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# The Causality Between U.S.A. and Australian Wheat Prices

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It has been generally agreed that Australia is a price follower on the world wheat market. However, to date, this has not been tested empirically. In this paper, a transfer function model between prices of U.S.A. wheat and Australian wheat is set up to examine the existence, if any, of a leader-follower relationship. By employing the causality criteria as described by Granger, this analysis is implemented to draw inferences about causality among these wheat prices. Results indicated that a significant leader-follower relationship exists, with the U.S.A. taking the leader role. The results reported are particularly useful for wheat price forecasting work and provide a basis for further modelling work.

## 1. Introduction

The Australian Wheat Board sets the daily offer quotations for Australian wheats for export. These prices are set according to the commercial judgment of the Board, and take into account the supply-demand situation on the world market at any given point in time, as reflected in prices offered by competing exporters.

The United States of America (U.S.A.) may be regarded as the market leader in the wheat market because it typically supplies about 40 per cent of world wheat exports. As well, prices for wheat in the U.S.A. are determined by the interaction of suppliers and buyers in a relatively open system of price determination. The operation of the loan rates embodied in the Farm Program tends to underpin farm prices for wheat when there is substantial farmer participation in the program.

In this paper the nature of the causality between Australian and U.S.A. wheat prices is investigated to test the hypothesis that Australia is a price follower in the world wheat market. Results will be of relevance to the widespread debate concerning the role of Australia in the international wheat market.

It is anticipated that information yielded by this research will further assist in the analysis of price formation in world wheat markets and provide a more solid foundation for forecasting Australian prices. Also, the analysis is relevant to the hedging operations of the Australian Wheat Board on the U.S.A. futures markets, as such activities require a detailed knowledge of how closely Australian prices are related to U.S.A. prices.

In the following section, a backgound discussion including a relevant literature review is presented. The data used and methodology adopted are then outlined and the results presented. In the final two sections, some qualifications of the results and conclusions are presented.

## 2 Background

### 2.1 U.S.A. wheat

There are five major classes of wheat grown in the United States of America (U.S.A.). These are hard red winter, hard red spring, soft red winter, durum and white wheats. By far the most important class grown is hard red winter wheat, which accounts for about 52 per cent of total U.S.A. wheat production. This wheat is also the largest exported class, representing about 44 per cent of all U.S.A. wheat exports in 1982–83 (International Wheat Council 1984). About 80 per cent of hard red winter wheat is traded from Gulf of Mexico ports, the rest from Pacific Northwest ports.

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The average U.S.A. farm price for wheat is an average of the farm prices of all wheat types. However, due to the overwhelming share of hard red winter wheat in U.S.A. production, coupled with the substitutability between different wheats at the margin, movements in the average farm price basically reflect the price movements in hard red winter wheat. (The correlation coefficient between the U.S.A. average farm price for wheat, and the cash price for hard red winter wheat at Kansas, from January 1970 to December 1983 is 0.99).

## 2.2 Pricing of Australian wheat

When establishing its daily f.o.b. (free on board) price quotations, it could be expected that the Australian Wheat Board takes into account the spot and futures prices prevailing in the U.S.A., as well as prices offered by the Canadian Wheat Board and other exporters and the world grains supply-demand situation in general. Since world prices are not significantly affected by changes in Australian supplies or marketing strategies, it may be hypothesized that Australia may be considered a price follower on the world market. It is this hypothesis that is to be tested in this paper.

Australian standard white (ASW) wheat is the largest class of wheat grown in and exported from Australia. About three-quarters of Australia's wheat exports in the five years to 1982–83 fell into this category. Hard red winter wheat is the class of U.S.A. wheat most closely aligned with ASW wheat in terms of end use and protein characteristics (Perkins *et al.* 1984). It has been argued that Australia has market power as a result of the different characteristics of its wheat (that is, that Australian wheat is a different product from other wheats). However, if it can be shown that a price leader-follower relationship between U.S.A. wheats and Australian wheats exists, then this market power argument is somewhat diminished.

## 2.3 Related literature

Many studies have explored price relationships between different grains, both on domestic and international markets. However, to date, little information has been available on price relationships between Australian wheat prices and other world wheat prices.

Spriggs *et al.* (1982) investigated the presence of a lead-lag relationship between Canadian and U.S.A. wheat prices. By using time series modelling techniques, they were able to conclude that only in 1974–75 and 1975–76 did the prices for wheat in the U.S.A. lead Canadian prices. Prior to, and following these particular years, no significant lead-lag relationships between the price series were detected. The results suggested that structural change in the world wheat market may have been responsible for the variable behaviour of the model.

