Price Linkages in the International Wheat Market

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Abstract: *This paper brings time series techniques to bear on the relationships between the prices of the principal types of wheat traded internationally. In all, the relationships between eleven wheat prices (categorised by wheat quality, harvest date and port of despatch) are scrutinised to uncover the structure of the wheat market implicit in the behaviour its prices reveal. The statistical evidence supports the notion of a highly integrated market that is segmented according to wheat strength – the principal determinant of end-use. Three segments are identified: a market for 'strong' (bread-making) wheat, another for 'weak' (confectionary products-making) wheat and a third for medium strength wheat suitable for unleavened breads and noodles. Whilst informative, market integration - detected by cointegration among prices – is not altogether surprising, yet the presence of cointegration implies a causal structure, which is of more cogent interest. Among a number of complementary techniques, linkages are uncovered using an innovative concept of irreducible cointegration vectors (Davidson 1998, Barassi et al 2001) which provides new evidence on price linkages. Statistical evidence is robust and not test-dependent. Specifically, we find a dominant price leader in each sub-market. In terms of its pricing, the EU is found to play a passive role in the world market, confirming a widely held view.*

Key words: Wheat market, price linkages, irreducible cointegration vectors

Introduction

Wheat exports account for a substantial volume of trade in agricultural commodities and emanate from the five principal exporters (USA, Canada, EU, Australia and Argentina) that together account for 90% of the wheat traded (Antle and Smith 1999). Policy regimes play a significant role in the production and export shares of these major players and the impact of the Common Agricultural Policy of the European Union is a case in point. For example, during the 1980s the EU emerged as the second largest exporter of wheat, having previously been a net importer. However, wheat is far from the homogenous commodity it is typically believed to be. Variation according to location and numerous dimensions of quality may affect the pattern of trade and the end-uses to which the particular form of wheat may be put. Such differences demarcate markets and are likely to impact upon the linkages for what may often be imperfect substitutes.

It is commonly believed that the Law of One Price (LOP) holds for primary commodities that are traded in the international markets, once prices are adjusted for transactions costs (Baffes 1991; Goodwin 1992; Mohanty *et al* 1999). Therefore most analysts maintain the assumption of perfect and instantaneous arbitrage in their theoretical and empirical models. The LOP plays an important role in defining the extent of the market and measuring market integration (Stigler and Sherwin 1985). If a single price drives the prices of several spatially separate markets, it implies that these markets are integrated as a single market (Yang *et al* 2000).

The objective of this study is to examine the nature of the relationships between wheat prices of major exporters by wheat type and port location using time series methods. A new concept of irreducible cointegrating (IC) vectors (Davidson 1998) has been applied. The main idea of IC vectors is that without imposing any arbitrary identifying conditions on the cointegrated price series, one can learn about the structural relationship among the prices directly from data analysis. The structural nature of the price relationships between prices may be examined using the Extended Davidson Methodology (Barassi *et al* 2001) where IC vectors may be ranked according to the criterion of minimum variance to identify the structural relations.

Using these methods, we find that different classes of wheat can be divided into sub markets according to their end use and substitutability. A multivariate cointegration approach (Johansen 1988) is used to examine the price behaviour of wheats with similar end uses. Causal influences of one price on another within and across sub-markets can be considered using this framework. An understanding of the world wheat market using this framework would enable to answer questions as to how a large increase in the supply of a particular class of wheat can have an impact on the price of a different class of wheat. Further information regarding the dynamics of the wheat price transmission may be unfolded.

Section 2 describes the wheat classes used in this study, followed by an outline of the methodology in Section 3. Section 4 describes the methodological issues in detecting price linkages and Section 5 describes the data. Section 6 discusses the results of the empirical analysis followed by a conclusion in Section 7.

1. Wheat Characteristics

Many different varieties of wheat are produced commercially around the world although we confine our analysis to those of the major wheat exporting countries. Although a temperate product, wheat is grown in all hemispheres of the world and is thus planted and harvested at different times of the year. In the Northern Hemisphere, the harvest occurs in June to October, whereas in the Southern Hemisphere, it is November to January. Spring wheats are generally harvested after the winter varieties and tend to be of lower yields. Both winter and spring wheat's produce grain that is red, white or amber in colour.

One of the principal ways for classifying wheat is ‘hardness’ which is a milling characteristic that is usually determined by protein content[1]. ‘Hard’ wheats are characterised by a high protein content whereas softer varieties have a low protein content. Whereas the hardest varieties produce elastic dough suitable for the making of bread, those of medium hardness are used to make unleavened breads, Arabic and Indian-style flat breads and steamed breads. Soft wheat, with low protein content is milled into flour for cakes, cookies, pastries and crackers.

The end use of wheat depends more on its baking quality (dough strength) than on its milling quality. Wheats that yield flour which has the ability to produce bread of large loaf volume and good crumb texture generally have a high protein content and are called ‘strong’ whereas those yielding flour from which only a small loaf with coarse open crumb texture can be made, and which are usually characterised by low protein content are called ‘weak’. The flour from weak wheat is ideal for biscuits and cakes,

[1] Protein content per se is not the primary factor determining milling quality. Samples of English soft wheat varieties "Riband" or "Galahad" may have a high protein content and yet mill like a soft wheat (Kent and Evers 1994).

although unsuitable for bread making unless blended with a strong flour. Table 1 in the Appendix summarises the various classes of wheat.

Strong wheat's include No.1 Canadian Western Red Spring (CWRS) and Dark Northern Spring wheat from the U.S. The U.S. Hard Red Winter wheat, Argentinean Trigo Pan and Australian Standard White and Prime Hard fall under the category of medium strong wheat. The EU standard wheat along with Soft Red Winter wheat and Western White wheat from the U.S. are of the weak variety.

