0.0000	0.0000	0.0000	0.0000

Note: Standard errors are given in parenthesis. ***significant at one percent, **significant at five percent, and *significant at ten percent.

The results indicated that the regression for *Model 1(d)* is the best fit to the data. The results also suggest that the relative expected price is statistically significant and has a positive effect on the wheat area sown. Its effect is, however, more for Western Australia than the South Eastern states. This implies that the wheat growers in Western Australia are more price responsive than the growers in the South Eastern states. This result is therefore related to the specific agro-ecological characters of Western Australia compared to the South Eastern states (as detailed in section 4) such as the export market dominant, smaller domestic market, grain storage practice and the transport advantage to the South East Asian countries.

Further, the coefficient for the lagged wheat area is one which indicates that the current wheat area is highly dependent on the previous year's wheat area. And also there is no statistically significant difference between Western Australia and the South Eastern states in the area adjustment during the study period (1990-2015).

5.1.1 Econometric Methods

This section considers the circumstance under which the econometric methods employed in this study are applicable. In particular, when testing the autocorrelation in the presence of lagged dependent variables for *Model 1*. The partial adjustment model of the general form considered is

$$Y_t = \beta_0 + \beta_1 Y_{t-1} + \beta_2 X_t + u_t \qquad (5)$$

This model was estimated as an AR1 regression by Prais-Winsten method (that involves GLS procedure) to account for the first-order autocorrelation

$$u_t = \rho u_{t-1} + e_t \qquad (6)$$

An explanation for the autocorrelation in the model is that the factors omitted from the time-series regression are correlated across periods. This may be due to serial correlation in factors that should be in the regression model. *Failing to account for autocorrelation when it is present is almost surely worse than accounting for it when it is not* (Greene, 1993).

Since a relatively small sample (1990-2015) in this study, the Prais-Winsten method favored over the Cochrane-Orcutt method which may be more appropriate for estimating models with lagged dependent variables. The Cochrane-Orcutt method involves omitting the first observation in the data, and therefore the sample should be large enough to follow this method.

However, there has not been a presence of autocorrelation in the estimated model according to the Durbin-Watson Statistics (and also from the statistically insignificant autocorrelation coefficients). It is reported that either the Durbin *h-test* or Breush-Godfrey test could be used for testing the autocorrelation when a lagged variable is present in the model (Greene, 1993), provided the sample is large enough.

The other concern is when estimating the models with lagged variables and the presence of trending in the exogenous variables. The model estimated with exogenous variables that are trending, such as the expected relative prices between wheat and wool and the time-trend. It is a valid concern that when there is heavy trending in the exogenous variables and disturbances, the lagged variable will dominate the regression and destroy the effect of other variables whether they have real causal power or not (Achan, 2001). This means the lagged variable can artificially dominate the regression whether it has a great deal of explanatory power or not.

Due to this reason, *Model 1* has tested for different specifications as *Model 1(a)*, *Model 1(b)*, *Model 1(c)* and *Model 1(d)*. In *Model 1(d)*, one of the exogenous variable time-trend has omitted. Further, the model also shows no evidence for the presence of autocorrelation (disturbances) as mentioned earlier. However, the lagged variable gets the coefficients 1 in all the model specifications meaning that the areas of wheat grown in the past predict the future area very well.

The presence of trending in the relative prices therefore still warrant that the model estimates are valid, even though the model was estimated by the Prais-Winsten method. Ramanathan (2002) reported that estimating a larger sample by the Cochrane-Orcutt procedure could minimize the dominance of the lagged variable in the regressions.

5.2 Wheat Production

Regression results for the *Model 2* (production function) are presented in Table 4, which was estimated by OLS for the fitness to the data and the statistical significance of the relevant variables. As in Table 3, the regression results were checked and corrected for the first-order autocorrelation (AR1) following Greene (1993).

Table 4. Estimates for the Production Function (Model 2)