Grant *et al.* (1983) looked at U.S.A. domestic price relationships for all major grains at different cash markets. They attempted to single out any causal relationships between these prices. Using a Ljung-Box test to test for any causality, and a bivariate autoregressive model to measure the strength of these relationships, they concluded that domestic corn and wheat prices tend significantly to lead other grain prices.

Van Dijk and Mackel (1983) carried out a study on the United Kingdom feed grain market to determine which prices affect one another. Using spectral analysis techniques, as described by Granger (1969), they found that, prior to 1979, feed barley played the major role in determining feed grain prices in the U.K.

Anh (1982) used a transfer function approach to model the ASW export price from the export price of U.S.A. hard red winter wheat. Modelled on a monthly basis, he concluded that the lead-lag relationship between U.S.A. and Australian wheat prices is strongest contemporaneously—that is, at zero lag. The procedures employed in this paper are similar to those of Anh although, after establishing this contemporaneous

relationship, the analysis in this paper goes on to investigate relationships on a daily basis to draw out possible causality inferences from the data.

## 3. Data and Methodology

### 3.1 Data

For modelling purposes, the monthly price data series used were the ASW export quote (f.o.b. eastern States) and the average farm price for U.S.A. wheat. Both series were collected for the period January 1970 to December 1983. Prices were expressed in U.S.A. dollars per tonne for ease of comparison, and to remove the effects of exchange rate movements between Australia and the U.S.A. Sources of data were published prices issued by the International Wheat Council (1984), the Australian Wheat Board (1985), and the UNICOM Newswire Service (1985). A graph of the prices used is presented in Figure 1. Even prior to any statistical analysis, the close relationship between the two prices is clearly illustrated.

### 3.2 Methodology

In this study, a time series model is constructed to establish the existence of any lead-lag relationship between the above-mentioned prices. The type of model used is called a transfer function model and is used to model dynamic input-output relationships. The modelling process is explained step-by-step in following sections. The model is then evaluated to test whether or not causality inferences may be drawn from results obtained.

#### 3.2.1 The monthly model

Under the null hypothesis that a causal relationship exists from the U.S.A. price to the Australian price, the average farm price for U.S.A. wheat (from here on called the U.S.A. price and designated as