2. Econometric Methodology

In principle, the differences that exist between internationally traded wheats may be sufficient to divorce one market from another with the result that prices may evolve independently from one another. Alternatively, the wheats may be sufficiently differentiated to ensure that they have distinct behaviours but sufficiently substituable to ensure that their prices are tied together over the long term. When considering these long run relationships, it becomes necessary to consider the underlying properties of the processes that generate time series variables. That is, we must distinguish between stationary and non-stationary variables, since failure to do so can lead to a problem of ‘spurious regression’ (Granger and Newbold, 1974).

Accordingly, all of the price series used in this study are tested for their order of integration as a prelude to the examination of the relationships that exist between the price series. In the analysis that follows, we bring cointegration techniques (Johansen (1988) and Johansen and Juselieus (1990)) to bear on the issue of market integration in the world wheat market. For n price series that are I(1), if there are r cointegrating relationships, then there are $n-r$ common trends (Stock and Watson 1988). A standard VAR with lag length equal to k can be written as:

$$X_t = A_1 X_{t-1} + A_2 X_{t-2} + ... + A_k X_{t-k} + \varepsilon_t \qquad \varepsilon_t \sim \text{n.i.d.}(0, \Sigma) \qquad (1)$$

where X_t is a $p \times 1$ vector of prices, A_i is a matrix of coefficients to be estimated using the data and ε_t are independently and identically distributed white noise error terms. The VAR may be formulated as an error correction model

$$\Delta X_t = \Gamma_1 \Delta X_{t-1} + ... + \Gamma_{k-1} \Delta X_{t-k+1} + \Pi X_{t-k} + \varepsilon_t \qquad (2)$$

where Γ_i captures the dynamic effects and Π contains the long run information in the system. The number of cointegrating vectors is determined by the rank of Π. When Π is of reduced rank $(r < n)$ there exist r linear combinations of the n variables in X_t that are I(0) and Π may be expressed as the outer product of two $r \times n$ matrices, i.e. $\Pi = \alpha\beta'$, where β' is a matrix of the cointegrating vectors and α is a matrix of the error correction coefficients.

Perfect market integration implies that any single price should be representative of the entire group of prices, or alternatively, only a single stochastic trend should exist among the prices. Thus for a group of n prices, there should be $n-1$ cointegrating vectors to imply perfect market integration (Goodwin 1992). If all the prices are cointegrated it follows that there is one common stochastic trend in the system. In other words, if there are n price series in the system, finding $n-1$ cointegrating vectors implies that all the prices are cointegrated in pairs. If we find that there is one common stochastic trend then we can conclude that there is one common market for all types of wheat. In other words all wheat types are substitutes for one another to some degree.

Alternatively, if we use a multivariate test with n variables and obtain $n-1$ cointegrating vectors, we can impose one normalisation restriction and $n-2$ zero restrictions on each cointegration vector exactly identifying the system. In this case we have:

$$\beta = \begin{bmatrix} 1 & 1 & 1\ldots & 1 \\ -1 & 0 & 0\ldots & 0 \\ 0 & -1 & 0 & 0 \\ \vdots & \vdots & \vdots\ldots & \vdots \\ 0 & 0 & 0\ldots & -1 \end{bmatrix} \qquad (3)$$

An economic interpretation is that there is some factor (substitution or arbitrage) that binds the prices together over time.

The speed of adjustment towards the long run equilibrium relationship is given by the matrix of loading α. The error correction coefficients can be used in exogeneity inference. Johansen (1992) develops a test based on the notion that variables that do not respond to 'disequilibrium' in the system of which they are a part may be considered weakly exogenous to that system. Johansen's test of weak exogeneity is thus a test of the statistical significance of the error correction coefficients that comprise α. An insignificant loading coefficient thus indicates the corresponding weakly exogenous price.

A novel concept of irreducible cointegration is employed in this study. A set of I(1) variables will be called *irreducibly cointegrated* (IC) if they are cointegrated, but dropping any of the variables leaves a set that is not cointegrated (Davidson 1998). In other words, IC vectors are defined as a subset of a cointegrating vector that does not have any cointegrating subsets. Recently a lot of interest has been shown regarding the identification problem of long-run relationships in a linearly cointegrated model with I(1) variables (Johansen 1995). Johansen's paper focuses on the problem of imposing and testing restrictions on the space of the cointegrating vectors in the context of a vector error correction model (VECM), so as to determine the long-run structural relations.[2] These parameters and relations containing them are structural cointegrating vectors. The term 'structural' is used to mean simply parameters/relations which have direct economic interpretation and may therefore satisfy restrictions based on economic theory. It is standard practice to orthonormalise the matrix of long-run coefficients first, and then test for the identification of the columns. The problem with this approach is that it involves dealing with the presence of potentially redundant variables that interact with the other cointegrated series that drive the cointegrating regression coefficients towards some other element of the cointegrating space (Barassi *et al* 2001). To eliminate the redundant or non-cointegrated series, cointegration tests are performed on each pair of series, so that the number of cointegrating vectors obtained are by definition irreducible.

