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MAJOR INTERNATIONAL INFORMATION FLOWS ACROSS THE SAFEX WHEAT MARKET

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Abstract

We study information flows across four wheat futures markets on four continents: Zhengzhou Commodity Exchange (ZCE), South African Futures Exchange (SAFEX), Euronext/Liffe and Kansas City Board of Trade (KCBT). Three approaches for studying information flows among non-synchronous markets are applied: cointegration techniques, vector autoregressive analysis and multiple regression proposed. Although comparable underlying assets are traded in the four markets, our results indicate that no long-run links exist among them. ZCE is by far the most endogenous market, and Euronext/Liffe is the most exogenous one. Finally, the model points to KCBT as the most influential and sensitive wheat market. Our findings indicate that the relative openness of the SAFEX wheat market supports information flows and linkages from KCBT and Euronext/Liffe. Therefore, our results suggest that more supportive policies to incentivise higher wheat production in South Africa are required to mitigate the impact of price shocks emanating from the global wheat markets.

JEL Classification: C32, G15, G23

Keywords: Wheat futures, information flows, cointegration, vector autoregressive, multiple regression

1. INTRODUCTION

Wheat is one of the most-traded food commodities across international markets and is the underlying asset both of futures and options contracts in multiple venues.[1] A number of papers have shown the prominent role of US wheat futures markets when contributing to the international price discovery process (see Garbade and Silber, 1983; Crain and Lee, 1996; Bessler *et al.*, 2003; Götz *et al.*, 2013; Hernandez *et al.*, 2014, among others). However, according to Fung *et al.* (2010), growing demand in emerging countries and speculation in

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[1] Compared to other agricultural commodities, wheat globally recorded the largest volumes traded across international borders during 2014/15. Over this period, USDA (2016) confirms global wheat imports and exports were 158.3 million tons and 161.3 million tons, respectively, much higher than corn imports (122.0 million tons) and exports (127.8 million tons) for the same period.

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derivative markets that provoked recent food market turmoil in 2006, 2008 and 2010, may have affected the patterns of information flows across commodity financial markets.

A high number of empirical studies have provided evidence of the dominant role of futures markets in the price discovery process between spot and futures markets (see Garbade and Silber, 1983; Crain and Lee, 1996; Antonakakis *et al.*, 2015, among others), surprisingly, as Hua and Chen (2007) indicate, only a few studies have sought to understand the relationship between futures prices of the same underlying asset in different markets. Within these studies, Geoffrey *et al.* (1998) analysed the information flows between US and Canadian wheat futures from 1980 through 1994 and found that futures prices on Winnipeg Commodities Exchange (WCE) and Chicago Board of Trade (CBOT) are cointegrated. Balcombe *et al.* (2007) studied the relationship among maize, wheat, and soybeans markets in Brazil, USA and Argentina from 1988 through 2001. It was found that information causality for wheat and soybeans flowed from Argentina and USA to Brazil. Sendhil and Ramasundaram (2014) analysed wheat information flows between CBOT and the National Commodities and Derivatives Exchange (NCDEX), then the largest wheat futures market in India. Following the commencement of wheat futures trading in India in June 2005, trading in the contract was banned between 2007 and May 2009. In their study, Sendhil and Ramasundaram (2014) investigated information flows before and after the banning and no evidence of wheat price cointegration between CBOT and NCDEX could be confirmed.

Some literature has also focused on agricultural commodity price transmission involving European Union-based futures markets. Bessler *et al.* (2003) analysed information flows in five wheat markets using the error correction method and directed acyclic graphs. Wheat data from 1981 through 1999 was collected from the Canadian, Australian, European Union, Argentinian and USA markets. Using monthly free on board export price quotations for each market, USA wheat prices were found cointegrated with those of the European Union and Argentina.

Lence *et al.* (2013) examined long-run linkages between wheat contracts on Chicago Mercantile Exchange (CME) and Euronext/Liffe. They observed that the CME wheat futures curve reverts to the mean in the long-term, as opposed to the Euronext curve which seems not to. Lence *et al.* (2013) attribute this difference to the fact that CME is much more liquid than Euronext/Liffe as far as the wheat contracts are concerned. Yang *et al.* (2003) examined cross-market linkages of wheat futures in the European Union, USA and Canada. Data for the study covered 1996 through 2002 and was collected from London International Financial Futures Exchange (LIFFE), CBOT and WCE. EU prices were found independent of US prices as opposed to the opposite causal direction where EU prices significantly influenced US prices in the long-run. Wheat prices in Canada were found influencing US wheat prices while the reverse relationship was rejected.