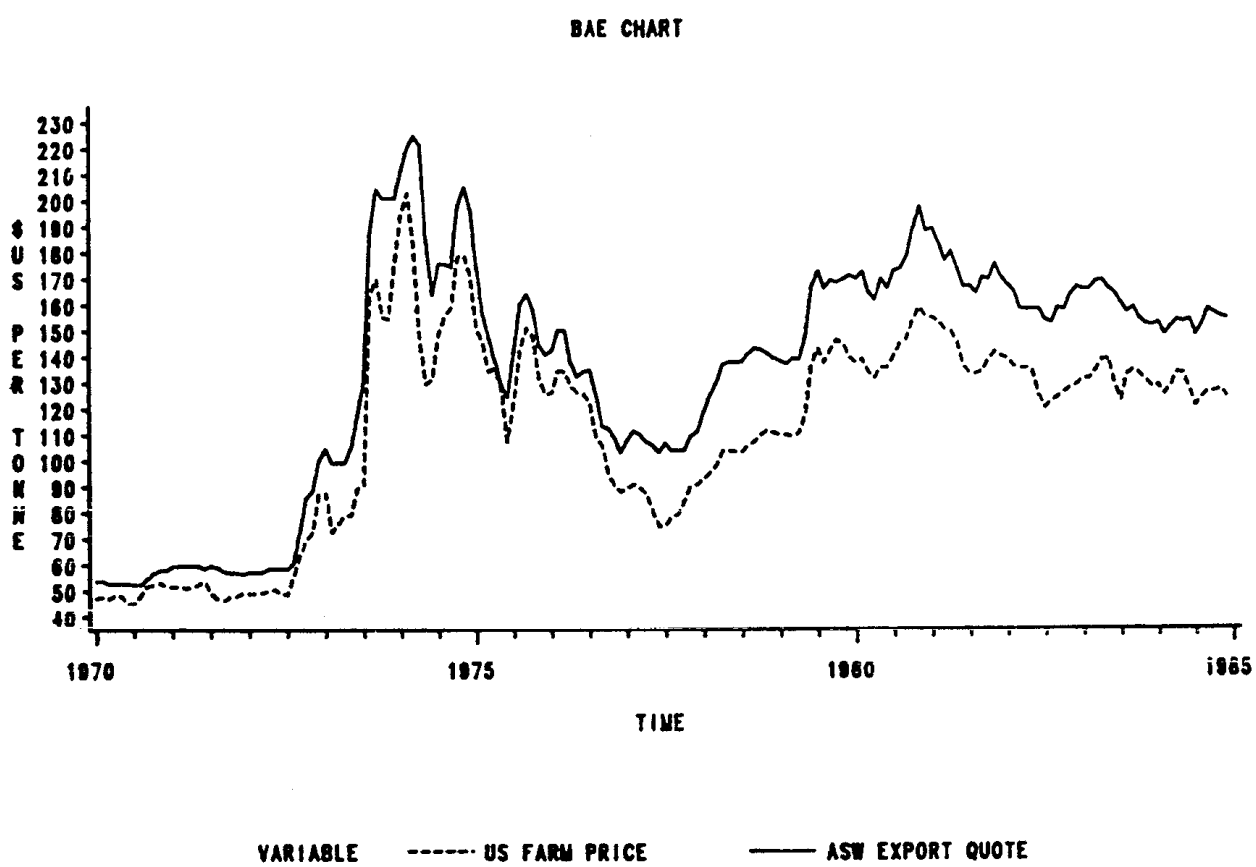


*Figure* 1—Wheat Prices: ASW Quote and U.S.A. Average Farm Price

AV) is treated as being the input of a system which affects an output price (the export price of ASW wheat, designated as ASW). A change in the U.S.A. price from one level to another may have both an immediate and delayed effect on the output price for ASW wheat. This is referred to as a dynamic response and the model being built to capture this kind of response is called a transfer function model. For a detailed explanation of the theory underlying the procedures used here, the reader is referred to Granger and Newbold (1977a).

This approach is used to assess causality between series. According to Granger (1969), given two processes $X$ and $Y$, $X$ is said to cause $Y$ if the present $Y$ can be better predicted by using the past values of $X$ than by not doing so, all other information including past values of $Y$ being used in either case. Causality from $Y$ to $X$ is defined similarly and feedback occurs if $X$ causes $Y$ or $Y$ causes $X$.

The step-by-step procedures for building the transfer function model to assess causality are outlined below.

## Step 1: Identifying filters for input and output series

First, univariate models of the ARIMA (autoregressive integrated moving-average) type are fitted to the input and output series such that:

$$\Phi_1(B)(1 - B)^d AV_t = \Theta_1(B)\alpha_t$$

$$\Phi_2(B)(1 - B)^d ASW_t = \Theta_2(B)\beta_t$$

where

– $d$ is the degree of differencing and $B$ is the backward shift operator; so that, for example $(1 - B)^1 AV_t = AV_t - AV_{t-1}$

– $\Phi_i(B)$ are auto regressive operators (in equation $i$, $i=1,2$) with order $p$, that is:

$$\Phi(B)AV_t = \phi_1 AV_{t-1} + \phi_2 AV_{t-2} + \dots + \phi_p AV_{t-p}$$

– $\Theta_i(B)$ are moving-average operators (in equation $i$, $i=1,2$) with order $q$, that is:

$$\Theta_i(B)\gamma_t = \theta_1 \gamma_{t-1} + \theta_2 \gamma_{t-2} + \dots + \theta_q \gamma_{t-q}$$

(where $\gamma = \alpha$ if $i=1$
$\beta$ if $i=2$)

$$\alpha_t \sim N(0, \sigma_\alpha^2)$$

$$\beta_t \sim N(0, \sigma_\beta^2)$$

These models are used to "pre-whiten" (or "filter") both the input and output series (that is, to filter the series to contain white noise error only) by their respective past history alone (for details of ARIMA-type models and terminology used in this paper, see Box and Jenkins 1970).

This pre-whitening is necessary because the sample cross-correlation function between the two original auto-correlated series will usually contain spurious values, and hence provide a misleading picture of the relationship between the two time series. This comes about because time series data, by nature, usually move in such a way that an observation in any one time period is usually closely related to the previous (and following) period's observation (see Jenkins 1979, p. 17). Therefore, the information which the cross-correlation function on raw data series contains concerning the relationship between the output series ASW and the input series AV may be obscured by auto-correlation functions of either series. For this reason, more reliable causality information can be drawn from pre-whitened series.

An ARIMA model was first developed for the output series ASW. No significant model could initially be established for the complete ASW series. However, because significant trends between September 1973 and December 1983 are observable, and since the autocorrelation function of the raw data shows a slow dampening through time, non-stationarity of the data series is indicated.

