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Determinants of land use 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 in wheat production for the Australian wheat-sheep zone. Land allocation between the wheat and the wool enterprises are considered in view of maximizing the expected farm profit. Wheat area supply response, is estimated across the wheat-sheep zone using data for the period 1990-2004. The statistical results indicate that the wheat growers in the Western Australia are more (relative expected) price responsive than the growers in the eastern states. 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 the wheat own-price and the cross-price elasticities are with the expected signs and all less than unity, though the cross-price elasticities are more inelastic. Wheat yield is positively influenced by the area sown. Rainfall also has positive influence on the wheat yield but the time-related exogenous factors had only minor influence on the yield. The results are discussed in view of providing guidance for the decision on the land use. The paper also discusses the econometric approaches for analysing larger sample size (data).

***Keywords*:** wheat production, land use, relative prices, rainfall, supply analysis

1. Introduction

The Australian grain industry is a very important 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. Wheat is grown all over Australia but mainly in the wheat belts of Western Australia and New South Wales. The total world consumption of wheat is around six hundred million tonnes per year and this figure is expected to rise in coming years (AWB 2006). Australia's wheat is exported to over twenty-five different countries around the world and Australia is the fourth largest exporter of cereal grains (ABARE 2012). 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 about five to six million tonnes of wheat is used by the domestic market 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 is 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 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.

Wheat is an important crop in Australian agriculture with 12.98 million hectares being sown in 2005-06 returning a yield of 1.93 tonnes per hectare and 25.09 million tonnes being produced. The area sown to wheat in Australia was expected to reach 13.32 million hectare by 2010-11 while global area sown to wheat was predicted to reach 213 million hectare for the same period. This increase also relates to a predicted increase in production with 27.17 million tonnes to be produced in Australia by 2010-11 and a world production of 650 million tonnes for the same period. The trends reflect the increased area of wheat sown in recent years as well as some improvement in the productivity (ABARE 2007).

There is a wide geographical spread of wheat growing areas in Australia with differing 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 largely 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 previous performance, the wheat industry should be able to overcome these challenges and continue to make an important contribution to the Australian economy and global food markets (ABARE 2007).

The world wheat market has been affected greatly by drought in some of the world's largest production and exporting countries. This has resulted in the world indicator wheat price increasing to the highest price in ten years (ABARE 2007). During the drought in 2006-2007 world wheat production fell by 61 percent. Climate conditions play a large part in the fluctuations in supply of wheat products in the Australian economy. 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, 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 decreased the national flock numbers of sheep. And combined with higher prices of lamb, lowering demand of wool has caused many producers to shift their enterprise focus to meat and crop production, and lowering the wool supply. Supply and demand of wool is 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 analyse 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 a number of 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 period 1967/68-1980/81. The same profit function approach has also been used for estimating the production responses (elasticites) 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 accounts for 65 percent of commercial farms in Australia and also 60 percent of the total value of agricultural output (Hall *et al.* 1988). The broadacre agriculture is however subject to the greatest change in production mix due to the multi-product nature of these enterprises. For this reason most studies disaggregate the 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 and 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 key determinants of land use in wheat production for the wheat-sheep zone. Land allocation between the wheat and the wool enterprises are mainly considered in view of maximizing the expected farm profit. Wheat area supply response is estimated across the wheat-sheep zone using data for the period 1990-2004. Further to the area response function, a physical relationship between the wheat production and the area of wheat grown is also specified. The empirical results are discussed in view of providing guidance for the decision on the land use.

The paper is organised as follows. Section 2 provides an overview of the Australian wheat and sheep/wool industries covering the study period. Section 3 details the economics of land allocation between enterprises and describes 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 and Griffith *et al.* 2001).

In fact, the very slight increase in production of wheat over the past years has been 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 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 unit value of production) for the Australian wheat industry during the study period 1990-2004 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 fluctuations 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).

Further, rising crude oil prices and the green-house gas emissions encouraged countries expand the land allocated to oilseed production to produce bio-fuels as 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 climate conditions and the price variations in domestic and international markets but also by the technological, biological, economic, social and institutional factors.