IC vectors can be structural or solved. Structural IC vectors have already been defined. Solved vectors are linear combinations of structural vectors. The argument put forward (Barassi *et al* 2001) is that if there are N variables and r structural IC vectors where $(r \leq N-1)$, then there may also exist k IC vectors which are simply subsets of the r structural ones. k is at most $\frac{1}{2}[(r-1)^2 - (r-1)]$. At most there can be $r+k$ cointegrating vectors. Solved cointegrating relations would display a higher variance

[2] The term 'structural' is used to mean simply parameters/relations which have direct economic interpretation and may therefore satisfy restrictions based on economic theory. If a structural

than solved cointegrating relations.[3] While constructing a cointegrating relationship with the help of economic theory it is possible that a cointegrating vector that contains redundant elements can be of no interest to us. The theory could be wrong; in which case this is just an arbitrary element of the cointegrating space. If the theory is correct, the relation is revealed to be under-identified and the estimate is inconsistent, representing a hybrid of different structural equations just as in the conventional analysis of simultaneity (Davidson 1998). Irreducibility is therefore an important diagnostic property of a cointegrating regression and pairwise cointegration is by definition, irreducible Barassi *et al* (2001)

4. Methodological Issues in Detecting Price Linkages

The objective of this section is to illustrate the advantages of the multivariate and bivariate cointegration framework to study market integration. For the world wheat market to be integrated, all wheat, irrespective of class, country of origin or region should share the same long run information. In a cointegration framework, the

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cointegrating relation is identified by the rank condition, then the cointegrating vector is irreducible (*see* Davidson 1994).

[3] It has already been mentioned that if an IC relation is found interest focuses on the problem of distinguishing between structural and solved forms. It is possible in the context of simultaneous cointegrating relations to discover structural economic relationships directly from a data analysis, without the use of any theory. To take a very simple example from Davidson (1998) we consider a system which consists of four I(1) variables, x_t, y_t, z_t and w_t. If the pairs (x_t, y_t) and (z_t, w_t) are found to be cointegrated [but not the pairs (x_t, z_t) or (y_t, w_t)] then these two cointegrating relations which are necessarily irreducible will also be necessarily structural. If on the other hand the pairs (x_t, y_t) and (x_t, z_t) are cointegrated, it necessarily follows that the pair (y_t, z_t) is also cointegrated. The cointegrating rank of these three variables is 2, and one of these three IC relations is a solved vector; but it is not possible to know which one without a prior theory. Barassi *et al* (2001) detect which of these cointegrating relations are solved and which ones are structural on the basis of the magnitude of the variance of these cointegrating relations. Let the error terms in our example of (x_t, y_t) and (x_t, z_t) be ε_1 and ε_2 respectively and distributed independently as $N(0, \sigma_1^2)$ and $N(0, \sigma_2^2)$. If the (y_t, z_t) pair is a solved relation of the (x_t, y_t) and (x_t, z_t) pairs, then the residual from this relationship would be a function of ε_1 and ε_2 and would be distributed as

condition is equivalent to requiring the existence of one common trend to all series of prices. Thus, given a set of price series, the Johansen (1988) method would be appropriate to serach for a single common trend. The Johansen (1988) test is based on a VAR model. VARs also capture statistically the dynamic interactions of a set of variables. Hence VARs are useful in identifying some key attributes of the data.

In a market of n prices, the finding of a single common trend implies that there must be $n-1$ cointegrating vectors (Stock and Watson 1988). The Johansen and Juselius procedure (1990) allows hypothesis testing on these cointegrating vectors. In the case of testing the LOP, it is the parameters in the cointegration vectors that are of most interest. As the cointegration vectors are identified only upto a non-singular transformation, any set of restrictions that make the columns of the cointegrating vectors add up to zero will do (Johansen and Juselius 1992). A natural procedure is to normalise upon one price. This makes the cointegration vectors $(1 \quad -1)$ with respect to this price. More specifically, in the bivariate case there are two prices in the price vector. Provided the price vector is cointegrated the number of cointegrating vectors is equal to 1. Of particular interest is the LOP which can be tested imposing the restriction $(1 \quad -1)$. Hence in the market integration context, multivariate and bivariate tests can in principle provide the same information (Asche *et al* 1999).

However, the two approaches have different statistical merits and demerits. If there are a large number of variables n then using the multivariate approach, one is exposed to what Hendry labels the 'curse of dimensionality' in dynamic models (Hendry 1995

$N(0,\sigma_1^2+\sigma_2^2)$. The cointegrating relations (x_t, y_t) and (x_t, z_t) that display lower variance should be the structural ones; the remaining (y_t, z_t) pair being just solved a cointegrating relation.

p.313). Under this problem, the number of parameters, p, grows as the square of the number of variables n, times the maximum lag l, so that $p = n^2 l$. Hence the more variables are included in the system, the more quickly the available degrees of freedom will dissipate. Another problem with the Johansen (1988) and Johansen and Juselius (1990) approach for a large number of variables, is that it involves dealing with potentially redundant variables that interact with the other cointegrated series driving the cointegrating regression coefficients towards some other element in the cointegrating space. To eliminate the redundant or non-cointegrated series, a new method of irreducible cointegrating vectors is used (Davidson 1998). In this method the cointegration tests are made on pairs of prices so that the series of prices that are not cointegrated are dropped from the relation. These cointegrating relations are termed irreducible (IC) as they do not have any subset of cointegrated variables.

In a bivariate analysis, one is less exposed to this problem. However, a certain problem lies with the bivariate analysis as well. It would be difficult to determine which of the locations belong to the same market. Given n prices there would be at most $n(n-1)/2$ pairwise cointegrating relations, of which $n-1$ are relevant. The exercise would be unnecessarily complicated and lead to inconclusive results (Gonzalez-Rivera and Helfand 2001). However the bivariate tests can be used to aid the specification of the multivariate tests. The Davidson (1998) methodology has been extended by ranking the cointegrating relations according to the criterion of minimum variance to distinguish the $n-1$ structural cointegrating vectors from the $\frac{n(n-1)}{2}-(n-1)$ solved relations (Barassi *et al* 2001). This concept allows the possibility of detecting potential sub-markets. In this paper, the estimation will be based using both bivariate and multivariate methods of cointegration.

