Deregulation of the Australian Wheat Export Market: What Happened to Wheat Prices?

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Abstract

This paper investigates whether deregulation of the Australian wheat export market induced a structural change in the price data generation process. We examine the unit root properties of Western Australian wheat prices by testing for the possibility of single and double structural breaks in the price series. Daily prices for the period 20th of May 2003 to 14th of September 2010 are used. We find that the wheat price series has a unit root with two structural breaks but neither break coincided with the time when the *Wheat Export Marketing Act 2008* came into effect on 1 July 2008. We conclude that change in local market behaviour would have started prior to actual deregulation with subsequent effect on local price.

Key Words: deregulation, unit root, structural breaks, wheat price

JEL Codes: Q13, Q18

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1. Introduction

Wheat is one of the most significant crops grown in Australia in terms of area sown, volume of grain produced and value of the crop. The majority of wheat is destined for export in bulk. Over the period, 2004-05 to 2008-09, the average annual gross value of wheat produced was $4.9 billion and accounted for 12 per cent of the gross value of total farm production in Australia. During the same period, the value of wheat exports averaged $3.5 billion per annum, making wheat Australia's second most valuable agriculture export after beef and veal (ABARE 2009). In the past, Australia has on average utilized 30 per cent of wheat produced domestically, allowing the majority to be exported. Australia is the fourth largest exporter behind the European Union, United States and Canada (ABS 2009).

Western Australia is the largest producer of wheat among the five states, has the largest wheat farms, in terms of farm area, and exports 90 per cent of its crop. Other states produce smaller quantities of wheat and export between 30 per cent and 75 per cent on average (ABARE 2009). As a major exporting state, the Western Australian wheat market price was controlled by the single desk, held by the Australian Wheat Board (AWB), a monopsony state trading enterprise (McCorriston & MacLaren 2007).

In July 2008, The *Wheat Marketing Act 2008* established a new era for Australia's export wheat marketing arrangements. The newly introduced arrangements represented a significant transition for bulk wheat exports which had been regulated under the single desk marketing arrangements for over 60 years. Under the act, any merchant wanting to export from Australia is now able to apply for an export license. Consequently, the intensity of competition between grain traders increased. As of March 2010, there were 29 organizations accredited to export

wheat in bulk from Australia. This has provided a number of changes for growers, marketers and buyers of Australian wheat. Australian growers have greater choice and flexibility about who grain is sold to.

Commodity prices have been observed to be highly volatile, appear to contain stochastic trends when sampled at high frequencies, and tend to move together even when unrelated in both production and consumptions (Myers 1994). Commodity prices are also influenced by dynamic factors that create systematic price behaviour with spikes, as well as by changes in farm price and trade policies (Wang & Tomek 2007, p. 886). These characteristics have significant implications for the econometric analysis of commodity markets. The deregulation of the wheat industry in Australia coincided with unusual volatility in the world wheat prices and industry participants, especially small growers, have found marketing and managing production and risk challenging. Some growers blame the price volatility on the move to deregulate the industry (Productivity Commission 2010). Given this inference, the question arises: Has there been a permanent change in the wheat price in response to the newly introduced market structure?

Previous literature have generally advocated that the single desk allowed price discrimination and growers were prevented from exposure to risk associated with international prices (Berry *et al.* 2005; Brewin *et al.* 2008; Carter & Wilson 1997; Ryan 1994; Wait & Ahmadi-Esfahani 1996; Watson 1999). However, there is little empirical evidence that suggests Australia's competitive position in international markets will be affected by the loss of the single desk. Instead, theoretical literature concluded that the impact of the removal of single desk may be welfare enhancing from the resulting formation of a competitive trading sector (McCorriston & MacLaren 2007). In addition, practical evidence from the *Grain Marketing Act 2008* in Western Australia demonstrated that barley prices received by growers would increase

if the industry was deregulated (Department of Treasury and Finance 2008; Layman 2006; Wilkins et al. 2006).

Given the substantial adjustments that have occurred within the Australian domestic wheat market structure, there is a possibility that deregulation coincided with a structural change[1] in the *wheat price data generation* process. This study will examine the unit root properties of Western Australian wheat prices and test for the possibility of a structural break. We use the procedure developed by Zivot and Andrews (1992) to test the null of a unit root against the break stationary alternative hypothesis. We also compare these results with the conventional unit roots tests that do not account for any break in the data. A test with the case of more than one structural break in the series will also be tested. We test the following hypothesis: *deregulation is expected to introduce a structural change in the wheat price data generation process.* Perron (1989) showed that failure to allow for a structural break leads to bias that reduced the ability to reject a false unit root hypothesis. The modeling of a structural break is important because failure to do so can lead to bias estimations and inappropriate conclusions of the data set at hand (Dawson *et al.* 2006).