The development of Chinese commodity markets has seen increased research focused on futures contracts behaviour. Du (2004) examined the Zhengzhou Commodity Exchange (ZCE) wheat market and the CBOT market using data from 1999 to 2003 and found ZCE and CBOT wheat prices not cointegrated. Similar results were obtained for the same markets by Hua and Chen (2007) using data from 1998 to 2002. Li and Lu (2012) analysed cross-correlation between USA and Chinese agricultural futures contracts. For small fluctuations, cross-correlations for maize and wheat were persistent in the short-run. However, cross-correlations for large fluctuations were found not persistent in the long-run. Finally, Fung *et al.* (2013) examined 16 futures contracts in China and compared them with foreign contracts.[2] Foreign markets included were Japan, Malaysia, USA and UK and wheat data was from 2003 to 2011 comprising contracts listed on ZCE. Although no evidence of cointegrating relationships involving wheat was found, short-run relations in prices for strong gluten wheat from USA markets to ZCE were confirmed.

Compared to the other markets described above, studies on price transmission between the South African Futures Exchange (SAFEX) and other futures markets are scarce. Minot (2010) looks at linkages between agricultural prices in 11 Sub-Saharan African markets compared to US Gulf prices, used as a proxy for world prices. Vector Error Correction Method (VECM) techniques are used for the analysis of data running from 1994 through 2006 to detect a long-run relationship between South African and US Gulf maize and wheat prices.

This paper examines information flows among four comparable wheat futures contracts located in different continents taking into account their relative market trading times. Specifically, we look at wheat futures information transmission among ZCE, SAFEX, Euronext/Liffe and Kansas City Board of Trade (KCBT). Three main econometric approaches have been applied to study information flows among the markets: cointegration techniques, vector autoregression analysis and, finally, a multiple regression model suggested by Peiró *et al.* (1998). This model, unlike the previous ones proposed in the wheat markets literature, allows the separation of the ability to influence and the sensitivity of the different wheat markets. Further, this study is the first to estimate interaction and dependence involving the SAFEX wheat contract simultaneously with comparable contracts on three major global markets using three distinct estimation approaches. As far as we know, the multiple regression approach of Peiró *et al.* (1998) has not been applied to agricultural futures located on four continents.

The paper is of interest to global market participants as it addresses an important problem statement. Firstly, it is critical to understand the nature and behaviour of interactions and dependencies amongst some of the largest wheat futures markets on four continents. A second point is the need to acquire deep insight on how price shocks emanating from any of the markets may adversely impact SAFEX or any of the other markets. Thirdly, it is of interest to find out which of the four markets studied is the most influential and which is the most sensitive or even vulnerable to be impacted by the other markets. This guides economic planning at all levels of the value chain. Fourthly, we seek to find out which market has the largest contribution to change in the prices of the other markets and what the implications of the interactions amongst the markets may be. Finally, the study seeks to consider what some possible policies open to the South African government could be, if any, to mitigate any negative consequences from adverse shocks from the other markets.

The paper is organised as follows. Section 2 describes the data used in the study and carries out preliminary analysis. Section 3 describes the methodology and presents the empirical analysis. Section 4 concludes.

[2] Underlying assets examined were aluminium, copper, zinc, gold, natural rubber, long-grain rice, white sugar, hard white wheat, strong gluten wheat, cotton, soybeans, soybean meal, crude soybean oil, corn and palm oil. These futures contracts are traded on the Shanghai Futures Exchange (SHFE), the Zhengzhou Commodity Exchange (CZCE) and the Dalian Commodity Exchange (DCE).

2. MARKETS AND DATA

Wheat plays a prominent role at the international level. Out of the total wheat produced globally, 18% goes into export markets (Taylor and Koo 2012); around 70% of global wheat output goes directly to human consumption (FAO, 2011); and wheat provides about 20% of total human calorific supply (Atchison *et al*., 2010). Major global wheat producing regions include the EU (21%), China (17%), India (12%), USA (9%), Russia (4%) and Australia (4%) (CME, 2014). However, when all the countries are taken into account individually, China produces and consumes more wheat than any other country (Zhang, 2008).