The lack of detection of an appropriate pre-whitening filter on the complete ASW series may have resulted from the length of time series used. As Jenkins (1979, p. 48) has observed concerning such cases, "With long series it may happen that changing circumstances cause the structure of the series to change slowly with time". Following the procedure explained by Jenkins (1979), the time period was shortened by "cumulative truncation", that is, by one month at a time, from the beginning of the series, to a length in which an appropriate pre-whitening filter for the output could be established. The justification for truncation of this type is that more recent price movements would tend to be more representative of what may happen in the future. It is more appropriate to truncate data from the beginning rather than the end. An adequate filter was established over the time period December 1978 to December 1983.

The establishment of an adequate filter over this time period coincides with the emergence of Australia as a major wheat exporter with the harvest of the 1978–79 wheat crop. Although its share in total world exports remained relatively unaltered from this crop onwards, the absolute levels of Australian exports characteristically rose to above 10 Mt with the 1978–79 crop of 18.1 Mt. The 1978–79 crop was a new record—almost twice the previous year's crop, over 6 Mt greater than the crops of each of the previous nine years, and 3.3 Mt greater than the previous record crop of 14.8 Mt harvested in 1968–69. Closing stocks increased accordingly. Prior to the 1978–79 season, stocks did not exceed 2.7 Mt; after the record crop, 2.0 Mt has represented a minimum. Clearly then, the Australian wheat industry entered an expansionary phase with the harvesting of the 1978–79 wheat crop, a structural shift which has remained stable since then.

The filter on the output which reduced this truncated series to white noise was established by looking at the auto-correlation function and partial auto-correlation function of the data to establish the type of ARIMA filter to be used. The filter was evaluated by looking at the autocorrelation and partial auto-correlation functions of the residual of the established filter, and by testing the residual for randomness. In the case of ASW data, the filter was discovered to be a series' first difference, thus defining the series to be a random walk with trend. The Ljung-Box test (at the 5 per cent level of significance) was used to test the randomness of the series of residuals of the pre-whitened price series.

The test statistic for the Ljung-Box test is:

$$Q = n(n+2)\sum_{k=1}^{j} (n-k)^{-1} r_k^{\,2} (\hat{\alpha})$$

where

$N$ = number of observations (61 in this case)

$d$ = degree of differencing (1 in this case)

$n$ = $N - d$

$^2(\hat{a})$ = the square of the auto-correlation function (ACF) of the residuals

$j$ = number of relevant lags in the test (in this case 12, since monthly data are used)

and $Q$ is approximately distributed as $\chi^2$ ($j$-$q$-$p$), where $q$ and $p$ are moving average and autoregressive parameter orders, respectively, as previously outlined (and in this case are zero).

The $Q$ statistic for the pre-whitened output, at 11.8 ($\chi^2_{0.95}(12) = 21.0$), did not result in the rejection of the null hypothesis that the residual of the whitened series is random. Therefore the first difference of the monthly *ASW* export price represents an adequate univariate pre-whitening transformation.

Therefore the model for the output series becomes:

$$ASW_t - ASW_{t-1} = \alpha_t$$

The same time period used to develop this output filter was then used to develop the filter for the input series AV (the average price received by U.S.A. farmers) since, under the null hypothesis of a relationship existing, it is this time period over which the model is constructed.

By looking at the characteristics of the auto-correlation and partial auto-correlation functions of the data, the model for the input series was established of the form:

$$\Delta AV_t = \phi_1 \Delta AV_{t-1} + \phi_{12} \Delta AV_{t-12} + \theta_2 \beta_{t-2} + \beta_t$$

where $\varphi_1 = 0.563609$, (3.6)

$\varphi_{12} = 0.430628$, (2.5)

$\theta_2 = 0.567893$ (3.6)

$\Delta$ represents the first difference operator (*i.e.* $\Delta AV_t = AV_t - AV_{t-1}$)

$t$ ratios are shown in parentheses

(in strict filter notation, the residual would be expressed as the left hand side).

Therefore the univariate filter which reduced input data to white noise was an autoregressive moving average (ARIMA) model on the *first* difference of the series, of autoregressive degree *12* [AR(12)], with autoregressive coefficients on the *first* and *twelfth* order terms only, and moving average degree *2* [MA(2)], with a moving average coefficient on the second order term only. (In normal time-series modelling terminology, this would be referred to as an ARIMA(12,1,2) model, with the coefficients on the AR(2) to AR(11) parameters constrained to zero.) The AR(12) parameter implies that some seasonal pattern in prices exists on an underlying 12-month cycle. On this basis, seasonal differencing of both raw data series was tested, but the filters on the seasonally differenced series were less

adequate (that is, higher Ljung-Box $Q$ statistic on the residual) than the ARIMA filter. The model suggests that the first difference of the average farm price of twelve months previous has some explanatory power in determining the current first difference of the average farm price. This result is consistent with *a priori* expectations of a 12-month seasonality pattern resulting from the annual nature of wheat production.