This paper is organized as follows: Section 2 provides an overview of the empirical methodology. Section 3 describes the data. The main empirical results are reported in Section 4. The final section provides the conclusions of the paper.

2. Empirical Methodology

Our primary interest in this study is to test whether the Western Australian wheat price series was affected by government policy of removal of single desk in wheat export which is expected to introduce a structural change in the data generating process.

[1] Structural change is a permanent change of the fundamental structure and in the parameters of the structure generating the time series

Before proceeding, it is necessary to establish whether the series in question is stationary. By their nature, most economic time series data contains unit roots and are non-stationary, thus their means and variances change over time (Enders 2010; Jasper 2009). These violations of the assumptions of the classic linear regression model produce 'spurious' regressions with high R^2 and significant *t*-statistics that have no real meaning (Granger & Newbold 1974). A unit root process can be changed to a stationary process by differencing the series. This process involves expressing each variable as the difference between its current and lagged values. If a series is stationary after differencing it once, it is integrated of order one, which by convention is denoted as *I*(1) (Engle & Granger 1987).

2.1 Augmented Dickey-Fuller unit root test

We begin by testing for the presence of a unit root in the wheat price series using the Augmented Dickey Fuller (1979) test (ADF). The dependant variable can be specified as a level or as a first difference. If the dependant variable is a first difference and if the right-hand side is the lagged variable, the null hypothesis is that its parameter is zero. The null hypothesis implies that the wheat price has a unit root and the alternative is that the series is stationary (Wang & Tomek 2007, p. 875). Full details of the three different forms for constructing the ADF test statistic are available in the appendix, Section 1. The number of lagged difference terms included needs to be sufficient to eliminate serial correlation in the error term, ε_t. Inference about the existence of a unit root are sensitive to the choice of lags (Schwert 1989). The general-to-specific sequential method is employed for lag specification. This model was suggested by Campbell and Perron (1991) and involves the choice of a maximum number of lags which is then reduced by one until the last coefficient is statistically significant and the residuals are white noise (Wang & Tomek 2007). If a structural break has occurred, but is not modelled in the test equations, then the ADF test result is biased towards a false acceptance of a unit root (Perron 1989).

2.2 Structural Change and Unit Root tests

2.2.1 Phillips-Perron unit root test

The Phillips and Perron (1988) (PP) unit root test extends the ADF specification to allow for possible structural breaks in the time series. Like the ADF test, the PP test chooses the number of lags in a similar way. The null hypothesis of the PP test is that a unit root exists with a structural break and the alternative is stationary around a broken level (Perron 1989). Full details of the three different forms for constructing the PP test statistic are available in the appendix, Section 2. The same critical values are used for the ADF and PP tests. Perron's (1989) method of assuming the break date as exogenously determined and known *ex-ante* has been considered inappropriate within some theoretical and empirical literature (Banerjee *et al.* 1992; Christiano 1992; Perron & Vogelsang 1992; Zivot & Andrews 1992). Instead, tests have been developed for the case when the date of the structural change is unknown.

2.2.2 Zivot and Andrews unit root test

The daily wheat price series involves uncertainty about the timing and nature of a potential structural change. Therefore, we employed Zivot and Andrews (1992) unit root test which assumes that the exact time of the break point is unknown. This method regards every point as a potential break and runs a regression for every possible break date sequentially. The break date is selected where the *t*-statistics of the model is at a minimum (most negative). Consequently, a break date will be chosen where the evidence is least favourable for the unit root null (Zivot & Andrews 1992). Zivot and Andrews unit root test consists of three specific models: model (7A), allows for a one time shift in the intercept of the series; model (8A), allows for a one-time change in the slope of the trend function and model (1), combines one-time changes in the level and the slope of the trend function of the series (regression model equations (7A) and (8A) are tabled in the appendix, Section 3). Based on past empirical studies, model (1) was deemed the most appropriate specification for our analysis of unit root and

potential breakdate (Sen 2003; Ben-David & Papell 1998). Let T_B be a potential break point in (y_t), model (1) proceeds by estimating the regression below as follows:

(1) $$\Delta y_t = \mu + \alpha y_{t-1} + \theta DT_t + \gamma DU_t + \sum_{j=1}^{k} d_j \Delta y_{t-j} + \varepsilon_t$$

where the intercept dummy variable, DU_t represents a change in the level, the slope dummy variable, DT represents a change in the slope of the trend function. Formally:

$$DT_t = \begin{cases} 1 \; if \;\; t \; > TB \\ 0, \; \text{otherwise} \end{cases} \text{ and } DU_t = \begin{cases} t - TB \; if \;\; t \; > TB \\ 0, \; \text{otherwise} \end{cases}$$

Like the ADF and PP tests, the choice of lags is used to eliminate serial correlation in the error term. In this instance, we adopt the general to specific sequential procedure to obtain the lag specification. Critical values in Zivot and Andrews are different to critical values in Perron (1989) and are obtained from Zivot and Andrews 1992. The null hypothesis implies the series contains a unit root that excludes any structural break; the alternative hypothesis implies that the series is a stationary process with a one-time break occurring at an unknown point in time.

2.2.3 Clemente, Montañés, Reyes unit root test

Other tests used in this paper which address the question of the existence of unit roots from a different perspective include the Clemente, Montanes & Reyes unit root test. An extended version of the Perron-Vogelsang methodology, tests for stationary in the presence of a double structural break in the series (Clemente *et al.* 1998). There are two models for this unit root test. The first is labelled model (2) and (3), the Additive Outlier (AO) model, where structural change is assumed to take effect instantaneously, using zero-one variables to account for the break, i.e., a shift in the mean. The second is model (9A), the Innovative Outlier (IO) model, where the structural change is supposed to effect the level of the series gradually, that is there

is a transition period (Perron & Vogelsang 1992) (regression model (9A) is tabled in the appendix, Section 4). The AO model seems to be more appropriate for analysis of the wheat time series variable as it seems to have sudden changes rather than gradual shifts. The AO model is a two step process which involves the estimation of:

(2) $$y_t = \mu + d_1 DU_{1t} + d_2 DU_{2t} + \tilde{y}_t$$

Where DU_{it} =1 for t > TB_{Bi} and 0 otherwise, for *i* = 1, 2. TB_1 and TB_2 are the dates when the shifts in mean occur. The residuals from the regression, $\tilde{y}_t$, are then dependant variable in model equation 3 to be estimated. They are regressed on their lagged values, a number of lagged differences and a set of dummy variables needed to make the distribution of the test statistic tractable (Baum 2001, p. 11) :

(3) $$\tilde{y}_t = \sum_{1=0}^{k} \omega_1 DTB_{1t-i} + \sum_{i=0}^{k} \omega_{2i} DTB_{2t-i} + \rho \tilde{y}_{t-1} + \sum_{i=1}^{k} c_i \Delta \tilde{y}_{t-i} + \varepsilon_i$$

Where DTB_i (i=1,2) are pulse variables that take the value 1 if $t = TB_i+1$ and zero otherwise. No intercept is necessary as $\tilde{y}_t$ is mean zero. Model (3) is sequentially estimated and the unit root hypothesis is tested by obtaining the minimal values of the t-statistic. The null hypothesis is that the series has a unit root with structural breaks against the alternative hypothesis that they are stationary with structural breaks (Clemente *et al.* 1998). The critical value is provided by Perron and Vogelsang (1992), as they do not follow the standard 'Dickey-Fuller' distribution (Baum 2001).

3. Data

The data used for this study were daily Free-In-Store (FIS) wheat price quotations for the period of 20th of May 2003 to 14th of September 2010. The price series in Australian dollars per tonne

contained 2675 observations with a mean and standard deviation of 237±66 along with a minimum and maximum of 150 and 430, respectively. Daily prices were used because they were accessible and they improved the sample size for the period. In addition, daily pricing should improve accuracy of respective unit root tests included in this study. Australian Premium White (APW) was selected as the specific grade as it accounts for a large proportion of the Western Australian market. The data has been made available from MarketAg Independent Commodity Advisors and is the best possible price quoted by buyers of Western Australian wheat.

Figure 1 provides a plot of the wheat price series over the study period. There is no visual evidence of a deterministic time trend. However, it is obvious that wheat prices have been subject to significant volatility over the last 3 years. The price of APW in WA has fallen from a high of AUD 430 per tonne on the 11th of March 2008 to AUD 218 on the 20th of January 2010. Since then the price of wheat rallied to reach a 2010 high of AUD 359 per tonne on the 6th of August. Figure 2 represents the wheat price series after it has been differenced between its current and lagged values. Tests in this paper have been carried out in Stata data analysis software, version 11.