The three key wheat categories are *triticum aestivum*, *triticum durum* and *triticum compactum* (Lukow *et al*., 2006). *Triticum aestivum* is typically known as bread wheat or, sometimes, common wheat (Angus *et al*., 2011). *Triticum durum* is identified as durum wheat used in pasta production while *triticum compactum* is a minor wheat category, produced in the Pacific North West of the USA, that includes club wheats known to have low protein content (Bettge, 2009). Bushuk (1997) estimates that 95% of global wheat supplies are *triticum aestivum,* while about 5% are the durum type. *Triticum compactum* comprises less than 1% of total global wheat supplies.[3]

The focus is on four commodity exchanges, each the largest hard wheat futures market within the continents examined. Hard wheat, the underlying commodity in this study, is suitable for producing bread and is typically traded as hard white wheat or hard red wheat. Firstly, the commodity of interest in the USA, hard red wheat, is predominantly traded on KCBT. Secondly, ZCE, the Chinese futures market trading the largest wheat volumes domestically, has listed hard white wheat, also known as common wheat (Fung *et al*., 2013). Thirdly, Euronext/Liffe, the largest commodity derivatives market in the European Union area, lists its bread wheat, as milling wheat. Euronext/Liffe consolidates futures businesses located in Amsterdam, Brussels, Lisbon, London and Paris. Fourthly, the main wheat contract on SAFEX, locally referred to as bread milling wheat, trades virtually all South African produced wheat. It is important to point out that domestically produced South African wheat meets only about half of national consumption requirements (see DAFF, 2012; Phukubje and Moholwa, 2006; Van Wyk, 2012). As such, it remains an interesting question if South African wheat imports potentially explain some information spill-overs with the global system. It is worth pointing out that the KCBT-based hard red wheat contract has also been listed on SAFEX for trading in Rands. Meyer and Kirsten (2005) indicate that KCBT hard red winter wheat No. 2 is the USA wheat type comparable to wheat traded in South Africa. Wheat contract specifications for the four markets are provided in Appendix B.[4]

Wheat contracts on the four markets are traded in Rands/ton (SAFEX), US$/ton (KCBT), Euro/ton (Euronext/Liffe) and Yuan/ton (ZCE). However, as we have mentioned, underlying wheat contracts traded on the four futures markets present similar

[3] A table on the classification and identification of wheat is presented in Appendix A.

[4] The Indian wheat futures market was another possible candidate to represent the wheat futures price in Asia. However, the first Indian futures market began to trade in 2005 and, as we have mentioned, trading in wheat futures market was banned between 2007 and 2009 (see Ghosh (2010) for further details). Therefore, the election of Indian wheat market would have shortened the whole sample considerably.

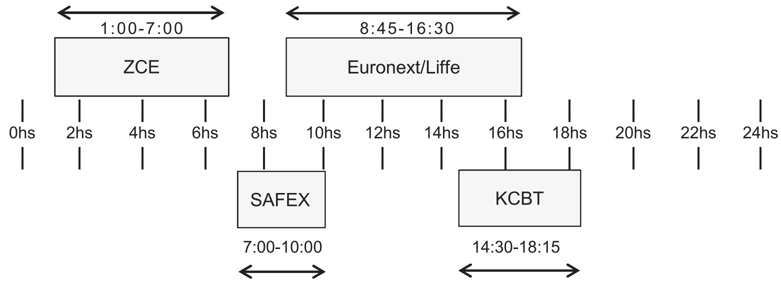

Figure 1. Diagrammatic comparative trading times for the 4 markets
Notes: Universal coordinated times (UCT) for operations on ZCE, SAFEX, Euronext/Liffe and KCBT are given above. UCT provides a 24-hr standardised global clock. The order of opening and closing times is comparable using the UCT system.

features that make them comparable. Appendix B shows that hard red wheat traded on KCBT has protein content between 9.5% and 13.5% and is comparable to the hard wheat traded on SAFEX, the milling wheat on Euronext/Liffe (originating from the EU region) and the hard white or common wheat traded on the ZCE. Wheat impurities amount to about 2.0% for each of the four markets. Foreign matter ranges between 0.7% and 1.0% across the four markets. Maximum moisture content permissible ranges between 13.0% and 15.0%.

Firstly, we present diagrammatically the trading times for the four markets under study. Fig. 1 shows relative market operating times using the coordinated universal time (UCT). The UCT standardises global timeframes to a uniform 24-hour day.

The first market to open amongst the four is ZCE (at 1:00 am in UCT terms). ZCE closes at 7:00 am UCT time. At this same time, SAFEX opens. Euronext opens at 8:45 am UCT time. SAFEX and Euronext close at 10:00 am UCT and 4:30 pm UCT, respectively. The overall order of market closing is therefore, ZCE, SAFEX, Euronext, and KCBT. Each market is potentially impacted by the markets closing ahead of it, such that the order of closing determines how the markets relate to each other.