5. Data

The data used for the analysis are monthly average export price quotations (FOB) prices from July 1980 to December 1998. They include, Argentinean Trigo Pan Wheat (ATP); Australian Soft Wheat (ASW), Canadian Western Red Spring wheat No.1 from St. Lawrence port (C1L) and Pacific ports (C1P), US Dark Northern Spring wheat from the Gulf port (USDG) and Pacific ports (USDP), US Hard Red Winter wheat from the Gulf ports (USHG), US Soft Red Winter wheat from the Gulf ports (USSG), US Western White wheat from the Pacific Ports (USWP) and EU soft winter (EUSW) wheat. The data source was the *World Grain Statistics*, published by the International Grains Council. All prices are quoted in US dollars per tonne. The subsequent analysis of the data is carried out on the logarithm of prices. The 11 wheat prices are illustrated in Figure 1 in the Appendix

6. Empirical Analysis

(a) Unit Root tests

The price series were initially tested for their order of integration. The Augmented Dickey Fuller (ADF) tests for each of the price series expressed in log-levels and in growth form (first difference log levels) were used. The hypothesis tests are based on the comparison of calculated statistics with the McKinnon (1991) critical values. The results in Table 2 (see Appendix) indicate that unit roots cannot be rejected for the price series in levels at the 5% significance level yet are rejected for all price series in growth form. We conclude that the log level of each price series is integrated of order one , *i.e*. I(1).

Each of the wheat export prices were checked for cointegration in pairs to see if any of the pairings form a long-run stationary relationship. Cointegration in pairs was tested using the Johansen's maximum likelihood procedure. The number of lags was determined using the Schwartz Bayesian Criterion. The rank of Π equals to the number of cointegrating vectors which is tested by the trace statistics. The results of the cointegration tests using Johansens maximum likelihood method are summarised in the Table 3 in the Appendix.

The results show that most of the prices cointegrate in pairs indicating that the prices of wheat on the world market are linked together through arbitrage and substitution. We find that the APH wheat does not cointegrate with any of the other wheats. The Australian Standard White (ASW) does not cointegrate with the U.S Western White (USWP) and the Soft Red Winter (USSG) wheats. The rest of the wheat prices are characterised by the same underlying trend. Given that the long run trend is statistically distinct, it may be concluded that both the Australian Standard White and Prime Hard wheat behave quite differently from other wheats in the sample. However, the failure to find cointegration between two price series does not necessarily imply that the prices are independent, since markets may be linked by a third price which might be the price of a weak substitute.

For those pairs that are found to be cointegrated it follows that those prices follow a common stochastic trend. Hence it is expected that if there are n prices in the system and all n prices contain the same common trend, then it is expected that there are $n-1$ cointegrating vectors in the system. A problem that arises from pairwise cointegration is which pairs to choose. For instance, n prices can be organised into $n(n-1)/2$ pairs. Out of these $n(n-1)/2$ pairs, only $n-1$ cointegrating vectors will be relevant as they would denote the structural relations and the rest will be solved relations. If all the pairs of prices are not chosen, then different conclusions may emerge with different subsets of pairs. Hence, the choice of pairs might make a lot of difference to the results. The pairwise cointegrating relationships may be ranked according to the criterion of minimum variance (Barassi *et al* 2001) to distinguish the structural relationships from solved ones. Table 4 in the Appendix presents the standard deviations of the cointegrating vectors.

Two interesting implications arise from the results. First, the variance associated with the cointegrating vectors are minimum in the case of the hard wheats that mill flour classified as 'strong' and the demand for these wheats are for the same end uses. Similarly, the low variance associated with the weak wheat price pairs also show that the price relationships are characterised by the end uses of wheat. Second, the variance associated with the wheat prices paired with medium hard wheat are relatively high implying that the relations might be solved and hence these wheats may indirectly affect the wheat prices of other countries by the price of a third wheat which might be a close substitute. Overall, we might suggest that the wheat market can be classified according to end use of wheat.

This finding supports the research results of Veeman (1987), Wilson (1989) and Larue (1991). They suggest wheat should be differentiated by end use in econometric modelling. A major implication of these studies is that the econometric models of wheat prices that assume product homogeneity, generate estimates with no clear interpretation of market integration. Classes of wheat have genetic differences that make them more or less suitable for particular end uses. Quality differences that exist in these individual wheats could influence international price linkages if these wheat types are imperfect substitutes for one another. Past studies have ignored this issue and have assumed that even in the light of quality differences, individual wheat types are reasonably close substitutes in consumption.

In the remaining part of this section we analyse the price relationships in the international wheat market to test the LOP and to evaluate the possibility of product aggregation for different classes of wheat. Under this framework, econometric evidence is presented about the potential roles of major wheat exporting countries as price leaders or followers. To facilitate this analysis, the wheat prices are grouped according to similar end uses as (a) strong wheat, (b) medium-strong wheat and (c) weak wheat. A multivariate cointegration framework is utilised for the analysis. Analyses are made to (i) determine whether there exists a single market for the different wheat classes sub-divided into markets according to end-use, (ii) test for price leadership within and across these sub-markets and (iii) examine the short-run dynamics within and across these separate sub-markets.

(b) Cointegration Results

We use the multivariate analysis using Johansen's Maximum Likelihood method of testing for the presence of multiple cointegrating vectors in the three sub-markets grouped according to similar end uses. The results of the test are given in Table 5 in the Appendix.