By using the same test for randomness as for the output series, the hypothesis that $\beta_t$ (the residual of the ARIMA filter described above) is a white noise series could not be rejected ($Q = 8.64$, $\chi^2_{0.95}(12) = 21.0$).

## Step 2: "Overfitting" to test for adequacy of filters

Both the input and output series were therefore pre-whitened by individual pre-whitening filters. To ensure the adequacy of these filters, these individual univariate models were "overfitted" using various additional parameters. This overfitting involves introducing additional time series parameters into the models. If the additional variables are then found to be insignificant in describing data behaviour, then the original model is adequate for filtering purposes. In both input and output models, overfitting did not lead to model improvement.

## Step 3: Identifying lead-lag structure between pre-whitened series

The next step in the analysis is to establish the direction and degree of lead or lag association between the two pre-whitened series. This information can then be used to formulate the transfer function model between the two original series.

The cross-correlation function between the two white noise series indicates those leads and lags of the output which are most highly correlated with the input. The statistically significant correlation between the residuals, at the 5 per cent level of significance, occurred only at the instantaneous lag/lead. These cross-correlations are outlined in Table 1. Leads and lags of 6 months' duration are considered appropriate for analysis. For the purposes of this model, therefore, any significant lags outside the 12-month range are considered to be aberrations, using the "plausible parameterization" principle described by Granger and Newbold (1977b, p. 262). If using this principle results in the establishment of an adequate and plausible model which generates good forecasts, then the approach is considered appropriate. The results of the cross-correlations indicated the presence of a strong instantaneous relationship between the U.S.A. average farm price and the ASW export quote. There was no apparent lagged effect on the ASW export quote from the U.S.A. average farm price at the monthly level within 6 months of the zero lag.

To imply that this instantaneous relationship defines an instantaneous causal linkage would be premature at this point. However, if it can be shown that time series models employing relationships defined by cross-correlations of the residuals of the pre-whitened series can better explain price movements than those without, then causality inferences according to Granger's definition (as previously discussed) may be drawn.

The "instantaneous" causality between U.S.A. farm prices and the Australian ASW export quote may hide a lead-lag structure on a smaller time scale. This is tested by leaving the monthly analysis at this point, and breaking down the data into daily data to examine this instantaneous relationship more closely.

## 3.2.2 The daily model

Daily average U.S.A. farm prices were unavailable for this exercise. A proxy was chosen, the daily export quote for hard red winter wheat at Pacific ports. This proxy was chosen because it is the U.S.A. export quote which shows the strongest degree of association with the U.S.A. average farm price for wheat, with a correlation

*Table 1: Cross-Correlations between Monthly Filter Residuals*

Pre-whitened input

$$\beta_t = \Delta AV_t - \phi_1 \Delta AV_{t-1} - \phi_{12} \Delta AV_{t-12} - \theta_2 \beta_{t-2}$$

where $\phi_1 = 0.563609$, $\phi_{12} = 0.430628$, $\theta_2 = 0.567893$.

Pre-whitened output

$$\alpha_t = ASW_t - ASW_{t-1}$$

| | Number of lagged period | Covariance | Correlation | Standard deviation | Cross-correlation significant* |
|---|---|---|---|---|---|
| ↑ | - 6 | 1.62 | 0.09 | 0.1291 | no |
| | - 5 | 2.41 | 0.14 | 0.1291 | no |
| $\beta_t$ | - 4 | 1.61 | 0.09 | 0.1291 | no |
| lags behind | - 3 | 4.01 | 0.23 | 0.1291 | no |
| $\alpha_t$ | - 2 | 1.12 | 0.06 | 0.1291 | no |
| ↓ | - 1 | -2.27 | -0.13 | 0.1291 | no |
| ---------- | 0 | 6.87 | 0.40 | 0.1291 | yes |
| ↑ | 1 | 3.18 | 0.18 | 0.1291 | no |
| $\alpha_t$ | 2 | -4.26 | -0.25 | 0.1291 | no |
| lags behind | 3 | -0.44 | -0.03 | 0.1291 | no |
| $\beta_t$ | 4 | -2.91 | -0.17 | 0.1291 | no |
| | 5 | -2.43 | -0.14 | 0.1291 | no |
| ↓ | 6 | 2.77 | 0.16 | 0.1291 | no |

* At the five per cent level of significance.

coefficient between the two prices exceeding 0.98 on a monthly basis. Daily data from January 1984 to September 1985 were used for the analysis. The daily Australian and U.S.A. prices are referred to as ASWD and AVD, respectively. Steps 1, 2 and 3, as previously outlined, were repeated for daily prices.