Daily wheat futures data were collected through Thompson Reuters and include daily settlement prices of the nearest-to-maturity futures contract traded on ZCE, SAFEX, Euronext/Liffe, and KCBT. Price data is collected in local currencies for each market. Daily average foreign exchange rates for ZCE, SAFEX and Euronext/Liffe were sourced from databases of central banks in China and South Africa as well as from the European Central Bank. The analysis on information flows across the four markets is carried out in US dollars. Prices in local currency and in US dollar terms have been used for the preliminary analysis. However, similar to many comparable studies, all prices are converted to US dollars when conducting the analysis on market linkages (Francis and Leachman, 1998; Hauser *et al.*, 1998; Fung *et al.*, 2003; Xu and Fung, 2005, among others).

Our sample covers the period December 2003 through September 2013. The one year period between September 2013 and September 2014 is used for out-of-sample forecasting purposes. It is important to highlight that notable events happened over the period under study such as the world food price crisis, the global financial crisis and the European sovereign debt crisis.

Secondly, based on the last day criterion, we have generated a single time series representing wheat futures prices for each market (see Carchano and Pardo, 2009). Daily

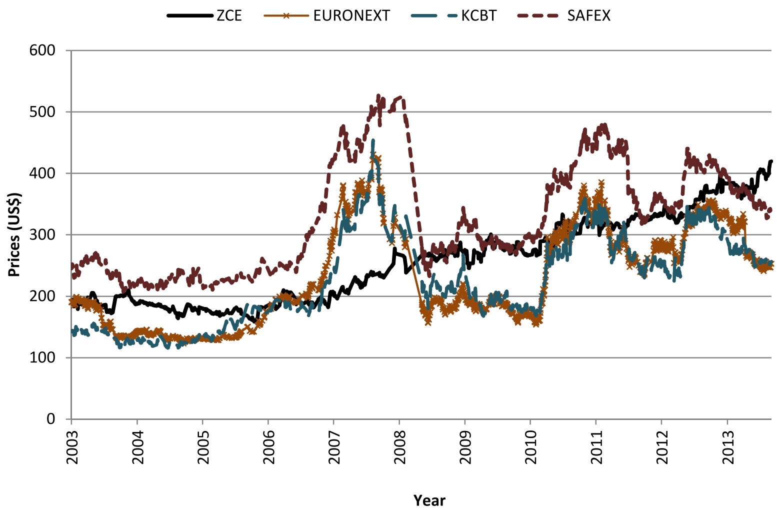

Figure 2. Comparative daily prices for the four markets
Notes: The daily wheat price series for ZCE, SAFEX, Euronext/Liffe and KCBT are presented. All prices are converted to US$for ease of comparison. Prices shown cover the period 2003 to September 2013.

wheat prices for the four markets are plotted in Fig. 2. KCBT and Euronext wheat prices appear to be closely tracking each other. SAFEX wheat prices also follow this joint pattern but with generally higher prices than for KCBT and Euronext. The difference between the KCBT or Euronext wheat prices with SAFEX prices is probably a reflection of approximate logistics costs of moving wheat from the US or Europe to South Africa.

It is observed that wheat prices on ZCE appear to be out of sync with the other three markets. ZCE wheat prices have been on a gradually increasing path and appear not to have been affected by the global commodity price shocks around 2007/2008 or 2010/2011. Fang (2010) contends there is significant government participation in agricultural markets in China. Support for production of maize, rice and wheat culminated in surplus output for the three crops leading up to 2008. Intervention by the Chinese government includes farm support subsidies, export restrictions through withholding VAT rebates on grain exports, bans on grain export licenses and temporary taxes on grain exports. Furthermore, a floor price system that guarantees high producer prices is managed by SinoGrain, a state enterprise responsible for managing the national strategic grain reserves. Therefore, it appears there was no scope for arbitraging across the Chinese and other markets given rigid controls governing the movement of wheat into and out of China.

