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Abstract This paper attempts to model the price relationship between the major exporters of wheat. The motivation of such research is to reveal whether prices are integrated and whether potential nonlinearities in price adjustment exist. Given the perception that transactions costs may be highly variable in the wheat market, the paper aims to test for the presence of cointegration in the presence of smooth transition adjustment. The results conclude that the further the prices deviate from each other, the larger will be the arbitrage and substitution that will drive the prices close to each other. However, the results suggest that the arbitrage will be limited as the various wheat prices employed in this study may be linked to highly variable transactions costs or some other form of imperfect competition.

Keywords : Cointegration, ESTAR, Wheat, Price Adjustment.

JEL Classification **:** Q13, Q17, C22

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1. Introduction

The Law of One Price (LOP hereafter) states that after conversion to a common currency, the price of identical goods in spatially separated markets should be the same. When the price for identical goods are different then there is an incentive for spatial arbitrage, however, deviations from the LOP can be linked with high transactions costs. Since independent information about transactions costs is rarely available, linear models have been developed which assume transactions costs are constant or proportional to the commodity prices over the period of study. This assumption is questionable in light of the potential volatility of transactions costs. Binkley and Harrer (1981) show that transport costs for certain commodities can be highly variable and may be influenced by several factors including ship sizes and trade volumes. Linear cointegration methods ignore the potentially important role played by transactions costs and are inconsistent with discontinuous trade (Baulch 1997).

Balcombe *et. al.,* (2007) advocate threshold models which allow for a neutral band where prices are not equilibrium restoring but adjustment takes place outside the band which is synonymous to the situation where price differentials exceed transactions costs. However, a limitation of this approach is that the band is assumed to be constant which is an unduly restrictive assumption. In this note it is argued that the speed of adjustment is an increasing function of the size of the discrepancy; such that small deviations from the LOP may not be corrected through the process of commodity arbitrage, but larger discrepancies are expected to be mean reverting. The presence of transactions costs implies a nonlinear process characterized as an exponential smooth transition autoregressive (ESTAR) model. In this case, adjustment takes place in every period, but the speed of adjustment varies with the extent of deviation from the LOP.

Wheat is one of the most important grains and is produced and consumed widely across the world. The major wheat exporting countries are the U.S., Canada, EU, Australia and Argentina, and together account for approximately 90% of the total wheat traded (Ghoshray 2002). Among individual countries price differences arise principally because of factors such as transportation costs and quality differences. Differences in environment and genetics among wheat producing areas of the world

or within one country result in wide variations in the characteristics of wheat produced. The U.S. alone exports three classes of wheat in significant amounts; these being the Hard Red Winter (hereafter U.S. HRW), Soft Red Winter (hereafter U.S. SRW) and Dark Northern Spring (hereafter U.S. DNS). Australia predominantly exports a winter wheat, Australian Standard White, hereafter (ASW) which is very similar in quality and end use characteristics to the U.S. HRW wheat. Argentinean Trigo Pan wheat (hereafter ATP) competes with the U.S. HRW as it has similar end use characteristics. Australia and Argentina compete with the U.S. HRW wheat. The U.S. DNS competes with Canadian Western Red Spring (hereafter CWRS) wheat. In the case of spring wheat, the U.S. and Canada compete for the East Asian markets. The EU exports wheat which is considered as a soft winter wheat. The U.S. SRW wheat and the EU wheat compete for market share particularly in North African countries (Barassi and Ghoshray 2007).

This note proposes an alternative novel framework for the empirical analysis of wheat export price relationships. The rationale for gradual rather than sudden regime shifts lies in the heterogeneous reaction of agents to changes in transactions costs, with each exporter responding differently especially to changes occurring in the proximity of the thresholds (Michael *et al.,* 1997). Further, this study employs weekly data which reduces the aggregation bias found in studies that use monthly data (Taylor 2001). The following section describes the econometric model, followed by a discussion of the empirical results. The final section concludes.