The multivariate cointegration test finds three cointegration vectors for the strong wheat sub-market and thus one common trend in the system. We can therefore conclude that there is one market for all strong wheat. In other words, all strong-wheat types considered in the above analysis can be classified as close substitutes for one another and hence there exists a long-run relationship among the wheat prices. When finding 3 cointegrating vectors it follows that all prices are pairwise cointegrated. If all pairs are found to be cointegrated, all prices contain the same stochastic trend - an equivalent approach to test for market integration. A test for the Law of One Price (LOP) was carried out using the restriction given by (3). The LR test statistic of identifying restrictions on the cointegrating vector gave a value of $\chi^2(3) = 4.36[0.22]$, which does not reject the null hypothesis that the LOP holds.

In the medium strong wheat market, the multivariate cointegration test finds 1 cointegration vector and thus three common trends in the system at the 5% significance level indicating quite strong interdependencies among the prices series. One implication that arises from the results is the lower substitutability between the wheat prices in the medium strong wheat market in comparison to the strong wheat markets. A possible interpretation could be that a price shock in the U.S Hard Red Winter wheat prices (say) will affect the prices of the ASW wheat indirectly through the affect from ATP wheat prices. Having established the presence of a single cointegrating vector, the Johansen and Juselius procedure (1990) allows us to test for the significance of the price series in this long-run relationship. This is done by implementing null restrictions on the long-run parameters in β, and employing likelihood ratio exclusion tests which are, asymptotically, chi-square distributed with one degree of freedom. At the 5% significance level, the ATP wheat $\chi^2(1) = 11.6[0.00]$, ASW wheat $\chi^2(1) = 5.67[0.01]$ and the USHG wheat $\chi^2(1) = 17.47[0.00]$ could be rejected. However, the exclusion test cannot be rejected at the 5% significance level for the APH wheat $\chi^2(1) = 3.08[0.08]$. The test statistics showed that the null hypothesis of exclusion can be rejected in the case of all the wheat prices at the 10% significance level. These results provide support to the hypothesis that all four wheat prices belong to the same market. The rejection of the exclusion test in the cointegration analysis shows that weak substitutes may be important to consider when delineating markets.

Similarly, for soft wheat, we find 2 cointegration vectors and thus one common trend in the system at the 5% significance level. We can therefore conclude that there is one market for all soft wheat. In other words, all weak wheat's considered in the analysis are close substitutes for one another to some degree. A test for the LOP was carried out using restriction (3). The LR test statistic of identifying restrictions on the cointegrating vector gave a value of $\chi^2(2) = 7.88[0.02]$, which is rejected at the 5% significance level but can be accepted at the 1% level. For the weak wheat market though we find evidence of a single market, the LOP does not hold.

(c) Weak Exogeneity Results

The factor loading matrix, α, contains information about the dynamic adjustments of the long-run relationships. Given that there is one common trend in both the strong and weak wheat markets it might be of interest if we investigate to what extent this might be caused by the price of a particular class of wheat. This amounts to test for each of the prices for weak exogeneity, and can be tested on the α matrix. In the case of the strong wheat market, we found three cointegration vectors. The null hypothesis of weak exogeneity is $H_0 : \alpha_{i1} = \alpha_{i2} = \alpha_{i3} = 0$ for all *i*, where *i* is respectively C1L, C1P, USDG and USDP. The tests are distributed as χ^2 with 3 degrees of freedom. The results for the hard and soft wheat markets are given in Table 6 in the Appendix.

The null hypothesis of weak exogeneity are clearly rejected for all wheat classes in the strong wheat market except for the C1P. Hence it seems that in the long-run, the price of C1P determines the price in the strong wheat market. In the case of the medium-strong wheat market the null hypothesis of weak exogeneity cannot be rejected separately in the case of the ATP and ASW prices. The null hypothesis that both the prices are weakly exogenous gave an LR test statistic $\chi^2(2) = 4.79[0.09]$ that cannot be rejected at the 5% significance level, though at the 10% level the null can be rejected. These results indicate that the ATP prices might be driving the other prices in the medium-strong wheat market and additional weak evidence that both ATP along with ASW prices might be evolving independently in this sub-market. Similarly, in the case of the weak wheat market, it was found that we could not reject the null hypothesis that USWP wheat is weakly exogenous. Thus it might be the case that the USWP wheat drives the price of all the wheat's in the weak wheat market.

(d) Modelling the Short Run

Having obtained the long run cointegrating relations using the Johansen approach and tested for weak exogeneity, we can obtain further information about the short-run dynamics of the prices by modelling a conditional PVECM. The results are reported in Table 7 in the Appendix.

In the strong wheat market, the weakly exogenous term C1P is in bold. The impact of current changes in the C1P price are fairly high around 0.8. This implies around 80% of changes in prices are incorporated in the C1L, USDG and USDP prices within a month. The error correction coefficients indicate that the speed of adjustment to equilibrium is slow but significant. At the 10% significance level, one period lagged U.S. Dark Northern Spring wheat prices from the Gulf affect the Canadian St Lawrence prices and own prices but do not affect the Dark Northern Spring prices from the Pacific port. The Dark Northern Spring wheat prices are affected only by its own one-period lagged changes. The diagnostic tests, at the 5% significance level, reveal that there is no evidence of serial correlation in the residuals but there is evidence in squared residuals in the case of U.S. Dark Northern Spring wheat from both the Gulf and Pacific ports. Test for normality fails. For the medium-strong wheat market, the weakly exogenous price, ATP (given in bold), indicates that the impact of current changes on its own price are fairly low in comparison to the strong wheat market. Around 20% of changes in prices are incorporated in the USHG and APH prices and 28% in case of the ASW price. None of the prices are affected by their own one period lagged prices except for the APH price. One period lagged USHG prices affect ASW whereas current USHG prices are affected by one period lagged ASW and APH prices. Diagnostic tests reveal that there is no evidence of serial correlation and ARCH effects at the 5% significance level. However, the test for normality fails. In comparison with the strong wheat markets the speed of adjustment coefficients in the weak wheat market are slightly higher and significant in two cases. The weakly exogenous term USWP is in bold. The impact of current changes in the USWP price are fairly high i.e. 0.9 in the case of the USSG short run equation and 0.57 in the case of the EUSW. This implies around 90% of changes in prices are incorporated in the USSG price and 57% in case of the EU price. One period lagged USWP and EUSW prices affect the current USSG price, whereas the EUSW price is affected by one period lagged USSG and EUSW prices. The diagnostic tests reveal that the model passes the test for autocorrelation in residuals and squared residuals. Tests for normality fail at the 5% significance level.