Thirdly, we calculate wheat returns using the relation

$$R_t = 100^{*}\ln\left({}^{P_t}/_{P_{t-1}}\right) \quad (1)$$

where R_t are the wheat returns for each of the four markets and P_t and P_{t-1} are the price and lagged price series, respectively. Fig. 3 is a joint plot of the returns (calculated using US Dollar prices) for the four price series, presented in percentage terms. In the plots of the return series, volatility clustering and major price shocks are observable around 2004, 2008, 2010 and 2011. For SAFEX, Euronext and KCBT, wheat prices reached their

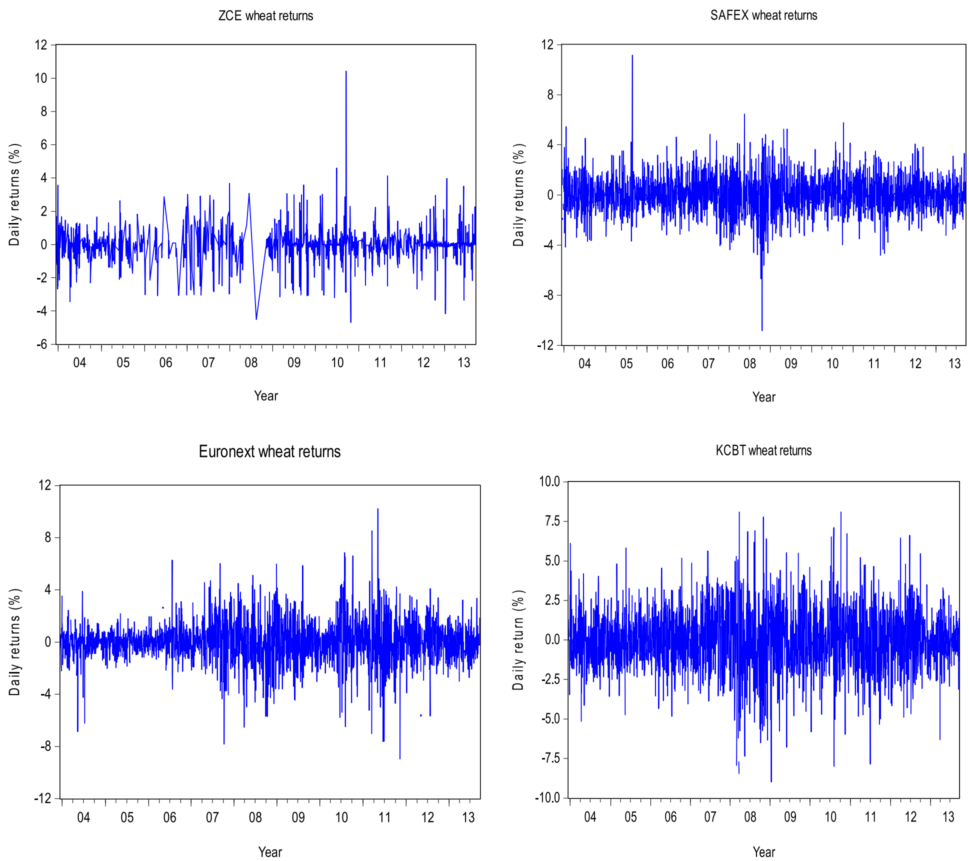

Figure 3. Wheat returns for ZCE, SAFEX, Euronext/Liffe and KCBT
Notes: Daily wheat returns for ZCE, SAFEX, Euronext/Liffe and KCBT are presented. All prices are first converted to US$ for ease of comparison. Returns are in percentage terms and cover the period 2003 to September 2013.

Table 1. Wheat returns daily summary statistics

Summary Statistics	ZCE_t	SAF_t	EU_t	KCB_t
Mean	−0.0378	0.0356	0.0295	0.0138
Median	−0.0015	−0.0170	0.0279	0.0000
Maximum	10.434	11.151	10.222	8.0977
Minimum	−4.6863	−10.842	−8.9500	−8.9948
Std. deviation	0.9760	1.4821	1.5817	1.9724
Skewness	0.6628	0.1259	−0.1044	−0.0605
Kurtosis	15.582	6.3526	6.9041	4.5124
Jarque-Bera	9,703.2	1,076.6	1,484.0	214.09
Observations	1,455	2,286	2,567	2,232

Notes: The returns series for wheat on ZCE, SAFEX, Euronext/Liffe and KCBT are represented as ZCE_t, SAF_t, EU_t and KCB_t, respectively. The returns are calculated after first converting prices in local currencies for China (Yuan), South Africa (Rands) and the Eurozone (Euros) to US dollars. Returns are expressed in percentage terms. For each market, the sample covers the period December 2003 through September 2013.