## Steps 1 and 2:

The pre-whitening filter for the daily ASW quote was an AR(1) model (that is, auto-regressive model of order 1) on the price's first difference. That is:

$$(1) \quad E_{ta} = \Delta ASWD_t - \phi_1 \Delta ASWD_{t-1}$$

$$Q = 8.61 \qquad \chi^2_{0.95}(11) = 19.68$$

where $\varphi_1 = 0.231656$; (5.0)

$E_{ta}$ = residual, and is distributed as $E_{ta} \sim N(0,\sigma^2_{E_a})$.

This model was then overfitted with an AR(2) parameter which was found to be insignificant, and so the model may be regarded as adequate.

The filter for the U.S.A. export quote was an AR2 model on the series' first difference, with no parameters on intermediate lags. That is:

$$(2)\ E_{tu} = -\Delta AVD_t + \phi_2\ \Delta AVD_{t-2}$$

$$Q = 9.56 \qquad \chi^2_{0.95}(11) = 19.68$$

where $\varphi_2 = 0.109965$; (-2.33)

$E_{tu}$ = residual, and is distributed as $E_{tu} \sim N(0, \sigma^2_{E_u})$.

This model was also overfitted with an AR(3) parameter which was found to be insignificant. Therefore this model was also judged to be adequate.

*Table 2: Cross-Correlations between Daily Filter Residuals*[a]

Pre-whitened input

$E_{tu} = -\Delta AVD_t + \phi_2\ \Delta AVD_{t-2}$ where $\phi_2 = -0.109965$

Pre-whitened output

$E_{ta} = ASWD_t - \phi_1 \Delta ASWD_{t-1}$ where $\phi_1 = 0.231656$

| | Number of lagged periods | Covariance | Correlation | Standard deviation | Cross-correlation significant* |
|---|---|---|---|---|---|
| | -6 | 0.032 | 0.04 | 0.0472 | no |
| | -5 | -0.029 | -0.04 | 0.0472 | no |
| $E_{tu}$ | -4 | -0.028 | -0.04 | 0.0472 | no |
| lags behind | -3 | 0.007 | 0.01 | 0.0472 | no |
| $E_{ta}$ | -2 | 0.018 | 0.03 | 0.0472 | no |
| | -1 | 0.028 | 0.04 | 0.0472 | no |
| ---------- | 0 | 0.140 | 0.19 | 0.0472 | yes |
| | 1 | 0.365 | 0.51 | 0.0472 | yes |
| $E_{ta}$ | 2 | 0.049 | 0.07 | 0.0472 | no |
| lags behind | 3 | 0.019 | -0.03 | 0.0472 | no |
| $E_{tu}$ | 4 | -0.043 | -0.06 | 0.0472 | no |
| | 5 | 0.055 | 0.08 | 0.0472 | no |
| | 6 | -0.039 | -0.05 | 0.0472 | no |

a Cross-correlations were taken into account within 25 trading days of the zero lag. No lags outside the range reported here were significant.

* At the five per cent level of significance.

## Step 3:

The cross-correlation between $E_{ta}$ and $E_{tu}$ is outlined in Table 2, and suggests that the "innovations" model (that is, the model between the residuals of the prewhitened daily price series) is of the form:

$$(3) \quad E_{ta} = B_1 E_{tu} + B_2 E_{tu-1} + U_t$$

$$D.W. = 2.34$$

where $B_1 = 0.113025$; $B_2 = 0.34738$ with $t$-ratios 4.0 and 12.3 respectively, using Ordinary Least Squares (OLS) regression techniques.

## Step 4: Specification of the transfer function model

At this point, the prewhitening filters established earlier are substituted into this innovations model to establish the structure of the transfer function model—that is, the forms of equations (1) and (2) are substituted into (3) to yield:

$$(4) \quad ASWD_t = d_1 ASWD_{t-1} + d_2 \Delta ASWD_{t-1} + d_3 \Delta AVD_t - d_4 \Delta AVD_{t-2} + d_5 \Delta AVD_{t-1} - d_6 \Delta AVD_{t-3} + U_t$$

where $d_1$ is constrained to 1 by definition and the other $d$ are estimated coefficients.