7. Conclusion

An important aspect of study in this paper has been the study of price linkages including wheat prices differentiated by country of origin and class. The analysis revealed that almost all prices cointegrate in pairs, indicating that the prices of wheat on the international market are linked together either through substitution or arbitrage. The long run relationships that are found to exist between wheat prices are expected, because they are linked through derived demand suggesting that end use of wheat is important in determining price linkages. A novel method of irreducible cointegrating vectors lends some support to the perception that the wheat market should be classified according to end use of wheat. The classification is that the wheat market can be divided into three sub-markets: strong, medium strong and weak wheats where each different sub-market for wheat has different end uses. The method of irreducible cointegrating vectors show some evidence that strong wheats have structural relations and medium strong wheats have solved relations. This suggests that a distinct market exists for strong wheat. However, apart from the US Hard Red Winter (USHG) no separate market is likely to exist for the wheats that mill ‘medium strong’ flour. This might be due to the fact that there is a considerable variation in the protein levels of these wheats and hence are not perfect substitutes or homogenous from a technical perspective. Little support is found for the weak wheat sub-market.

The analysis continues by examining the wheat sub-markets according to end use. This classification follows from the results in Table 1. A separate market was found to exist in the case of strong-wheats. This result is not surprising as the wheats included in this sub-market are not only used in the production of high volume pan breads. Interestingly the competition between U.S. and Canada has been in the strong wheat market given that the wheats are close substitutes. The finding that the C1P is a price leader is consistent with the view that the imports from Canada reflect not just the marketing strategy from the 'single desk' seller, but the higher quality wheat that it exports. In the case of the medium-strong wheats there was no evidence of a single market but a robust cointegrating relationship implying the wheat prices are bound together by common trends or a long-term equilibrium relationship. Hence, it seems that even though the wheats can be grouped according to similar end uses, there still seems to be differences in end-use or quality of wheat. In the case of the weak wheats, the empirical evidence suggests that a single market seems to exist. The C1P was found to be weakly exogenous in the strong-wheat market and the USWP wheat in the weak-wheat market. This suggests that these wheat's are unaffected by price changes in other wheat's belonging to the same market. Among the medium strong wheats, the ATP wheat was found to be weakly exogenous. This implies that these wheat prices may be price leaders of other wheats which belong to the same wheat sub-market. In the strong wheat market this result is consistent with the fact that the Canadian wheat is superior in quality than the U.S. wheat and the share of the Pacific port has been increasing and hence the tendency for the price of the Canadian wheat to 'lead' the prices of the other wheats in the strong wheat sub-market. The speed of adjustment in response to a disequilibrium is relatively the same within and across all the sub-markets and is found to be slow but significant. There is also evidence of very little deviation in the strong and weak wheat markets in the short run. This can be contrasted with the medium strong wheat market where there is substantial deviation in the short run.

Broader implications can be drawn from the empirical results. The gap between prices of high and low quality wheat can have a direct response to policy. This response can be are larger when the qualities of wheat are more substitutable. As the magnitude of quality response to a policy increases, the errors in the estimates of price, quantity and welfare effects of the policy caused by using the model of a homogenous commodity increase. Agricultural commodity markets are becoming more differentiated and segmented.

For commodities such as soyabeans, pork, beef, tea and coffee there are different quality grades that may lead to form different sub-markets. Since the wheat market is characterised by product differentiation, further research may be carried out to investigate whether the potential exists for an exporter to exert market power through price discrimination.

References

Antle, J.M. and V.H. Smith (1999) The Economics of World Wheat Markets, CABI.

Asche, F., H. Bremnes, C.R. Wessells (1999) “Product Aggregation, Market Integration and Relationships Between Prices: An Application to the World Salmon Markets” *American Journal of Agricultural Economics* (81) pp 568 – 581.

Baffes, J. (1991) “Some Further Evidence on the Law of One Price: The Law of One Price Still Holds” *American Journal of Agricultural Economics* (73) pp 1264 – 1273.

Barassi, M.R., G.M. Caporale, S.G. Hall (2001) "Irreducibility and Structural Relations: An Application to the G - 7 Long Term Interest Rates" *International Journal of Finance and Economics* (6) No. 2, pp 127 - 138.

Davidson, J. (1994) "Identifying Cointegrating Regressions by the Rank Condition" *Oxford Bulletin of Economics and Statistics* 56 (1) , pp 103 - 108.

Davidson, J. (1998) "Structural Relations, Cointegration and Identification: Some Simple Results and their Application" *Journal of Econometrics* 87, pp 87 - 113.

Dolado, J.J., H. Lutkepohl (1996) “Making Wald Tests Work for Cointegrated Systems” *Econometric Reviews* (15) 4; pp 369 – 386.