Table 1. Area, production, productivity and prices for Australian Wheat (1990-2004)

(Source: ABARE 2006)

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	13,151	21,905	1.63	197.1

Table 2. Sheep numbers, wool production and average prices for wool (1990-2004)

(Source: ABARE 2006)

Year	Sheep numbers (million)	Wool Production ('000 t)	Average price (Eastern Market Indicator) (c/kg)
1990/01	166.6	989.2	699.6
1991-92	151.0	801.2	592.6
1992-93	140.5	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	100.6	519.7	766.6

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 thereafter the wool price, which stayed flat over the 1990’s, has made wheat as an attractive crop than the alternatives. The impact of lowering demand of wool, which also decreases the price received by Australian wool producers, has decreased 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 1990-2004. 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 reveals that total wool production has declined over the years as a result of decline in sheep numbers. However, the variation in the prices indicates that the wool price has not improved over the period (though some improvement can be seen in 2002-03). Combined with higher prices of lamb, lowering demand of wool has caused many producers to shift their enterprise focus to meat and crop production.

Opportunities over the coming years will provide greater 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. Economics of land allocation between the enterprises

Farming systems in the Australian wheat-sheep zone can be characterized by positive interaction or complementarities between the enterprises. For analytical purposes, a typical farm management model where a farmer allocates homogenous farmland between two alternative enterprises A and B is considered (Fraser 1990). It is assumed that A is an enterprise based on an *annual crop* such as wheat and B is another enterprise based on *perennial pasture* such as sheep for wool production.

The expected farm returns $E(\Pi)$ are

$$E(\Pi) = E[\alpha\, a + (1-\alpha)\, b + f\,(\alpha)] \tag{1}$$

where

a = uncertain net return from enterprise A,

b = certain net return from enterprise B and $E(a) > b$,

α = proportion of farmland allocated to enterprise A, and

$f\,(\alpha)$ = incremental net return for enterprise A by interaction with enterprise B.

Hence, the farmer's decision is a choice of α to maximize the expected profit. The first-order condition for the optimal level of α is

$$Max\ E(\Pi):\ a - b + f\,'(\alpha) = 0 \tag{2}$$

where $f\,'(\alpha) < 0$ and $a - b = -f\,'(\alpha)$.

From the first-order condition, the optimal level of α can be expressed as a function of net returns for the enterprises A and B

$$\alpha^* = f\,[\,a + f\,'(\alpha),\, b] \tag{3}$$

For this functional relationship (3) an optimal level of land allocated to enterprise A can be studied as an area response function as described below. A general functional form for the area response takes the form

$$Y_t^* = c + d\,X_t + e\,Z_t + v_t \tag{4}$$

where

Y_t^* is desired area for the proportion of land α^* allocated to enterprise A,

X_t is expected relative value of economic decision variable (net retuns) from enterprises A and B,

Z_t is a set of time related exogenous factors, and

v_t is an error term for the classical properties.

For enterprise A the producers can adjust their desired area each year, therefore, to allow for the possibility of adjustment lags, a *Nerlovian partial adjustment model* is specified (Nerlove 1958)

$$Y_t - Y_{t-1} = \gamma\,(Y_t^* - Y_{t-1}),\ 0 \leq \gamma \geq 1, \tag{5}$$

where γ is the coefficient of adjustment.

The partial adjustment model (5) is a dynamic model based on the assumptions of static expectations. The model explicitly implies that the change in actual area is proportional to the difference between the desired and the actual area.

Substituting and readjusting gives the model

$$Y_t = c\,\gamma + d\,\gamma\,X_t + e\,\gamma\,Z_t + (1\text{-}\gamma\,)Y_{t\,\text{-}1} + \gamma\,v_t$$

$$= \beta_0 + \beta_1\,X_t + \beta_4\,Z_t + \beta_5\,Y_{t\,\text{-}1} + u_t. \qquad (6)$$

The partial adjustment (γ) is due to the presence of different factors such as technology, institutional variables and the cost of change (adjustment cost). Thus, in (6) testing the null hypothesis that $\beta_5 = 0$, which means $\gamma = 1.0$, can be used to assess a significant adjustment lag.