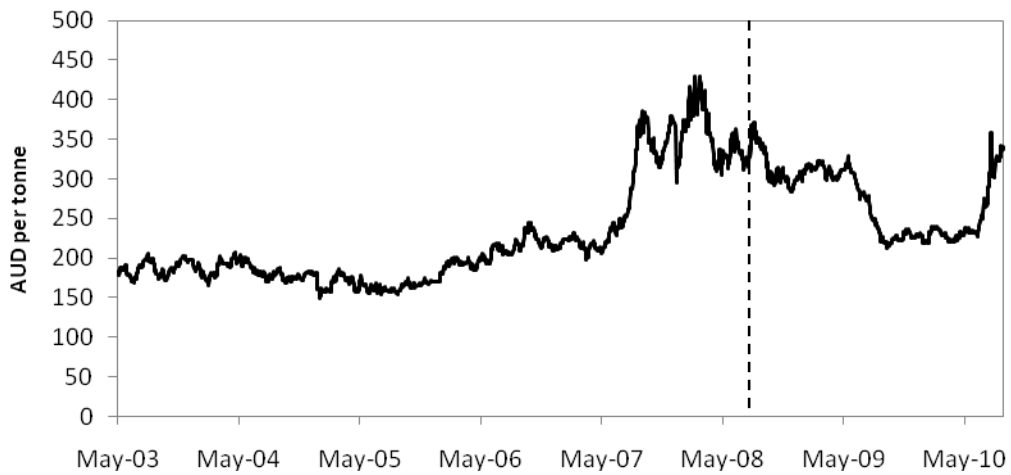

Figure 1: *Daily Australian Premium Wheat (APW) prices, May 2003 to September 2010 ($AUD/tonne). Prices are quoted on a Free In Store (FIS) basis. Dashed line indicates the introduction of Deregulation, July 2008. Source: MarketAg Independent Commodity Advisors.*

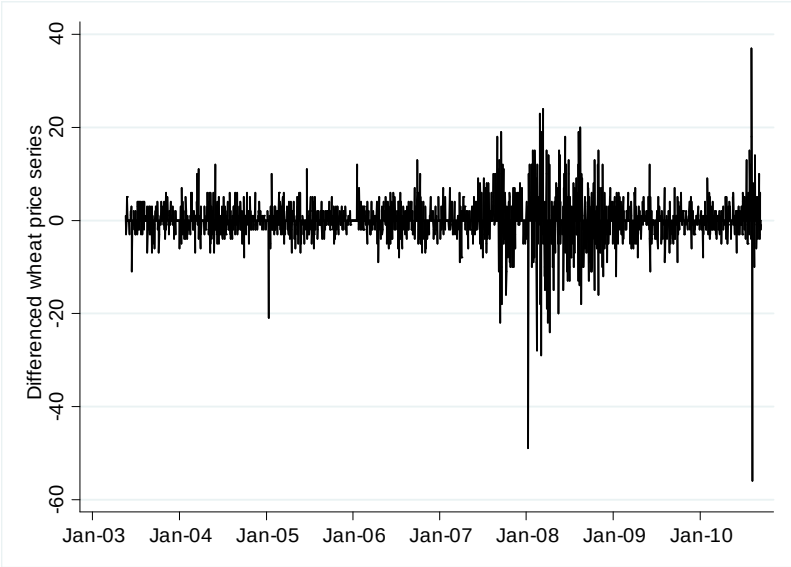

Figure 2: *Differenced Daily Australian Premium Wheat (APW) prices, May 2003 to September 2010 ($AUD/tonne). Prices are quoted on a Free In Store (FIS) basis.*

4. Empirical Results

4.1 Unit Roots without Structural breaks

The t-statistic values for the ADF and PP tests are presented in table 1. For the ADF tests, the lag length, *k*, is optimally chosen using the sequential procedure suggested by Campbell and Perron (1991), the lag length for each test is presented in table 1. Both tests fail to reject the null hypothesis for the level representation of the series at the 5 per cent significance level. However, the results obtained for the first differenced data were significant at the 1% level and therefore it can be concluded that each series is integrated at order one or *I* (1).

The following generalizations can be made. First, data transformation is necessary to ensure that the null hypothesis of a unit root is rejected. Second, the ADF and PP test results

made little difference in the hypothesis conclusions. The PP unit root hypothesis was rejected suggesting that a structural change has occurred in the data generating process. The presence of a structural break means the ADF test is inappropriate when applied to the wheat price series. The regression results consist of choice of lag specifications for the ADF are reported in appendix, section 5 and 6. We now to turn to specification issues relating to structural change.