Table 2. Wheat returns daily cross-correlations

	ZCE_t	SAF_t	EU_t	KCB_t	ZCE_{t-1}	SAF_{t-1}	EU_{t-1}	KCB_{t-1}
ZCE_t	1.0000							
SAF_t	0.0419	1.0000						
EU_t	−0.0024	0.1544*	1.0000					
KCB_t	−0.0098	0.1069*	0.5744*	1.0000				
ZCE_{t-1}	−0.0255	−0.0374	−0.0059	0.0291	1.0000			
SAF_{t-1}	0.0070	−0.0001	−0.0069	−0.0295	0.0826	1.0000		
EU_{t-1}	0.0443	0.3234*	0.0465	0.0293	0.0080	0.1913*	1.0000	
KCB_{t-1}	0.0394	0.3643*	0.1457*	0.0193	0.0059	0.1315*	0.5468*	1.0000

Notes: Correlations in wheat daily returns cover the period December 2003 to September 2013. The wheat returns on the four markets are denoted as ZCE_t, SAF_t, EU_t and KCB_t corresponding to ZCE, SAFEX, Euronext/Liffe and KCBT futures markets, respectively. The * indicates correlation coefficient significantly different from zero at 1% level.

peak in 2008. Except for the ZCE, return volatility had been increasing exponentially leading up to around mid-2008. The absence of a peak in prices in China in 2008 is explained in Fang (2010) as resulting from government participation through setting floor prices, providing subsidies and export restrictions.

Finally, we next look at the summary statistics for the returns series. Table 1 presents summary statistics from 2003 to September 2013. Mean wheat returns are expressed in percentage terms. The highest wheat daily mean returns were experienced on SAFEX (0.0356%) while the lowest are observed on ZCE (−0.0378%). Regarding volatility, KCBT appears as the most volatile futures market while ZCE is the least. SAFEX daily returns present the highest difference between the maximum and the minimum, which indicates the high spread of SAFEX data. Measures of skewness and kurtosis indicate that series are far from being normally distributed.

Wheat daily returns contemporaneous and non-contemporaneous cross-correlations for the four markets are presented in Table 2. As was expected, all cross-correlation coefficients that are significant are also positive. SAFEX, Euronext and KCBT have significant cross-relationships among them. Cross-correlations between Euronext and KCBT, both contemporary (57.44%) and lagged (54.68%), are the highest. This is not surprising given that both markets are overlapped during 2 hours of their respective trading sessions. Furthermore, SAFEX is significantly correlated with Euronext/Liffe and KCBT. Finally, no correlation is detected between ZCE and the rest of the markets.

3. METHODOLOGY AND EMPIRICAL ANALYSIS

Following a handful of studies on commodity transmission, our methodological approach firstly looks at cointegration and the VECM (see Du, 2004; Du and Wang, 2004; Minot, 2010; Rosa and Vasciaveo, 2012, among others). We then use the vector autoregressive (VAR) approach as applied in Balcombe *et al.* (2007). In Engle *et al.* (1991) and Ito *et al.* (1992), a financial market may disseminate information influencing the next open markets. With this in mind and given that the wheat markets under study are non-synchronous, we have applied the model by Peiró *et al.* (1998). The system of seemingly unrelated equations they proposed, originally used with stock markets data, fits in well with the context of our study. The methodology and empirical analysis for each of the three approaches is presented below.

Table 3. Unit root tests

	ZCE	***SAFEX***	***Euronext***	***KCBT***
Level series	0.8333 [0.9946]	−0.8796 [0.7951]	0.0276 [0.9599]	−1.7106 [0.4258]
First order differences	−37.84*** [0.0000]	−46.54*** [0.0001]	−44.62*** [0.0001]	−45.20*** [0.0001]

Notes: Augmented Dickey-Fuller tests are carried out to determine the stationarity of the wheat price series for ZCE, SAFEX, Euronext/Liffe and KCBT. The log of the price series for wheat on ZCE, SAFEX, Euronext/Liffe and KCBT are used for unit root tests for the level series. First order differences are the series of returns for each market, whose unit root tests are presented in the second row. Parentheses present the p-values. For each market, the sample covers the period December 2003 through September 2013. Significance at 1%, 5% or 10% is shown as ***, ** or *, respectively.