The economic decision variable X_t is defined as a relative net rate of return from the function $\alpha^* = f\,[a + f\,'(\alpha),\, b]$ and it can be disaggregated into two components N_t and Mt where N_t measures relateive returns between enterprises and M_t mesaures agronomic influences such as the benefits of crop rotation or offsetting over time acheived by having perennial pastures and trees in the farimng system

$$X_t = [a_t + f\,'(\alpha)_t\,]/\,b_t$$

$$= [\,a_t\,/b_t\,] + [f\,'(\alpha)_t]/b_t$$

$$= N_t + Mt \qquad (7)$$

The economic decision variable N_t can be measured as the relative gross returns for the enterprises A and B

$$N_t = [\mathrm{P_t}^{\mathrm{A}} * \mathrm{Q_t}^{\mathrm{A}} - \sum \text{Ø}_{\mathrm{nt}}{}^{\mathrm{A}} * \mathrm{C_{nt}}] \,/\, [\mathrm{P_t}^{\mathrm{B}} * \mathrm{Q_t}^{\mathrm{B}} - \sum \text{Ø}_{\mathrm{nt}}{}^{\mathrm{B}} * \mathrm{C_{nt}}] \qquad (8)$$

where

Q_t^A and Q_t^B are respectively the expected yields for enterprise A and enterprise B,

P_t^A and P_t^B are respectively the expected prices of Q_t^A and Q_t^B,

C_{nt} is the cost of input *n*, and

$Ø_{nt}^A$ and $Ø_{nt}^B$ are respectively the coefficients denote the use of input *n* for Q_t^A and Q_t^B.

Alternatively the economic decision variable can be measured in terms of relative prices for the enterprise A and enterprise B as P_t^A / P_t^B. However, producers extract information from the observed prices in *forming price expectations*. Therefore, *the naive model*, $P_t = P_{t-1}$, is considered

$$N_t = P_{t-1}^{\ A} / P_{t-1}^{\ B} \tag{9}$$

The second expected economic decision variable M_t is related to agronomic influences and cannot easily be measured in practice, a proxy for land quality or structural changes in the farming system could be employed. In an empirical setting, the effect of M_t on Y_t can be assumed through regional differences in land quality (soil fertility) and addressed by use of a dummy variable, *D*, for the regional differences.

The economic conditions in which wheat produced in the Australian wheat-sheep zone is constantly changing because of the structural changes, in particular decreasing number of farms and increasing farm size (Kingwell and Pannell 2005). This change has significant implications for the productivity and technological progress in the wheat industry. Therefore, the effect of Z_t on Y_t can be assumed by employing a trend variable (time trend) as a proxy for the Z_t in the empirical models.

The conceptual model is defined in Equation 10.

$$Y_t = \beta_0 + \beta_2 N_t + \beta_3 M_t + \beta_5 Y_{i\,t-1} \beta_9 T + u_t \qquad (10)$$

3.1 Empirical models

Given the characteristics of wheat production discussed above, an area response function for wheat can be specified by the empirical model in Equation 11 (*Model 1*)

$$Y_t = \beta_0 + \beta_6 D + \beta_2 N_t + \beta_7 N_t D + \beta_5 Y_{i\,t-1} + \beta_8 Y_{i\,t-1} D + \beta_9 T + u_t \qquad (11)$$

where

Y_t is area of wheat grown,

D is a dummy (1 for Western Australia; 0 for South Eastern region of Australia),

N_t is expected relative price between wheat and wool,

Y_{t-1} is lag variable of the wheat area grown,

T is time- trend, and

u_t is an error term with classical properties.

The estimated coefficients β_2, β_5, β_7 and β_8 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 rainfall percentiles (for the period from March to October during which wheat is grown) are included as *Model 2* (see Equation 12) to assess the impacts of droughts on the wheat yield during the study period (Kingwell 2006)

$$Q_t = \lambda_0 + \lambda_1 D + \lambda_2 Y_t + \lambda_3 Y_t^{\,2} + \lambda_4 Y_t^{\,3} + \lambda_5 F_t + \lambda_6 T + w_t \qquad (12)$$

where

Q_t is wheat production,

F_t is average rainfall percentiles, and

w_t is an error term with the classical properties.

4. Data and sources

The sample consists of GRDC (Grain Research and Development Cooperation) South Eastern states region of Australia and Western Australia for the period 1990-2004. The two GRDC regions are distinguished with respect to their agro-ecological characters as described below (www.grdc.com.au).

The agro-ecological characteristics of the eastern states (Figure 1a) include temperate climate, relatively infertile soils, yield dependent upon reliable spring rainfall, smaller enterprise size, phase farming innovator, shift in intensive livestock production and demand for feed grains in this region, diverse production patterns and opportunities, and large and diverse domestic market.

The agro-ecological characteristics of Western Australia (Figure 1b) 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. A description of the wheat growing areas under each region according to the GRDC classification is given in ABARE (1999).