Table 1: *Results of the Augmented Dickey-Fuller and Phillip-Perron unit root tests for the Presence of Unit Root*

			Critical Values for t-statistic		
Unit Root test (model)	**Level**	**Differenced**	**1%**	**5%**	**10%**
Random Walk					
ADF (1A)	0.516 (3)[a]	-55.516*** (0)	-2.58	-1.95	-1.62
PP (4A)	0.477 (8)	-52.871*** (8)			
Random Walk with Drift					
ADF (2A)	-1.084 (3)	-52.527*** (0)	-3.43	-2.86	-2.57
PP (5A)	-1.170 (8)	-52.827*** (8)			
Random Walk with Drift & Trend					
ADF (3A)	-1.773 (3)	-52.703*** (0)	-3.96	-3.41	-3.12
PP (6A)	-1.898 (8)	-52.821*** (8)			

1. The results of the computed augmented Dickey-Fuller and Phillips-Perron test statistics should be compared to the critical value. Reject the null hypothesis for computed values less than this critical value.
2. Model equations 1A-6A representing ADF and PP unit root tests are tabled in the appendix, sections 2 and 3.
3. Single (*), double (**) and triple asterisks (***) indicate statistical significance at 10%, 5% and 1% levels, respectively.
4. [a] number of lags chosen for PP and ADF tests. The general-to-specific method is employed for lag specification.
5. Tests have been performed using Stata version 11.

4.2 Unit Roots with Structural Breaks

Following from Phillips-Perron unit root test, we examined the location of the break endogenously in the wheat price series via the Zivot and Andrews test. Recall, that this test is performed by estimating the breakpoint that minimizes the *t*-statistic. Results of the Zivot and Andrews test are given in table 2, which generates models (7A), (8A) and (1), when the data is specified as a level and as a first difference. Based on the general-to-specific sequential method the number of lags chosen for the level and differenced data was 3 and 2, respectively.

Zivot and Andrews test models (7A), (8A) and (1) demonstrate that the wheat price series is stationary once the data is integrated in the order of *I* (1) (t-statistics are statistically significant). The break date, T_B, generated from the significant differenced wheat price data is the 12th of March 2008 (according to model (1)). On this day the t-statistic was -33.416, which is considerably less than the t-critical value of -5.08 at the 5% significance level. This result suggests that we can reject the null of a unit root in the data series and conclude that the series is stationary with a one-time break occurring on the 12th of March 2008. Figure 3 reveals the graph of the whole data series which displays the breakpoint t-statistics as a function of the observation dates. Other potential break dates based on model (7A) and (8A) were the 30th of June 2010 and the 2nd of April 2010.

Table 2: Results of Zivot and Andrews's unit root test in the presence of one structural break

ZA models	Level	Difference
Model 7A - *break in intercept*		
Min t-stat	-2.857	-33.326***
Break date	22-May-07	30-Jun-10
Model 8A - *break in trend*		
Min t-stat	-2.184	-33.246***
Break date	11-Sep-07	2-Apr-10
Model 9A - *break in trend and intercept*		
Min t-stat	-3.772	-33.416***
Break date	6-Jul-07	12-Mar-08

1. The results of the computed Zivot and Andrews test statistics should be compared to the critical value.
2. Reject the null hypothesis for computed values if test statistic is less than this critical value.
3. Model equations 7A and 8A are tabled in the appendix, section 3. Break-dates are chosen as a function of the minimum t-statistic.
4. Single (*) and double (**) indicate statistical significance at 5% and 1% levels, respectively. The 5% and 1% critical values are -4.80 and -5.43, respectively. The general-to-specific method is employed for lag specification.
5. Tests have been performed using Stata 11.

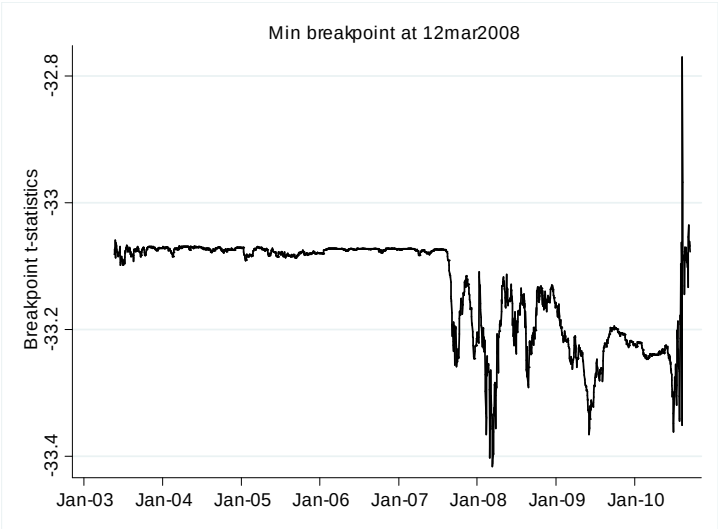

Figure 3: Graphical Representation of the Zivot and Andrews's unit roots test, estimating the possible break date of the difference wheat price series, between the 20th May 2003 and the 14th of September 2010.