2. Econometric Model

The most common expression of the LOP is given by the equation below:

$$P_{1t} = \alpha + \beta P_{2t} + z_t \tag{1}$$

where P_{1t} and P_{2t} are non-stationary I(1) prices in logs, α is an arbitrary constant that accounts for transactions costs, β measures the elasticity of price transmission and z_t is the error term which may be serially correlated. To test the LOP one may employ the standard Engle Granger test for cointegration of P_{1t} and P_{2t}. To illustrate

the method, (1) is estimated using OLS. The second step runs a Dickey-Fuller test on the estimated residuals of (1) of the following kind:

$$\Delta z_t = \gamma z_{t-1} + \omega_t \tag{2}$$

where ω_t is a white noise error term. If ω_t is not white noise, an Augmented Dickey Fuller (ADF) test may be used where lagged values of Δz_t may be added to (2). Rejecting the null hypothesis $(H_0 : \gamma = 0)$ of no cointegration implies that the residuals of (1) are stationary.

This note employs a test for cointegration allowing for nonlinear ESTAR adjustment to equilibrium designed by Kapetanios, Shin and Snell (2006), henceforth KSS. The test involves reformulating (2) to give the following nonlinear ESTAR process:

$$\Delta z_t = \gamma z_{t-1} \left[1 - \exp\left(-\theta z_{t-1}^2\right) \right] + \varepsilon_t \qquad \varepsilon_t \sim \text{i.i.d}\left(0, \sigma^2\right) \tag{3}$$

The null hypothesis of no cointegration for this test procedure is $H_0 : \theta = 0$ against the alternative $H_1 : \theta > 0$. However, testing this null hypothesis directly is not feasible, since γ is not identified under the null. Thus, KSS compute a Taylor series approximation to the ESTAR model under the null to obtain the following auxiliary regression:

$$\Delta z_t = \delta z_{t-1}^3 + \omega_t \tag{4}$$

In the general case when the errors in (3) are serially correlated in a linear fashion then (1) may be extended to

$$\Delta z_t = \sum_{i=1}^{p} \beta_i \Delta z_{t-i} + \gamma z_{t-1} \left[1 - \exp\left(-\theta z_{t-1}^2\right) \right] + \varepsilon_t \qquad \varepsilon_t \sim \text{i.i.d}\left(0, \sigma^2\right) \tag{5}$$

and the auxiliary regression with p augmentations is obtained to be:

$$\Delta z_t = \delta z_{t-1}^3 + \sum_{i=1}^{p} \beta_i \Delta z_{t-i} + \omega_t. \tag{6}$$

where the lagged values of Δz_t are included to correct for plausible serially correlated errors. To choose the number of lags we follow significance procedure proposed by KSS. In both cases the null hypothesis to be tested is $H_0 : \delta = 0$ against the alternative $H_0 : \delta < 0$ using a $\hat{t}_{NLEG}$ test. KSS show that the $\hat{t}_{NLEG}$ test does not have an asymptotic standard normal distribution and undertake stochastic simulations to obtain the asymptotic critical values.

The existence of cointegration motivates the specification and estimation of the following nonlinear ESTAR–ECM model:

$$\Delta P_{1t} = \gamma \left[1 - \exp\left(-\theta z_{t-1}^2 \right) \right] z_{t-1} + \beta \Delta P_{2t} + u_t \tag{7}$$

where u_t is a possibly autocorrelated error term. In order to overcome the problem that the γ is not identified under the null, (7) is approximated using the Taylor series to obtain:

$$\Delta P_{1t} = \delta z_{t-1}^3 + \beta \Delta P_{2t} + u_t \tag{8}$$

From (8) we compute the $\hat{t}_{NLECM}$ statistic for the null of no cointegration, that is, $H_0 : \delta = 0$ against the alternative of nonlinear ESTAR cointegration, that is, $H_0 : \delta < 0$. As with the $\hat{t}_{NLEG}$, KSS undertake stochastic simulations to obtain the asymptotic critical values of $\hat{t}_{NLECM}$. KSS show using Monte Carlo simulations, that the two proposed tests, $\hat{t}_{NLEG}$ and $\hat{t}_{NLECM}$ have good size properties and superior power properties than the standard Engle Granger test. The simulations conducted by KSS show that the power gain is substantial, when θ is relatively small. They further

demonstrate that the $\hat{t}_{NLECM}$ is superior to the standard Engle-Granger and $\hat{t}_{NLEG}$ when the regressors are weakly endogenous in the cointegrating regression.

3. Empirical Results

The data used for this analysis are weekly average export price quotations (FOB) from 9 September 2002 to 21 September 2007. The wheat prices used in this study include the ATP, ASW, U.S. HRW (Gulf port), U.S SRW (Gulf port), U.S. DNS (Gulf port), CWRS (St. Lawrence port) and EU Standard wheat. The data was obtained from the *World Grain Statistics* published by the International Grains Council. All prices are quoted in US dollars. The subsequent analysis of the data is carried out on the logarithm of prices.