Dependent variable: Q_t (wheat production in tonnes)				
Explanatory variables	*Model 2(a)*	*Model 2(b)*	*Model 2(c)*	*Model 2(d)*
Constant term (South Eastern states)	-7056.492 (3694.288)*	-8052.146 (3574.923) **	-8593.504 (3643.064)**	156.285 (44.732)**
D (dummy for Western Australia)	133.306 (47.50) **	128.490 (46.396) **	127.229 (47.674) **	97.329 (48.051) **
Y_t (wheat area in ha)	1.631 (0.232) ***	1.367 (0.113) ***	1.182 (0.051) ***	1.227 (0.049) ***
Y_t^2 (wheat area squared)	-0.0006 (0.0003)	0.0001 (0.0006)*		
Y_t^3 (wheat area cubic)	0.0000 (0000)			
F_t (average rainfall in mm)	-0.267 (0.119) **	-0.285 (0.118) **	-.320 (0.117)**	-0.293 (0.120) **
M_1 (Avg. rainfall in March in mm)	0.866 (0.409)**	0.911 (0.407)**	0.950 (0.410)**	1.100 (0.407)**
M_2 (Avg. rainfall in April in mm)	00308 (0.380)	0.027 (0.380)	0.079 (0.381)	|0.050 (0.384)
M_3 (Avg. rainfall in May in mm)	0.527 (0.423)	0.562 (0.422)	0.602 (0.422)	|0.466 (0.426)
M_4 (Avg. rainfall in June in mm)	0.536 (0.419)	0.561 (0.418)	0.667 (0.416)	0.657 (0.421)
M_5 (Avg. rainfall in July in mm)	-0.550 (0.472)	-0.487 (0.469)	-0.398 (0.469)	-0.438 (0.474)
M_6 (Avg. rainfall in August in mm)	0.481 (0.455)	0.554 (0.452)	|0.611 (0.454)	|0.569 (0.459)
M_7 (Avg. rainfall in Sept. in mm)	0.792 (0.528)	0.833 (0.527)	0.869 (0.530)	0.700 (0.533)
M_8 (Avg. rainfall in Oct. in mm)	-0.077 (0.472)	-0.062 (0.471)	-0.161 (0.473)	-0.402 (0.471)
T (time trend 1991-2015)	3.573 (1.848)*	4.082 (1.787) **	4.369 (1.820)**	
Durbin-Watson statistic	1.972	1.976	1.977	1.985
degrees of freedom	311	311	311	311
Adjusted-R^2	0.846	0.846	0.838	0.826
Prob > F	0.0000	0.0000	0.0000	0.0000

Note: Standard errors are given in parentheses. ***significant at one percent, **significant at five percent, and *significant at ten percent.

The results indicate that the regression for *Model 2(a*) can be the best fit to the data than the others. The results also suggest that Western Australia has in general far more production of wheat compared to the South Eastern states. Further, the physical input-output relationship for land and wheat is statistically significant and exhibits linearity which is in line with the findings for the other grain industries (ABARE, 1999).

AGO (2007) reported that change in rainfall patterns has a direct effect on agricultural productivity. The variable for annual average rainfall becomes statistically significant and negative with wheat production, but average seasonal rainfall has no significant impact. However, rainfall during the wheat growing months such as March, April, May, June, August, and September has a positive effect on wheat production. This implies that the droughts during the study period (1990-2015) had an impact on wheat production in the wheat-sheep zones. Among different months, March had significant drought effect on wheat production. Given adequate rainfall and soil moisture, early planting can set the potential for high yields. It aids fast establishment and good early growth compared with later-planted crops due to warmer days. It also allows roots to grow deeply to access moisture later in the season (GRDC, 2011). Heyhoe *et al*. (2007) reported that total factor productivity of wheat in Western Australia and New South Wales decreased by 7.3 percent and 4.2 percent respectively compared to the year 1990 due to drought effect in wheat production. Moreover, the time related exogenous factors such as technological progress has a significant impact on wheat production.

5.2.1 Wheat Productivity

Based on the results from *Model 2*, area sown to wheat is linearly related to the wheat production. Further, by looking at the figures in Table 1, wheat production has increased from 15 million tonnes in 1990/91 to 24 million tonnes in 2014/2015. This is an increase in the production by 60 percent during the period.

A similar trend can also be seen for the area sown to wheat during this period where the wheat area is 9 million hectares in 1990/91, but it has increased to 12 million hectares in 2014/2015. This is an increase in the area by 34 percent during the period. These figures imply that the area increment has been playing major role in increasing wheat production. This trend can be related to the lack of technologies for improving wheat productivity. In this condition, it is essential to segregate the effect of area sown and technological progress on wheat productivity.

Therefore, a panel data model was specified to measure the effect of area sown (i.e., land size) on productivity, as detailed in Equation 7 (*Model 2.1*). By estimating this model the group (location) effects and the period (time) effects can be fixed so that the effects of area sown (land size) on the productivity can be measured. The panel data model also includes an overall constant, a group effect for each group and a time effect for each period.

$$A_{it} = \mu_0 + \mu_i + \mu_t + \beta Y_{it} + \varepsilon_{it} \tag{7}$$

Where A_{it} is wheat productivity (t/ha), μ_i is location effect, μ_t is the period effect, and ε_{it} is error term with classical properties. *Model 2.1* was tested for different specifications. However, based on the diagnostic test statistics (Hausman test) and the fitness to the data, the random effect *model* was preferred.