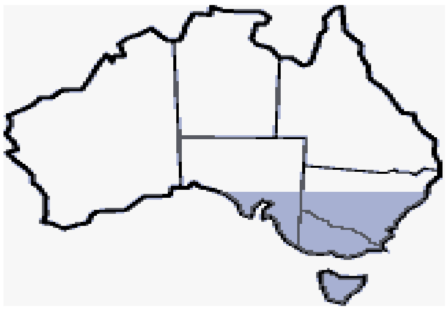

Figure 1a. South Eastern region of Australia

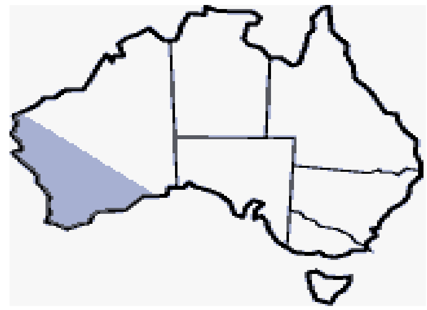

Figure 1b. Western Australia

The samples for both regions are detailed with the years of data availability. The sample for the eastern states consists of 103 observations from the areas of Central West (1990-2004), Riverina (1990-2004), Mallee (1990-2004), Wimmera (1990-2004), North pastoral (1990-2002), Eyre Peninsula (1990-2004), and Murrylands and York Peninsula (1990-2004). Whereas the sample for the Western Australia consists of 30 observations from the areas of Central and South Wheat Belt (1990-2004) and North and East Wheal Belt (1990-2004).

Data for wheat area grown (hectare), wheat production (tonne), price of wheat ($/tonne) and price of wool (cents/kg) were obtained from ABARE *AgSurf* data base (ABARE 2006). The price of wheat was estimated from the gross receipts for wheat sold during the year and the price of wool was estimated from the gross receipts for total wool sold during the year. Data on average rainfall percentiles (mm) for the period from March to October were obtained from the Australian Government Bureau of Meteorology (BOM 2006).

5. Results and discussion

5.1 Wheat area response

The regression results for the *Model 1* (area response) are 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).

The results indicate that the regression for *Model 1(d*) is the best fit to the data. The results also indicate 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 eastern states. This implies that the wheat growers in Western Australia are more (nearly five times) price responsive than the growers in the eastern states. This result is therefore related to the specific agro-ecological characters of Western Australia compared to the 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 close to 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 eastern states in the area adjustment during the study period (1990-2004).

Table 3. Estimates for the area response model (*Model 1*)

(Standard errors are in parenthesis)

Dependent variable: Y_t (wheat area in ha)

Explanatory variables	*Model 1(a)*	*Model 1(b)*	*Model 1(c)*	*Model 1(d)*
Constant term (eastern states)	-23.936 (12.958) *	-27.797 (12.49) **	-22.064 (12.557)**	-26.320 (11.888)**
D (dummy for Western Australia)	-140.489 (41.659) ***	-133.94 (41.245)***	-143.785 (41.476)***	-136.367 (40.866)***
N_t (expected relative price)	59.529 (19.674) ***	56.994 (19.558)***	63.371 (18.218)***	59.912 (17.924)***
N_t * D	285.636 (79.333) ***	309.263 (76.904)***	293.028 (78.631)***	313.407 (76.388)***
Y_{t-1} (lagged wheat area)	0.965 (0.037) ***	0.998 (0.022)***	0.968 (0.037)***	0.999 (0.022)***
Y_{t-1} * D	0.050 (0.046)		0.048 (0.046)	
T (time trend 1991-2004)	0.641 (1.238)	0.462 (1.238)		
ρ (autocorrelation coefficient)	-0.014 (0.090)	-0.007 (0.090)	-0.002 (0.090)	0.001 (0.090)
degrees of freedom	117	118	118	119
Adjusted-R^2	0.976	0.976	0.977	0.976

***significant at one percent **significant at five percent *significant at ten percent

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 the *Model 1*.

The partial adjustment model of the general form considered is

$$Y_t = \beta_0 + \beta_1 Y_{t-1} + \beta_2 X_t + u_t \qquad (13)$$

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

$$u_t = \rho u_{t-1} + e_t \qquad (14)$$

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, p. 424).