Engle, R.F. and C.W.J. Granger (1987) "Cointegration and Error Correction: Representation, Estimation and Testing" *Econometrica* (19) pp 40 – 47.

Gonzalez-Rivera, G. and S. Helfand "The Extent, pattern, and Degree of Market Integration: A Multivariate Approach for the Brazilian Rice Market" forthcoming in the *American Journal of Agricultural Economics*.

Goodwin, B. (1992) Multivariate Cointegration Tests and the Law of One Price in International Wheat Markets. *Review of Agricultural Economics*: (14) pp 117 - 124.

Granger, C.W.J. (1969) "Investigating Causal Relations by Econometric Models and Cross-Spectral Methods" *Econometrica* (37) pp 424 – 438

Granger, C.W.J. and P. Newbold (1974) "Spurious Regressions in Econometrics" *Journal of Econometrics.* (2): 111-120.

Harris, R.I.D. (1995) Cointegration Analysis in Econometric Modelling. Prentice Hall.

Hendry, D.F. (1995) Dynamic Econometrics. Oxford University Press.

Johansen, S. (1988) "Statistical Analysis of Cointegrating Vectors" *Journal of Economic Dynamics and Control* (12) pp 231 - 254.

Johansen, S. and K. Juselius (1990) "Maximum Likelihood estimation and Inference on Cointegration with Application to the Demand for Money" *Oxford Bulletin of Economics and Statistics* (52) pp 169 – 209.

Johansen, S. (1992) "Testing Weak Exogeneity and the Order of Cointegration in UK Money Demand" *Journal of Policy Modelling* (14) pp 313 - 344.

Johansen, S. (1995) "Identifying Restrictions of Linear Equations with Applications to Simultaneous Equations and Cointegration" *Journal of Econometrics* 69, pp 111 - 132.

Kent, N.L. and A.D. Evers (1994) Kent's Technology of Cereals. 4th Edition, Oxford.

Larue, B. (1991) Is wheat a Homogenous Product? *Canadian Journal of Agricultural Economics*. 39(1) pp 103 - 117.

Lutkepohl, H., H. Reimers (1992) "Impulse Response Analysis of Cointegrated Systems" *Journal of Economic Dynamics and Control*. (16) pp 53 - 78.

Mohanty, S., Meyers and D.B. Smith (1999) A Re-examination of Price Dynamics in the International Wheat Market. *Canadian Journal of Agricultural Economics*. (47) pp 27 – 29.

Osterwald-Lenum, M. (1992) "A Note With Quantiles of the Asymptotic Distribution of the ML Cointegration Rank Test Statistics" *Oxford Bulletin of Economics and Statistics* (54) pp 461 - 472.

Stigler, G.J. and R.A. Sherwin (1985) “The Extent of the Market” *Journal of Law and Economics* (28) pp 555 – 586.

Stock, J.H., Watson, M.H. (1988) Testing for Common Trends. *Journal of American Statistical Association*. (83): 1097-1107.

USDA (1999) Grain: World Markets and Trade Economics Research Service.

Veeman, M. (1987) Hedonic Price Functions for Wheat in the World Market: Implications for the Canadian Wheat Export Strategy. *Canadian Journal of Agricultural Economics*: (35) 535-552.

Wilson, W.W. (1989) Differentiation and Implicit Prices in Export Wheat Markets. *Western Journal of Agricultural Economics*: 14(1) 67-77.

Yang, J., D.A. Bessler and D.J. Leatham (2000) "The Law of One Price: Developed and Developing Country Market Integration" *Journal of Agricultural and Applied Economics* (32) 3 pp 429 - 440.

Appendix

Table 1. Classes of wheat

Types of wheat	Milling characteristics	Baking characteristics	Products	Consumers
Argentinean Trigo Pan	Semi-hard (Protein 10%)	Medium strong	Bread, rolls	FSU, Bolivia China, Peru, Iran.
Australian Prime Hard	Hard (Protein 13%)	Medium strong	Oriental noodles	Far East
Australian Standard White	Medium Hard (Protein 10%)	Medium strong	Flat Bread, Noodles	Middle and Far East
Canadian Western Red Spring wheat	Hard (Protein 12.5%)	Strong	Bread	Latin America and China
US Dark Northern Spring	Hard (Protein 12.5%)	Strong	Bread	Central America, Philippines Japan, FSU
US Hard Red winter	Hard (Protein 12.5%)	Medium strong	Bread, rolls, all purpose flour	Morocco, China, Japan, FSU, Poland
US Soft Red Winter	Soft (Protein 10%)	Weak	Biscuits, crackers, cakes and pastries	China, Egypt and Morocco.
US Western White	Soft (Protein 9%)	Weak	Biscuits, crackers cakes and pastries	Far East Asian region
European Standard	Soft (Protein 10%)	Weak	Steam bread, flat bread and oriental noodles	FSU, North and Sub- Saharan Africa

Source: Kent, N. and A. Evers (1994); Kents Technology of Cereals.
Morris, C. and S. Rose (1996); Wheat in Henry and Kettlewell (ed) Cereal Grain Quality
Haley, S.(1995). ERS Report, USDA Technical Bulletin No. 1838

Table 2. ADF tests for each price series

Prices	Levels (C+T)	Differences (C)	Levels (C)	Differences (NC)
LATP	-2.487	-3.595**	-2.384	-3.611**
LASW	-2.892	-3.794**	-2.393	-3.807**
LAPH	-2.89	-4.81**	-2.37	-4.82**
LC1L	-3.18	-4.244**	-2.18	-4.248**
LC1P	-3.177	-4.629**	-2.77	-4.639**
LUSDG	-2.525	-4.411**	-2.466	-4.418**
LUSHG	-2.621	-3.16*	-2.51	-3.162**
LUSSG	-2.80	-2.877*	-2.85	-2.872**
LUSDP	-2.512	-3.928**	-2.377	-3.928**
LUSWP	-2.403	-4.054**	-2.324	-4.048**
LEUSW	-2.153	-4.129**	-2.024	-4.137**

The critical value calculated from McKinnon Tables for levels with constant and trend at 5% significance level is 3.45 and at 1% significance level is -4.002. *Indicates rejection of the null hypothesis of non-stationarity at the 5% level and ** for the rejection at the 1% level. For differences with constant and without trend the 5% significance level is -2.89 and at 1% is -3.45.