The results for *Model 2.1* are presented in Table 5. The results show that the variable for the wheat area has a negative sign, but its contribution is minimal (equal to -0.0007). The group effects vary for the study areas, as some areas get positive signs, but others are with negative signs (see table 5). Results showed VIC Wimmera and NSW Riverina had significantly higher productivity, and Darling Downs and Central Highlands of Queensland had significantly lower productivity compared to North West Slopes and Plains of NSW.

Similarly, the period effects also vary for years, as some years get positive signs, but others are with negative signs (see table 5). After 2009/10, every year had positive productivity but the year 2011, 2012 and 2014 had significantly higher wheat productivity compared to 1990. The coefficients of the group and the period effects are reported mainly to provide the direction of their effects. Otherwise, the (overall) constant has a positive impact on productivity as it is statistically significant (and equal to 1.867).

Table 5. Estimates for the Wheat Productivity (*Model 2.1*)

Dependent variable: A_{it} (wheat productivity in t/ha)			
Constant term	1.8670 (0.1797)***	1999	0.3473 (0.2076)*
Y_{it} (wheat area in ha)	-0.0007 (0.0003)**	2000	0.5046 (0.2081)**
NSW Central West	-0.0050 (0.1416)	2001	0.3016 (0.2086)
NSW Riverina	0.4671 (0.1431)**	2002	0.5241 (0.2082)**
VIC Mallee	-0.1034 (0.1495)	2003	-0.8538 (0.2084)***
VIC Wimmera	0.4152 (0.1454)**	2004	0.4184 (0.2117)**
VIC: Central North	0.3195 (0.1528)	2005	-0.0493 (0.2111)
QLD: Eastern Darling Downs	-0.0157 (0.1566)	2006	0.3870 (0.2127)
QLD: Darling Downs and Central Highlands of Queens	-0.5531 (0.1435)***	2007	-0.6773 (0.2125)**
SA Eyre Peninsula	-0.1403 (0.1814)	2008	-0.6192 (0.2148)**
SA Murray Land and Yorke Peninsula	0.1845 (0.1403)	2009	-0.0908 (0.2157)
WA Central and South Wheat Belt	-0.1939 (0.1587)	2010	0.0531 (0.2227)
WA North and East Wheat Belt	-0.2852 (0.3603)	2011	0.8233 (0.2187)***
1991	-0.0144 (0.2063)	2012	0.7664 (0.2211)**
1992	-0.2816 (0.2066)	2013	0.3654 (0.2186)
1993	0.3771 (0.2063)*	2014	0.4924 (0.2191)**
1994	0.4248 (0.2063)**	2015	0.3033 (0.2166)
1995	-0.8742 0.2063)***	Adjusted R^2	0.591
1996	0.2510 (0.2063)	Wald chi2(37)	397.07
1997	0.5406 (0.2067)**	Prob > chi2	0.0000
1998	0.0675 (0.2066)		

Note: Standard errors are given in parenthesis. ***significant at one percent, **significant at five percent, and *significant at ten percent. In period effect, results are in comparison to 1990 whereas in location effect results are in comparison to North West Slopes and Plains of NSW.

The negative effect of wheat area (land size) on productivity can be due to better management practice, and inputs use in small land size compared to a large one. The *adoption of technology* in the wheat-sheep zone during the period 1990/91-2014/2015 has been playing major role in increasing wheat productivity. Therefore, technological progress has a vital role for productivity improvement in wheat production.

Further, wheat is also a commodity where the per-unit cost of production (average cost) can fall as the level of output increase (economics of scale). Therefore, technological progress, for example, through better farming practices, choice of the correct variety, pre-season soil management, etc. can contribute to both improving productivity and reducing the costs of production. However, these factors should also be considered together with the effects of rainfall.

5.3 Wheat Profitability

Most of the past studies have used cross-sectional data for the Ricardian model except some recent studies, for example, Fezzi and Bateman (2012); Massetti and Mendelsohn (2011) and Lang (2007) who have used the panel data in the Ricardian model. Recently, the scientific debate has focused on using panel data for the estimation of the Ricardian function to solve specific issues (Salvo, 2013). The use of panel data addresses the distortions caused by the correlation between farmers' strategies and climatic variables. Massetti and Mendelsohn (2011) demonstrated wider stability of the Ricardian climate coefficients using panel data. Therefore we also used the panel data for the analysis.