Since a relatively small sample (1990-2004) is analyzed in this study, the Prais-Winston method is favoured 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 preferred that either the Durbin *h-test* or Breush-Godfrey test could be used for testing the autocorrelation when a lagged dependent variable is present in the model (Greene 1993, p. 428), provided the sample is large enough.

The other concern is when estimating the models with lagged dependent variables and presence of trending in the exogenous variables. The model was 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 dependent variable will dominate the regression and destroy the effect of other variables whether they have true 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 been 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 been omitted. Further, the model also shows no evidence for the presence of autocorrelation (disturbances) as mentioned earlier. However, the lagged dependent variable get the coefficients close to 1 (i.e., between 0.95 and 0.99) in all the model specifications meaning that the area 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-Wiston method. However, as the sample for the estimated model is smaller, it is preferred that estimating a larger sample by the Cochrane-Orcutt procedure could minimize the dominance of the lagged variable in the regressions (Ramanathan 2002, p. 450).

Table 4. Estimates for the production function (*Model 2*)

(Standard errors are in parenthesis)

Dependent variable: Q_t (wheat production in tonnes)

Explanatory variables	*Model 2(a)*	*Model 2(b)*	*Model 2(c)*	*Model 2(d)*
Constant term (eastern states)	-11.439 (64.115)	9.889 (58.047)	-23.888 (53.426)	13.459 (47.430)
D (dummy for Western Australia)	105.036 (50.107) **	104.574 (49.240) **	93.404 (48.774) *	79.988 (48.238) *
Y_t (wheat area in ha)	1.369 (0.341) ***	1.076 (0.169) ***	1.303 (0.066) ***	1.331 (0.064) ***
$Y_t^{\ 2}$ (wheat area squared)	-0.403×10^{-3} (0.581×10^{-3})	0.173×10^{-3} (0.119×10^{-3})		
$Y_t^{\ 3}$ (wheat area cubic)	0.289×10^{-6} (0.280×10^{-6})			
F_t (average rainfall in mm)	1.929 (1.121) *	2.015 (1.107) *	2.057 (1.110) *	1.990 (1.116) *
T (time trend 1991-2004)	5.140 (4.012)	6.184 (3.796)*	5.549 (3.783)	
ρ (autocorrelation coefficient)	-0.239 (0.087) ***	-0.260 (0.087) ***	-0.262 (0.087) ***	-0.260 (0.087) ***
degrees of freedom	117	118	119	120
Adjusted-R^2	0.847	0.841	0.838	0.836

***significant at one percent **significant at five percent *significant at ten percent

5.2 Wheat production

Regression results for the *Model 2* (production function) are presented in Table 4. 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).

The results indicate that the regression for *Model 2(d*) is the best fit to the data. The results also indicate that Western Australia is in general far more productive in wheat production than the 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).

Furthermore, the variable for rainfall becomes statistically significant and positive. This implies that the droughts during the study period (1990-2004) had insignificant impact on the wheat yield in the wheat-sheep zone. However, the time related exogenous factors such as technological progress has no significant impact on the wheat yield, as this variable becomes statistically insignificant for the regressions *Model 2(a)* and *Model 2(c)*.

5.2.1 Wheat productivity

Based on the results from *Model 2*, area sown to wheat is linearly related to the wheat yield. However, the time related exogenous factors such as technological progress has no significant impact on the wheat yield. Further, by looking at the figures in Table 1, wheat production has increased from 15 million tonnes in 1990/91 to 22 million tonnes in 2004/2005. This is an increase in the production by 45 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 13 million hectares in

2004/2005. This is an increase in the area by 43 percent during the period. These figures imply that the increase in wheat production is mainly due to an increase in the area rather than an increase in the productivity. This trend can be related to lack of technologies for improving the productivity. It is also notable that the time-trend that was employed as a proxy for the technological progress (i.e. productivity in the wheat production) becomes statistically insignificant (see section 5.2).

Therefore, a panel data model was specified to measure the effect of area sown (i.e. land size) on the productivity, as detailed in the Equation 15 (*Model 3*). By estimating this model the group (location) effects and the period (time) effects can be fixed so that the effect 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.

$$A_{it} = \mu_0 + \mu_i + \mu_t + \beta Y_{it} + \varepsilon_{it} \qquad (15)$$

where

A_{it} is wheat productivity (t/ha),

μ_i is group effect,

μ_t is period effect, and

ε_{it} is error term with classical properties.