3.1. Analysis of Long-Run Relationships

Following Engle and Granger (1987), if the price series in two or more markets were cointegrated, a model expressed in first differences would not be well-specified. Hence, firstly, we look at the possible cointegration among the wheat markets in order to determine if there are any long-term price relationships. Our approach is to carry out unit root tests for the price series, both in levels and in first differences, and determine if the price series for each market is integrated of the same order. Where the price series for each market is, say $I(1)$, the Johansen cointegration test may be used to determine the number of cointegrating relationships. If it is confirmed that there are cointegrating relationships, we can proceed with the VECM. Following from Engle and Granger (1987), cointegration in the vector error correction approach is represented as

$$\Delta P_t = \alpha^* \beta' P_{t-1} + \sum_{i=1}^{q-1} A_i \Delta P_{t-i} + \zeta_t \tag{2}$$

P_t, the vector of prices for the four markets is given as follows

$$P_t = \left(P_t^{ZCE}, P_t^{SAF}, P_t^{EU}, P_t^{KCB}\right) \tag{3}$$

The above prices represent trade close prices on ZCE, SAFEX, Euronext/Liffe and KCBT, respectively. The cointegration rank for the system of prices is $r\ (\leq k)$. In the VECM(q), α and β are $k\ x\ r$ matrices. A_i is a $k\ x\ k$ matrix of parameters for $i = 1, \ldots\ldots, q-1$. An error correction coefficient is captured in $\alpha = (\alpha_{ZCE}, \alpha_{SAF}, \alpha_{EU}, \alpha_{KCB})$' corresponding to the four markets and β is the cointegrating vector. Random error terms are explained by

$$\zeta_{it} = \left(\zeta_{ZCE,t}, \zeta_{SAF,t}, \zeta_{EU,t}, \zeta_{KCB,t}\right) \tag{4}$$

$$\zeta_{it} \sim N(0, \sigma_i) \tag{5}$$

Cointegration analysis in this study follows Engle and Granger (1987). Unit root tests for the prices of wheat in the four markets are presented in Table 3. The table shows unit root results before and after differencing.

Non-stationary series, when combined together, may turn out stationary. If this is the case, then the series have cointegration. All the logged price series are not stationary as shown in Table 3. However, after taking the first order differences, the entire set of

Table 4. Cointegration test results

	Hypothesised cointegrating equations			
	None	**At most 1**	**At most 2**	**At most 3**
Panel A: Trace Test				
Eigenvalues	0.0101	0.0060	0.0020	0.0003
Trace statistic	13.677	6.1761	1.7201	0.2173
Critical value (0.05)	47.856	29.797	15.495	3.8415
Prob.	1.0000	0.9998	0.9978	0.6411
Panel B: Maximum Eigenvalue				
Max-eigen statistic	7.5009	4.4560	1.5027	0.2173
Critical value (0.05)	27.584	21.132	14.265	3.8415
Prob.	0.9994	0.9984	0.9980	0.6411

Notes: Both trace test and maximum eigenvalue tests confirm no cointegration of the log wheat price series on ZCE, SAFEX, Euronext and KCBT. For each market, the sample covers the period December 2003 through September 2013. MacKinnon *et al*. (1998) p-values are reported in the row "Prob." allowing representation of significance at 1%, 5% or 10% using ***, ** or *, respectively.

differenced series becomes stationary. Where the series compared are both $I(1)$, but $I(0)$ after differencing, cointegration may be suitable for further analysis (Engle and Granger, 1987). The cointegration framework we use is outlined in Johansen (1991) and Johansen (1995) and in practice starts off with an estimated VAR object incorporating the variables of interest. If cointegration is confirmed, the VECM can be used for estimating the cointegration equation. The critical values for the cointegration tests are given in MacKinnon *et al*. (1998). Johansen's cointegration test results for the system of prices for the four markets are presented in Table 4.

The test for cointegration has two parts, the trace test and the maximum eigenvalue test. These results are presented in Panel A and Panel B of Table 4. As shown in Table 4, we find no cointegrating relationships amongst wheat prices on ZCE, SAFEX, Euronext and KCBT. This means that there are no long-term relationships in the wheat prices of the four markets. Therefore, our results are in line with those obtained by Hua and Chen (2007) and by Fung *et al*. (2013) who found no evidence of cointegration between US and Chinese wheat futures. However, our findings are in contrast with those obtained by Bessler *et al*. (2003) who found cointegration between EU and USA wheat futures, using a different sample period.

3.2. Dynamic Analysis Using VAR

The absence of long-term relationships has no effect on possibilities for short-term market linkages. Therefore, dynamic analysis is next considered using the VAR approach that enables determination of short-term causality as explained in Granger (1969). The returns for the four markets are the endogenous variables in our VAR system and the variance decomposition analysis allows disentangling the effects and relative importance of a given market on the other three wheat markets. Variance decomposition results for wheat returns on ZCE, SAFEX, Euronext and KCBT are shown in Table 5 and the ordering has been established based on the chronology of the closing hours of the four wheat markets. It is important to point out that variance decomposition results may be influenced by the different time zones of the four markets.