## Step 5: Identifying and estimating structure of the residual of the transfer function model

Equation (4) was estimated using ordinary least squares, and results from this estimation are shown in Table 3. The next step involves looking at the residual, $U_t$, to examine whether it follows any systematic pattern which can be explained by a univariate time series model. An AR(2) process of the following form was found:

$$(5) \quad U_t = C_2 U_{t-2} + v_t$$

where $v_t \sim N(0, \sigma^2_v)$; and $c_2 = -0.098$. $(-2.06)$

This model was overfitted with an AR(1) parameter (*i.e.* an autoregressive first-order parameter) which was found to be insignificant. Therefore the model was appropriate in explaining the residual's behaviour.

## Step 6: Estimating revised transfer function model

The structure of this univariate model on the residual of the original transfer function model is then substituted into equation (4) to arrive at the final form of the transfer function model which will be used for forecasting purposes:

$$(6) \quad ASWD_t = d_1 ASWD_{t-1} + d_2 \Delta ASWD_{t-1} + d_3 \Delta AVD_t - d_4 \Delta AVD_{t-2} + d_5 \Delta AVD_{t-1} - d_6 \Delta AVD_{t-3} + d_7 U_{t-2} + e_t$$

where $e_t \sim N(0, \sigma^2_e)$

This model was then re-estimated, with the results shown in Table 4.

## Step 7: Model evaluation

Following standard model evaluation procedures, the above model was used to generate out-of-sample forecasts of ASWD in order to compare its predictive ability with other time series models. The forecasts were generated over a ten-period time horizon, or two weeks. The basis for model evaluation was the root mean squared errors (RMSE) of the forecasts, since it is the RMSE which can show the relative performance between different forecasting models against actual values. Results of model evaluation are described in detail in section 4.

*Table 3: Results of Initial Transfer Function Model*

$$ASWD_t = d_1 ASWD_{t-1} + d_2 \Delta ASWD_{t-1} + d_3 \Delta AVD_t$$

$$- d_4 \Delta AVD_{t-2} + d_5 \Delta AVD_{t-1} - d_6 \Delta AVD_{t-3} + U_t$$

where $d_1$ is constrained to 1 by definition and the other d are estimated coefficients

SSR= 157.00 COND(X)= 1.96

| Coefficient | Value | t-statistic |
|---|---|---|
| $d_2$ | 0.030 | 0.634 |
| $d_3$ | 0.120 | 4.252 |
| $d_4$ | 0.371 | 12.923 |
| $d_5$ | 0.114 | 3.432 |
| $d_6$ | 0.090 | 3.132 |

Where SSR = Sum of squared residuals.

COND(X) = An indicator of multicollinearity. (If COND(X) < 30, then multicollinearity is not present).

## 4. Results

The basis for model evaluation, the RMSE, is defined as:

$$RMSE = (1/n \sum_{i=1}^{n} (P_i - A_i)^2)^{1/2}$$

where
$n$ = number of forecasting periods = 10
$P_i$ = predicted value at time i
$A_i$ = actual value at time i.

Univariate models were constructed of the forms AR(1), AR(2), AR (2) with time trend, and AR(1) on a first differenced series (*i.e.* an ARIMA (1, 1, 0) model). These models were then compared to the predictive power of the transfer function model. The RMSEs for these models, as well as the forecasts generated by the transfer function model, are presented in Table 5. The RMSE of the forecasts over the ten-period horizon for the transfer function model is less than that for any of the univariate models. Therefore under the criterion of RMSE used for the purpose of this analysis, the transfer function model is a better predictor of ASW prices than univariate time series models.

On a *daily* basis, therefore, and according to the Granger causality principles, it is implied that because the U.S.A. price can be used to improve on

*Table 4: Results of Final Transfer Function Model*

$$ASWD_t = d_1 ASWD_{t-1} + d_2 \Delta ASWD_{t-1} + d_3 \Delta AVD_t$$

$$- d_4 \Delta AVD_{t-2} + d_5 \Delta AVD_{t-1} - d_6 \Delta AVD_{t-3} + d_7 U_{t-2} + e_t$$

where $d_1$ is constrained to 1 by definition and the other d are estimated coefficients

SSR= 155.00 COND(X)= 1.95

| Coefficient | Value | t-statistic |
|---|---|---|
| $d_2$ | 0.033 | 0.681 |
| $d_3$ | 0.124 | 4.400 |
| $d_4$ | 0.373 | 13.040 |
| $d_5$ | 0.114 | 3.436 |
| $d_6$ | 0.090 | 3.144 |
| $d_7$ | -0.099 | -2.040 |

Where SSR = Sum of squared residuals.