Table 6. Estimates for the Wheat Profitability (Net Revenue) (*Model 3*)

Dependent variable: Wheat net revenue per hectare in log form (AUS$/ha)			
Explanatory variables	*Model 3(a)*	*Model 3(b)*	*Model 3(c)*
Constant term (South Eastern states)	2.3103 (0.6073)***	2.6301 (0.5730)***	1.9501 (0.5445)
Seasonal rainfall (mm)	-0.000049 (0.0002)	0.00008 (0.0002)	0.0001 (0.0002)
Season rainfall squared (mm)	-0.0001 (0.0000))	-0.00025 (0.0001)	-0.00028 (0.0001)
Average seasonal maximum temperature	0.0426 (0.0642)	-0.0203 (0.0570)	0.0606 (0.0548)
Average seasonal maximum temperature squared	-0.0010 (0.0015)	0.00039 (0.0013)	-0.0014 (0.0013)
Average seasonal minimum temperature	-0.0001 (0.0379)	0.0415 (0.0357)	0.0633 (0.0327)*
Average seasonal minimum temperature squared	-0.0007 (0.0023)	-0.0027 (0.0021)	-0.0044 (0.0019)**
Age of the owner (Year)		0.00007 (0.0031)	-0.0037 (0.0029)
Population (number)		0.0033 (0.0001)**	0.0033 (0.0001)**
Farm business profit (AUS $)		0.000132 (0.0001))***	0.00014 (0.0001)***
Dummy (Western Australia)			-0.1581 (0.0359)***
R- Squared	44.69	65.82	60.99
F Statistics	F(6, 305) = 41.07***	F(11, 300) = 52.52***	F(12, 299) = 38.95***
Total observation	312	312	312

Note: Standard errors are given in parenthesis. ***significant at one percent, **significant at five percent, and *significant at ten percent.

The use of logarithm form of net revenue in the Ricardian analysis is most appropriate to estimate precise results (Mendelsohn and Dinar, 2009). So we had used the log form of wheat net revenue for the study. The detail explanations of the dependent and explanatory variables are presented in Appendix 1.

Several past studies explains that farm revenues will have U-shaped or hill-shaped relationship with climatic data due to non-linear form of response between them (for example, Mendelsohn *et al.*,1994; Kumar and Parikh, 1998; Deressa *et al.*, 2005; Wang *et al.*, 2008; Mendelsohn *et al.*, 2010; De Salvo *et al.*, 2013). Therefore, a quadratic formulation of climate variables is vital in the standard Ricardian model. Our results also showed the non-linear response between climatic data and wheat net revenue. In *Model 3a*, none of the climatic variables are contributing significantly to the wheat net revenue. To capture the effects of socioeconomic variables, *Model 3b* was run after adding some socioeconomic variables (age of the owner, population, farm business profit, total non-farm income, and total off-farm wages). The model was found better with 66 percent R-square value.

Among different socioeconomic variables, population and farm business profit were found positive and contributed significantly at 5% and 1% level of significance, respectively for wheat net revenue. Although the coefficient is statistically significant, the relationship is substantively negligible. *Model 3c* was run after adding regional dummy in *Model 3b*, the regional effect was found significant at 1% level on wheat net revenue. Similar to *Model 3b*, the population and farm business profit were found positive and contributed significantly at 5% and 1% level of significance, respectively for wheat net revenue. The significant regional effect on wheat net revenue is estimated (South Eastern wheat-sheep zone has significantly higher net revenue per hectare compared to Western Australia). More interestingly, the significant regional effect of minimum temperature was observed in *Model 3c*. GRDC (2011) reported that most of the Australian wheat varieties need cold temperature, is called ‘ vernalization’, and the low-temperature requirement can also vary from three to ten (or more) degrees above the freezing.

5.4 Elasticity Estimates of Area Responses

Although the empirical models analyzed above provide measurements for the effects of key decision variables on the wheat area responses, the supply elasticities for the area responses are the other useful measurements for the decisions on the enterprise mix and land allocation between wheat and wool production. For example, for the New South Wales wheat growers, Sanderson *et al.* (1980) estimated the wheat area response elasticities concerning some key variables. Their estimates were for the wheat growing areas in the four statistical divisions of the New South Wales, namely, Central Tablelands, Central Western Slopes, South Western Slopes and the Riverina for the period 1945/46-1974/75.