As illustrated in figure 3, the minimum breakpoint on the 12th of March 2008 corresponds with a period of high prices which was a result of global shocks and subsequent tightening of the demand and supply situation (Productivity Commission 2010).

Currently, this result is inconsistent with the expectation that Deregulation in July 2008 introduced a structural change in the data generating process. Before we conclude further, it is important to recognize that the above results are derived through endogenously determining the presence of a single structural break. Knowledge of a break point is central for accurate evaluation of any program intended to bring about a structural change (Myers 1994).

4.3 Unit Roots with Multiple Breaks

Recall that the Zivot and Andrews test identifies only one possible break point. Lee and Strazicich (2003) point out that considering only one break-date when two are present can result in loss of power of the test. To check for robustness of the Zivot and Andrews findings we carry out the Clemente, Montanes and Reyes unit root test, which tests for two structural breaks in the series. The estimation of IO and AO models are expressed in table 3. As we can see under the IO and AO case, wheat series is stationary after differencing. The minimized *t*-

statistics for the AO and IO models are -12.78 and -56.28, respectively. This is far less that the *t*-critical of -5.90. This means that once the data has been differenced we may reject the null hypothesis and conclude that the series is stationary when allowing for two changes in the means of the series.

Table 3: Clemente-Montañés-Reyes unit-root test with double mean shifts, Innovation Outlier and Additive Outlier Models

Clemente *et al.*	**Level**	**Difference**
Additive Outlier Model		
t-stat	-3	-12.78*
Optimal Breaks	18-Aug-07,22-Sep-08	01-Jan-08,07-Aug-10
Innovation Outlier Model		
t-stat	-4.331	-56.286*
Optimal Breaks	23-Jul-07,10-Mar-08	02-Jan-08,08-Aug-10

1. The estimated models were, for the Innovation outlier case, and the additive outlier case. The value of k was selected following the procedure suggested in Perron and Vogelsang (1992); k =12, Critical value is -5.90 at 5% significance level.
2. Model equations 2 and 3 are tabled in the methodology section or in the appendix, section 4.
3. Single asterix (*) indicates significance at the 5% level.
4. Tests have been performed using Stata 11.

According to Baum (2006) if the estimate of the Clemente-Montanes-Reyes unit root tests provide evidence of significant *t*-statistics within AO and IO models, the significant results derived from Augmented Dickey-Fuller, Phillips and Perron and Zivot and Andrews unit root tests are doubtful, because these models exclude single or multiple structural breaks in their model specifications (Baum 2006, pp. 183-185). Given our results in table 3, only the results from Clemente-Montanes-Reyes unit roots are considered. The two structural breaks, TB_1 and TB_2 expressed in both models, occurred on 1st of January 2008 and 7th of August 2010.

Despite the loss of power of the Zivot and Andrews tests, the breakdate from this test closely corresponds to the 1st of January 2008. Given, the close connection and the statistical significance of the Clemente *et al* test we can conclude that structural changes occurred during the first quarter of 2008 and August 2010 (see figure 4).

The expectation of this paper was that deregulation of the Australian wheat export market, introduced in July 2008, would generate a structural change in the price data generation process. Clearly, the predicted break date indicated in our results does not correspond to our expected July 2008 break date. This conclusion suggests that there are other factors affecting the price of Australian export wheat. Therefore, it is difficult to control for these other factors in sequence to quantify the effect associated with deregulation.