The *Model 3* was tested for different specifications such as simple-pooled regression, group effects fixed model, and group and period effects fixed model. However, based on the diagnostic test statistics and the fitness to the data, the *two factor fixed effects model* was preferred. This model was estimated by OLS method, where the coefficients for the group effects and also the coefficients for the period effects were *normalized to sum to zero* (Greene, 1998).

Table 5. Estimates for the wheat productivity (*Model 3*) ©			
Dependent variable: A_{it} (wheat productivity in t/ha)			
Constant term		1.7430 (0.2330)***	
$Y_{i\,t}$ (wheat area in ha)		0.0004 (0.0007)	
μ_i (group effects)		μ_t (period effects)	
NSW Central West	0.1950 (0.1692)	1991	-0.1745 (0.1506)
NSW Riverina	0.8029 (0.1929)	1992	-0.0929 (0.1571)
VIC Mallee	-0.0865 (0.1174)	1993	0.3015 (0.1482)
VIC Wimmera	0.6204 (0.1942)	1994	0.4360 (0.1491)
SA North Pastoral	-0.6811 (0.1572)	1995	-0.8420 (0.1475)
SA Eyre Peninsula	-0.4975 (0.1545)	1996	0.2114 (0.1448)
SA Murray Land and York Peninsula	0.2548 (0.1547)	1997	0.3070 (0.1436)
WA Central and South Wheat Belt	-0.0360 (0.1176)	1998	-0.1057 (0.1431)
WA North and East Wheat Belt	-0.6692 (0.5404)	1999	0.0889 (0.1431)
© Standard errors are in parenthesis		2000	0.0237 (0.1455)
***significant at one percent		2001	0.2046 (0.1520)
Adjusted-R^2 = 0.6439		2002	0.4833 (0.1482)
Degrees of freedom = 101		2003	-1.0951 (0.1669)
Model test: F (22, 101) (prob) = 11.11 (0.0000).		2004	0.1487 (0.1893)

The results for the *Model 3* are presented in Table 5. The results show that the variable for wheat area has a positive sign but it is not statistically significant. The group effects vary for the study areas, as some areas get positive signs but others are with negative signs (see table 5). Similarly, the period effects also vary for the years, as some years get positive signs but others are with negative signs (see table 5). 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 effect on the productivity as it is statistically significant (and equal to 1.7430).

The insignificant effect of wheat area (land size) on the productivity can be for two reasons: *the remoteness (distance)* of the wheat growing areas and *the lack of technological progress* in the wheat-sheep zone during the period 1990/91-2004/2005. Therefore, technological progress has an important role for the productivity improvement in the 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 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 Elasticity estimates

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. For example, for the New South Wales wheat growers, Sanderson *et al.* (1980) estimated the wheat area response elasticities with respect to some key variables. Their estimates are 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.

The wheat area response own-price and cross-price elasticities from this study are given in Table 6. These estimates were obtained by extending the *Model 1* to include the wheat and the wool prices. These estimates are based on the average sample values of the prices. The estimates are given for Western Australia, the 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 6).

Table 6. Estimated own-price and cross-price elasticity for the regions

	Western Australia	Eastern states	Wheat-sheep zone (Western Australia and eastern states combined)
Wheat-wheat	0.499	0.716	0.445
Wheat-wool	-0.285	-0.489	-0.241

The elasticity estimates are also all less than one (inelastic). In particular, the cross-price elasticities are more inelastic than the own-price elasticities (see Table 6). 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 shift 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 1990-2004) favored wheat production, the farmers had rarely switched *completely* 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

Empirical analysis for the area responses of the wheat growers reveals evidences that there are differences between the responses of the growers with respect to the relative expected price for wheat and wool. The wheat growers in the Western Australia are more price responsive than the growers in the 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 yield implies that the droughts during the study period (1990-2004) probably had no significant impact on the wheat yield. The time related exogenous factors had only little influence on the wheat yield.

Wheat own-price and cross-price elasticity estimates are comparable for Western Australia and the eastern states to provide guidance for the decisions on the enterprise mix and the land allocation. The implications of the elasticity estimates are that, although the economic conditions during the study period (1990-2004) favored more wheat production, the farmers have rarely switched *completely* out of the wool production in the wheat-sheep zone.

However, as the national sheep flock numbers increased in recent years, it may affect the available cropping land for wheat and also increase the demand of wheat grain for feed. The other factors such as water resources management, crop specialization, access to new biotechnologies, 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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