Figure 1 illustrates the wheat export prices used in this study. An interesting feature can be noticed from the data. The similar price patterns suggest that there is considerable opportunity for arbitrage among different classes of wheat. The similarity in price patterns is greater when considering the wheats' which compete directly with each other for market share.

[Figure 1 about here]

The prices were initially tested for their order of integration. A battery of unit root tests were conducted to assess the appropriate order of integration of the variables. Besides the ADF tests, more powerful tests such as the GLS de-trended version of the standard Dickey Fuller (DF) test due to Elliot *et. al.,* (1996) and the unit root test due Perron and Ng (1996) were employed. As a confirmatory test the KPSS test due to Kwiatkowski, *et. al.,* (1992) was conducted. All the unit root test results for the variables conclude that the prices are I(1). The results are not reported here for brevity.[2]

We apply the Engle Granger (1987) methodology on four different price pairs following the long run equilibrium relationship given by equation (1). The pairs are chosen by regressing ATP and ASW export prices on the U.S. HRW wheat; U.S.

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[2] The results are available from the author on request.

DNS on CWRS wheat; and U.S. SRW on EU wheat. These pairs are chosen carefully by establishing from the discussion in the earlier section as to which classes of U.S. wheat compete or are chosen as a reference price by other wheat exporters. The results of the test are shown in the second column of Table 1. The key point to note is that the Engle-Granger t-statistic is greater than the critical value in only one of the four possible pairs at the 10% significance level, that is, the [U.S.(DNS), CWRS] pair. This implies that for this pair, the null of no cointegration can be rejected, which implies that the two prices are cointegrated.

[Table 1 about here]

Using the linear method we find that the results are unfavorable to the LOP. However, a completely different conclusion emerges from the results of the $\hat{t}_{NLEG}$ test. In this case, except for the [CWRS,U.S.(DNS)] price pair, we are able to reject the null of no cointegration for all of the remaining three price pairs. However, when considering $\hat{t}_{NLECM}$, we find all the price pairs are cointegrated. Using Non-linear Least Squares, we obtain the estimates of $\hat{\theta}$ from the alternative ESTAR model. Given that θ is scale dependent, in order to facilitate convergence, we follow KSS by normalizing the z_t series to have a unit sample variance. The results for $\hat{\theta}$ and the t-statistic are given in Table 1. KSS acknowledge that although the t-statistic in this case cannot be employed to test for significance from zero, the estimate of θ can be considered "significant" if the asymptotic 95% confidence interval around the estimate excludes zero. Following KSS we find θ "significant" in all cases. It can be concluded that the power of the $\hat{t}_{NLECM}$ is substantial given the low value of $\hat{\theta}$ which varies between 0.001 to 0.003. The finding demonstrates that the results obtained from linear and nonlinear tests can be drastically different.

4. Conclusion

This note employs a novel method to determine whether the export prices of wheat are integrated. The results conclude that all the prices cointegrate in pairs, implying that the international wheat market is highly integrated. This result is obtained by testing for cointegration using a non-linear ESTAR–ECM approach which has good

size properties and superior power properties than the standard Engle Granger test. The results further suggest that owing to transactions costs, it is quite plausible that the further the prices deviate from each other, the larger will be the arbitrage that will drive the prices close to each other. However, arbitrage will be limited as the various wheat prices employed in this study may be linked to highly variable transactions costs or some other form of imperfect competition.

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Table 1: Cointegration Tests and Estimates for the ESTAR parameter

	$\hat{t}_{EG}$	$\hat{t}_{NLEG}$	$\hat{t}_{NLECM}$	$\hat{\theta}$	$\hat{t}_{\theta}$
ATP= f[U.S.(HRW)]	–2.31	–3.37**	–3.05*	0.002	2.94
ASW= f[U.S.(HRW)]	–2.57	–4.10***	–5.13***	0.003	11.94
CWRS= f[U.S.(DNS)]	–3.33*	–2.90	–3.64**	0.001	4.13
EU= f[U.S.(SRW)]	–2.43	–4.01***	–4.15***	0.002	5.06

***, **, and * denote significance at the 1% level, 5% level and 10% level respectively. Following Kapetanios *et. al.* (2006) the lag lengths for the cointegration tests are chosen using the general to specific method.

Figure 1: Wheat Export Prices

U.S./ton