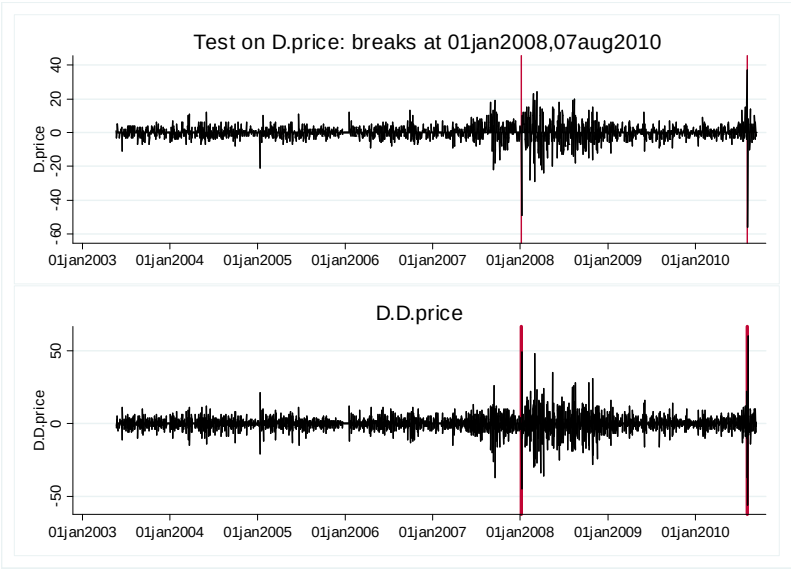

Figure 4: Graphical Representation of the Clemente-Montañés-Reyes unit-root test with double mean shifts, AO model.

The transition into a newly deregulated market has coincided with unusual volatility in world wheat prices which have been mainly affected by a pronounced commodity price cycle and the global financial crises (Productivity Commission 2010).

With this said, the resulting structural break occurring in the first quarter of 2008 coincided with a period of tightening in the supply and demand situation as a response to the following (Wright 2009, pp. 10-16):

- a reduction of supply attributed to extended drought in Australia and other countries;
- sustained increase in income in countries, such as India and China, which increased the demand for wheat (and other grains);
- An unexpected increase in biofuel production, induced by a spike in oil prices and government policies (subsidies) for biofuel production;
- Increase in international shipping rates;
- Exchange rate movements.

The net effect was a global rundown in wheat ending stocks and higher prices. The magnitude of the break diminished once the Global Financial Crisis came to the forefront. The second break, TB_2 occurred over the last month of our data set which coincided with a period of volatility surrounding the Black Sea production crisis and Russia's export ban on grain and flour. This decreased in supply contributed to a large spike in world market prices upwards which was identified as a possible break in the Clemente, Montanes and Reyes unit root tests (see table 3).

5. Conclusion

This paper examined the unit root properties of Western Australian wheat prices using daily data for 2003-2010. Based on previous studies, we used standard unit root tests to determine the possibility of a structural break in the wheat price series. We first utilized the Augmented

Dickey Fuller, Phillips and Perron and Zivot and Andrews's unit root tests for a single structural break that allow for possible breaks in slope and intercept. Second, we used the multiple structural break test of Clemente, Montane and Reyes to examine if there were multiple structural breaks in the wheat price series. It was expected that deregulation of the Australian wheat market, in July 2008, would introduce a structural change in the data generation process. This is justified based on concerns raised by some growers that the high volatility in the prices was a consequence of deregulation (Productivity Commission 2010).

Contrary to Wang and Tomek (2007, p. 888) who noted that there was no compelling theoretical reasons for finding unit roots in cash price series for agricultural commodities, our results show the wheat price series has a unit root with two structural breaks; however neither break coincided with the introduction of deregulation. The structural breaks identified in January 2008 and August 2010 was modelled with significance by the Clemente, Montanes and Reyes unit root tests. The former break coincided with a period of above average prices because of extended drought, improved global per capita incomes, increases in biofuel production and exchange rate movements during 2007-08. Whilst the break in August 2008 was a consequence of a tightening supply situation foregrounded by production failures in the Black Sea region and Russia's ban on imports of wheat.

The most important implications of this result are that deregulation has not induced a structural change in the price series, nor can deregulation be the main cause of local price volatility. Deregulation was introduced during a difficult period which coincided with unusual volatility in world wheat prices because of a pronounced commodity price cycle and the global financial crises. Contrary to expectation by some growers that deregulation may have led to a structural change in the wheat price series, our study indicates that the structural break in the series was a result of changes in demand, supply and expectation at the global scale. Evidence

suggest that grain prices reflect economic fundamentals (Wright 2009, p. 2). This is particularly apparent given that the Australian producer and exporter is typically a price taker in international market where the prices received is a product of variation in global demand, production and stocks as well as variation in the Australian exchange rate and shipping rates over time (Productivity Commission 2010).

Wheat prices are influenced by dynamic factors that create systematic price behaviour; therefore, failure to model a series with multiple structural breaks will provide misleading results. To avoid major errors in estimation and interpretation, commodity market analysts must be increasingly aware of the time series characteristics of the price series and of the resulting implications for the use of various econometric methods and techniques (Myers 1994).