Table 3. Results of the Pairwise Cointegration tests using the Johansens Method

	ATP	ASW	APH	C1L	C1P	USDG	USHG	USSG	USDP	USWP	EUSW
ATP		21.2*	15.86	25.9*	32.4*	30.2*	34.6*	25.7*	20*	24.0*	25.7*
ASW			17.23	15.9	18.4*	18.6*	20.4*	17.0	19.0*	15.4	22.9*
APH				16.68	18.5*	17.72	13.7	16.75	15.25	13.18	18.2*
C1L					30.1*	24.2*	23.0*	28.0*	33.8*	24.5*	27.3*
C1P						28.9*	25.1*	26.1*	34.3*	23.2*	28.6*
USDG							24.8*	24.5*	38.3*	22.7*	27.9*
USHG								32.3*	18.4*	36.2*	36.3*
USSG:									20.6*	32.9*	28.4*
USDP:										18.5*	23.1*
USWP											30.2*

Each cell contains the value is the trace statistic. *Indicates rejection of null hypothesis of no cointegration at the 10% significance level.

Table 4. Standard Deviations of the Pairwise Cointegration vectors

	ATP	ASW	APH	C1L	C1P	USDG	USHG	USSG	USDP	USWP	EUSW
ATP		0.143		0.095	0.080	0.0853	0.0775	0.102	0.0887	0.0931	0.1146
ASW				0.161	0.106	0.086	0.067		0.098		0.123
APH					0.072						0.189
C1L					0.050	0.0537	0.0856	0.1005	0.0484	0.0936	0.101
C1P						0.0524	0.0739	0.0885	0.0468	0.0827	0.997
USDG							0.0771	0.1017	0.0489	0.0986	0.0936
USHG								0.094	0.0869	0.0697	0.0677
USSG:									0.1097	0.0715	0.085
USDP:										0.1002	0.1072
USWP											0.0822

Table 5. Results of Johansen's Maximum Likelihood test for Cointegration

	Strong Wheat		Med-strong wheat		Weak Wheat	
H_0:Rank = p	Max	Trace	Max	Trace	Max	Trace
$p = 0$	38.62**	97.77**	36.7**	67.94**	28.49**	53.82**
$p \leq 1$	28.17**	59.76**	18.54	31.26	18.24*	25.34**
$p \leq 2$	24.78**	30.98**	8.62	12.72	7.01	7.01
$p \leq 3$	6.20	6.20	4.09	4.09		

*Indicates rejection of the null hypothesis of no cointegration at the 5% level and ** for the rejection at the 1% level.

Table 6: Weak Exogeneity Test

Strong Wheat		Medium Strong Wheat		Weak Wheat	
Potentially Exogenous Variable	Test Statistic	Potentially Exogenous Variable	Test Statistic	Potentially Exogenous Variable	Test Statistic
C1L	19.66[0.00]	ATP	0.83[0.36]	USSG	14.41[0.00]

C1P	4.14[0.24]	ASW	2.57[0.10]	USWP	0.92[0.63]
USDG	9.33[0.02]	USHG	15.88[0.00]	EUSW	13.16[0.00]
USDP	11.33[0.01]	APH	12.02[0.00]		

p-values in square brackets

Table 7 Conditional Parsimonious VECM

	Strong Wheat			Medium-Strong Wheat			Weak Wheat	
	$\Delta C1L_t$	$\Delta USDG_t$	$\Delta USDP_t$	ΔASW_t	$\Delta USHG_t$	ΔAPH_t	$\Delta USSG_t$	$\Delta EUSW_t$
$\Delta USDG_{t-1}$	0.19	0.12^						
$\Delta USDP_{t-1}$			0.16					
$\mathbf{\Delta C1P_t}$	0.78	0.81	0.82					
ΔASW_{t-1}					0.40			
$\Delta USHG_{t-1}$				0.17				
ΔAPH_{t-1}					0.15	0.2		
$\mathbf{\Delta ATP_t}$				0.28	0.18	0.17		
$\Delta USSG_{t-1}$								0.21
$\Delta EUSW_{t-1}$							0.09^	0.21
$\Delta USWP_{t-1}$							-0.25	
$\mathbf{\Delta USWP_t}$							0.90	0.57
$\varepsilon 1_{t-1}$	-0.10	-0.12	-0.12	-0.13	-0.22	-0.19	-0.19	
$\varepsilon 2_{t-1}$	0.07	0.21	-0.07					0.17
$\varepsilon 3_{t-1}$	-0.11	-0.02	0.18					
SC	1.87	0.42	0.55	1.48	1.47	0.75	0.19	0.41
Normality	22.4**	36.2**	86.6**	17.03**	25.27**	25.9**	25.9**	8.02*
ARCH	2.04	2.77*	3.33**	1.36	1.94	0.83	0.80	1.34

*Indicates rejection of the null hypothesis at the 5% level and ** for the rejection at the 1% level. SC implies serial correlation

Figure 1. Wheat Export Prices