Table 7. Estimates Own-Price and Cross-Price Elasticity for the Regions

	Western Australia	**South Eastern States**	**Wheat-sheep zone (Western Australia and South Eastern states combined)**
Wheat-wheat	0.165	0.248	0.238
Wheat-wool	-0.165	-0.063	-0.057

The wheat area response own-price and cross-price elasticities are given in Table 7. These estimates were obtained by extending the *model 1* to include the wheat and the wool prices. The lagged prices were used as last year prices would affect the area allocation next year. The double log (log transformation of both dependent and independent variables) model was used for estimates. The estimates are given for Western Australia, the South Eastern states and also for the wheat-sheep zone (as combined). The own price elasticities (wheat-wheat) and the cross-price elasticities (wheat-wool) are with the expected signs (see Table 7).

All elasticity estimates are less than one (inelastic). In particular, the cross-price elasticities are more inelastic than the own-price elasticities (see Table 7). This implies that the wheat growers would rarely shift the land from wheat production to wool production for the changes in wool prices however they would move more land for wheat production when there are changes in the wheat prices. The other implications of these estimates are that, although the economic conditions (that prevailed during the period 1990-2015) favored wheat production, the farmers had rarely switched *entirely* out of the wool production.

However, the current economic conditions, which are driven by the demand for meat and the rising costs of cropping tends to favor livestock production rather than cropping. This implies that a decision about producing one output is increasingly dependent on the decisions of producing the other outputs. Therefore, a shift in a farm's enterprise mix should be ultimately decided by the differences in the profits due to the adjustment costs and the investment decisions related to the farm infrastructure and so forth (Ewing *et al.,* 2004). Future analysis should, therefore, concentrate on these factors for the decisions on the land use for wheat production.

6. Conclusion

An empirical analysis for the area responses of the wheat growers reveals evidence that there are differences between the responses of the growers with respect to the relative expected prices for wheat and wool. The wheat growers in Western Australia are more price responsive than the growers in the South Eastern states. The results also indicate that current wheat area is highly dependent on the previous year's wheat area for the wheat-sheep zone. Area adjustment is also not significantly different between the regions.

Further, wheat production is linearly related and positively influenced by the area sown. The positive effect of rainfall on the wheat production in the wheat growing months such as March, April, May, June, August, and September implies that the droughts during the study period (1990-2015). Among different months, March had shown significant drought effect on wheat production. The time related exogenous factors and locations have shown considerable influence on the wheat yield. This implies that technological progress has been playing significant role to improve wheat production in Australia over the study period. The regional effect of minimum temperature observed on wheat net revenue. Socio-economics variables such as population and farm business profit are contributing significantly to the wheat net revenue in the Australian Wheat-Sheep zone.

Wheat own-price and cross-price elasticity estimates are comparable for Western Australia and the South Eastern states to guide the decisions on the enterprise mix and the land allocation. The elasticity estimates imply that, although the economic conditions during the study period (1990-2015) favored more wheat production, the farmers have rarely switched *entirely* out of the wool production in the wheat-sheep zone. The factors such as water resources management, crop specialization, access to new technologies, climate change and sustainable management practices can also effectively influence the land allocation for the wheat production. These factors should also be addressed and managed well to ensure the continued productivity improvements of the Australian wheat growers.

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Appendix 1. Descriptive Statistics of Variables Used in the Ricardian Analysis

Variables	**Variable descriptions**	**Mean**
Net revenue	Net revenue of wheat after deduction of wheat inputs costs such as fertilizer and soil conditioner, irrigation and land rent from the value of total wheat income. It is expressed in the Australian dollar in log form per hectare	2.637
Seasonal rainfall	Seasonal cumulative rainfall from March to October in mm	357.066
Season rainfall squared	Seasonal cumulative rainfall squared from March to October in mm	151768.352
Seasonal maximum temperature	Seasonal average maximum temperature from March to October in degree centigrade	19.734
Seasonal maximum temperature squared	Seasonal average maximum temperature squared from March to October in degree centigrade	399.871
Seasonal minimum temperature	Seasonal average minimum temperature from March to October in degree centigrade	7.585
Seasonal minimum temperature squared	Seasonal average minimum temperature squared from March to October in degree centigrade	62.912
Age of the owner	Age of the primary decision maker in the farm business. It is expressed in year	54.118
Population	Estimated number of farms in the study area	3097.721
Farm business profit	Farm business profit equals farm cash income plus buildup in trading stocks, less depreciation expense, less the imputed value of the owner-manager, partner(s) and family labor. It is expressed in the Australian dollar	6329.884
Total non-farm income	The total off-farm income of the owner-manager and spouse in the survey year including wages and salaries off-farm, government sourced income, rent, dividends, and interest. It is expressed in the Australian dollar	32223.282
Total off-farm wages	Total off-farm wages and salaries earned by the owner-manager and spouse during the survey year. It is expressed in the Australian dollar	16586.6154
Total observations		**312**