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Appendix

Section 1 – Augmented Dickey Fuller unit root test equations

Random walk process with no drift

(1A) $$\Delta y_t = \delta Y_{t-1} + \sum_{i=1}^{k} \alpha_i \Delta y_{t-1} + \varepsilon_t$$

Random walk with drift

(2A) $$\Delta y_t = \beta_1 + \delta Y_{t-1} + \sum_{i=1}^{k} \alpha_i \Delta y_{t-1} + \varepsilon_t$$

Random walk with deterministic trend and drift

(3A) $$\Delta y_t = \beta_1 + \beta_2 t + \delta Y_{t-1} + \sum_{i=1}^{k} \alpha_i \Delta y_{t-1} + \varepsilon_t$$

Section 2 – Phillips and Perron unit root tests equations

Allows for a one time break in the intercept (level) of the series

(4A) $$y_t = \alpha_0 + \alpha_1 DU_1 + d(DTB)_t + \beta_t + \rho y_{t-1} + \sum_{i=1}^{k} \phi \Delta y_{t-1} + e_t$$

Allows for one time break in the slope (rate of change) of the series

(5A) $$y_t = \alpha_0 + \gamma DT_t^* + \beta_t + \rho y_{t-1} + \sum_{i=1}^{k} \phi_i \Delta y_{t-1} + e_t$$

A hybrid of model (4) and (5) that allows for a one time break in both the intercept and slope of the series

(6A) $$y_t = \alpha_0 + \alpha_1 DU_t + d(DTB)_t + \gamma DT_t + \beta_t + \rho y_{t-1} + \sum_{i=1}^{p} \phi_i \Delta y_{t-1} + e_t$$

Section 3 – Zivot and Andrews unit root test equations

Allows for a one time change in the intercept of the series

(7A) $$\Delta y_t = c + \alpha y_{t-1} + \gamma DU_t + \sum_{j=1}^{k} d_j \Delta y_{t-j} + \varepsilon_t$$

Allows for a one time change in the slope of the series

$$\text{(8A)} \qquad \Delta y_t = c + \alpha y_{t-1} + \theta DT_t + \sum_{j=1}^{k} d_j \Delta y_{t-j} + \varepsilon_t$$

The model (1) that allows for both a one time change in the slope and intercept of the series is in the Empirical Methodology

Section 4 - <u>Clemente, Montane and Reyes unit roots test equations</u>

Model (2) and (3), the Additive outlier model is presented in the Empirical Methodology section

$$\text{(9A)} \qquad y_t = \mu + \rho y_{t-1} + \delta_1 DTB_{1t} + \delta_2 DTB_{2t} + d_1 DU_{1t} + d_2 DU_{2t} + \sum_{i=1}^{k} c_i \Delta y_{t-i} + \varepsilon_t$$

The Innovative Outlier (IO) model, where the structural change is supposed to affect the level of the series gradually, that is there is a transition period

Section 5 – Statistical Example of Augmented Dickey Fuller equation 3, for data at level specification. This shows appropriate choice of lags

Unit Root test(Model)	Lags	Level	Differenced	Critical Values for t-statistic 1%	5%	10%
Random Walk						
	0	0.46	-16.29***			
	1	-1.06	2.09			
	2	-1.73*	1.7			
	3	-4.08***	0.53			
	4	-0.16	0.52	-2.58	-1.95	-1.62
	5	-1.63	-0.04			
	6	0.14	-0.01			
	7	-0.04	-0.04			
	8	.25	0.56			
	9	1.31	1.56			
	10	0.26	2.45			
ADF(1A)		0.516(3)[a]	-52.516***(0)	-2.58	-1.95	-1.62
PP(4A)		0.477(8)	-52.821***(8)			
Random Walk with Drift						
ADF(2A)		-1.084(3)	-52.527***(0)	-3.48	-2.86	-2.57
PP(5A)		-1.170(8)	-52.827***(8)			
Random Walk with Drift and Trend						
ADF(3A)		-1.773(3)	-52.703***(0)	-3.96	-3.41	-3.12
PP(6A)		-1.898(8)	-52.821***(0)			

1. The results of the computed augmented Dickey-Fuller and Phillips-Perron test statistics should be compared to the critical value. Reject the null hypothesis for computed values less than this critical value.
2. Model equations 1A-6A representing ADF and PP unit root tests are tabled in the appendix, sections 2 and 3.
3. Single (*), double (**) and triple asterisks (***) indicate statistical significance at 10%, 5% and 1% levels, respectively.
4. [a] number of lags chosen for PP and ADF tests, resulting from the above general-to-specific method, employed for lag specification.