COND(X) = An indicator of multicollinearity (if COND(X) < 30, then multicollinearity is not present).

forecasts made of Australian prices, then the U.S.A. price can be said to *cause* the ASW price. (However, it is conceded that the U.S.A. price is not the only causal factor in the determination of Australian wheat prices.)

The significance of the one-day lag embodied in the model suggests that the Australian price responds to movements in the U.S.A. export quote made the previous (trading) day. The instantaneous daily response in the model cannot strictly be used to infer direction of causality, because direction cannot be isolated from the correlation at the zero lag. However, given the relative size of the correlation coefficient at the one day lag of U.S.A. prices to Australian prices compared to the zero lag correlation coefficient (see Table 2), that is, 0.51 as compared with 0.19 respectively, it seems unlikely that the zero lag correlation would embody any significant feedback from Australian prices to U.S.A. prices.

The significant one-way causality detected implies that the risk of the differences in cash prices between Australian wheats and U.S.A. wheats (based on quality differentials) widening during the time a futures position is established and closed is likely to be small. Therefore, the procedure of trading ASW wheat on U.S.A. futures markets should not expose the AWB to any significant additional levels of risk, other than normal basis risk levels and additional exchange rate risk.

*Table 5: Daily Transfer Function Model Evaluation*

| Model | RMSE | Thiel's U2 |
|---|---|---|
| AR(1) | 0.746 | 0.989 |
| AR(2) | 0.761 | 0.894 |
| AR(2) with trend | 0.760 | 0.885 |
| AR(1) on first difference | 0.763 | 0.892 |
| Transfer function | 0.662 | 0.861 |

Forecasts Generated from Transfer Function Model

| Date* | Observation | Actual | Prediction |
|---|---|---|---|
| 24.9.85 | 451 | 131.0 | 129.98 |
| 25.9.85 | 452 | 132.0 | 131.11 |
| 26.9.85 | 453 | 132.0 | 132.74 |
| 27.9.85 | 454 | 132.0 | 132.59 |
| 30.9.85 | 455 | 132.5 | 132.30 |
| 1.10.85 | 456 | 132.5 | 133.02 |
| 2.10.85 | 457 | 132.5 | 132.50 |
| 3.10.85 | 458 | 131.0 | 132.10 |
| 4.10.85 | 459 | 130.0 | 130.18 |
| 7.10.85 | 460 | 130.0 | 129.69 |

* Trading days only.

## 5. Qualifications

There exist some features of the analysis described in this paper which suggest that caution should be exercised when interpreting the results reported in the preceding section.

First, the data series themselves may be less than perfect indicators of actual market prices. The ASW quote, for example, is a daily quote published by the Australian Wheat Board, and so does not necessarily reflect the actual prices at which sales for a particular day have been made. Nevertheless, some trade would be expected to take place at that "card" price, and so model results indicate a willingness by the Board to follow the U.S.A. price for food wheat. Actual prices for contracts of wheat sales made by the Board are confidential.

Second, the complete world wheat market has not been examined in this paper. Only Australia and the United States have been analysed, so that conclusions drawn from this analysis may not be indicative of the wheat market in general. Further analysis would be required in order to say anything definitive about the world market structure in general.

Third, only the market for food wheat has been analyzed in this research, and only two prices of that market have been incorporated. However, given that hard red winter wheat exports represent about 44 per cent of U.S.A. exports of wheat, and ASW wheat about 75 per cent of Australian exports, and the relatively high degree of substitutability between grades of wheat at the margin, it may be assumed

that movements in these prices are indicative of movements of other grades of food wheat.

## 6. Conclusion

Using time series techniques and Granger's causality principles, the hypothesis that Australia is a price follower on the world wheat export market could not be rejected. The analysis was applied to monthly data, although when no monthly lag structure could be detected (other than an instantaneous relationship), daily price series were examined to test for causality on a smaller time scale. The resulting model forecast the Australian wheat price more accurately than did univariate models, implying that causality from U.S.A. wheat prices to Australian wheat prices exists.

In other words, there exists a price leader-follower relationship in wheat prices, with the U.S.A. being the leader and Australia the follower. Whether this result may be used to infer duopolistic or oligopolistic market behaviour is a suggestion requiring further empirical analysis on the complete export market for wheat.

The empirical results presented in this paper have confirmed that Australia is a price follower on the world wheat market, and are also useful to those engaged in price forecasting. The results provide some illustration of the price linkages involved in the pricing of Australian wheat, on a competitive basis, against wheat produced in the U.S.A. The results will provide a basis for further research into wheat price modelling in that it has emphasized the importance of U.S.A. supply-demand conditions in determining Australian wheat prices.

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