We focus on the decomposition of variance by market at the 5- and 10-day prediction horizons. This analysis points to the most exogenous market as the wheat market with

Table 5. Variance decomposition by wheat market

Market	Horizon	Changes in				
	(days)	ZCE	SAFEX	Euronext	KCBT	Rest
ZCE	5	0.0000	0.3851	69.4077	30.2071	99.9999
	10	0.0000	0.3852	69.4074	30.2074	100.000
SAFEX	5	0.0000	81.9190	12.2864	5.7947	18.0810
	10	0.0000	81.9187	12.2865	5.7948	18.0813
Euronext	5	0.0000	0.1695	96.4257	3.4048	3.5743
	10	0.0000	0.1695	96.4256	3.4049	3.5744
KCBT	5	0.0000	0.3983	34.1541	65.4476	34.5524
	10	0.0000	0.3985	34.1539	65.4476	34.5524

Notes: Each cell represents the variance decomposition of the return of the market in the first column as it is explained by the market displayed above each cell. In the "Rest" column, the cell gives the variance attributable to the rest of the markets other than the market in the first column. The sample for each market covers the period December 2003 through September 2013.

the highest percentage of forecast error variance accounted for by its own disturbances, while the most endogenous is the market that presents the highest percentage explained by other wheat futures markets. Euronext/Liffe is the most exogenous market with the bulk of its forecast error variance embodied in its own innovations (around 96%). Besides, in terms of largest impact on the other markets, Euronext/Liffe and KCBT show this largest influence in relative terms. On the other hand, the market appearing to be controlled by the largest number of other markets is ZCE and hence is the most endogenous. The next question would be whether there is a high degree of international linkages in the major wheat futures markets across the four continents covered in the study. At the 5- and 10-day prediction horizons, the influence of the rest of the markets on a given market ranges from 3.5744% to 100%. This indicates that there are high levels of international linkages in wheat returns among the markets under study.

3.3. Multiple Regression Analysis

Finally, we look at the model in Peiró *et al.* (1998) that postulates that the correlations of any two markets depend on the overlapping time periods running concurrently from the market-close on $t-1$ to the close on time t. This suggests that a given market tends to have higher correlation to the market which most recently closed operations in the last 24 hours. The approach proposed by Peiró *et al.* (1998) is particularly suited for our analysis because (*i*) wheat markets considered are non-synchronous and (*ii*) the model enables observation of each market's influence on, and sensitivity to, the other three wheat markets. Therefore, firstly, the regression equations below are resolved by ordinary least squares (OLS):

$$ZCE_t = \gamma_{10} + \gamma_{11} SAF_{t-1} + \gamma_{12} EU_{t-1} + \gamma_{13} KCB_{t-1} + u_{1t} \tag{6}$$

$$SAF_t = \gamma_{20} + \gamma_{21} ZCE_t + \gamma_{22} EU_{t-1} + \gamma_{23} KCB_{t-1} + u_{2t} \tag{7}$$

$$EU_t = \gamma_{30} + \gamma_{31} ZCE_t + \gamma_{32} SAF_t + \gamma_{33} KCB_{t-1} + u_{3t} \tag{8}$$

$$KCB_t = \gamma_{40} + \gamma_{41} ZCE_t + \gamma_{42} SAF_t + \gamma_{43} EU_t + u_{4t} \tag{9}$$

Returns for ZCE, SAFEX, Euronext/Liffe and the KCBT are represented by ZCE_t, SAF_t, EU_t and KCB_t, respectively. Lags for these returns are defined by SAF_{t-1}, EU_{t-1}

Table 6. Regressions for wheat returns for equations (6)–(9) and (10)–(13)

Independent Variables		**Dependent variables** ZCE_t (6)–(9)	ZCE_t (10)–(13)	SAF_t (6)–(9)	SAF_t (10)–(13)	EU_t (6)–(9)	EU_t (10)–(13)	KCB_t (6)–(9)	KCB_t (10)–(13)
Const.		−0.0606** [0.0357]	−0.0455 [0.1060]	0.0316 [0.4216]	0.0334 [0.2913]	0.0126 [0.7805]	0.0313 [0.4726]	−0.0144 [0.7549]	−0.0030 [0.9555]
γ_{11}, ϕ_{11}	SAF_{t-1}	0.0127 [0.5373]	0.0118 [0.5594]						
γ_{12}, ϕ_{12}	EU_{t-1}	0.0149 [0.5143]	0.0298 [0.1056]						
γ_{13}	KCB_{t-1}	0.0145 [0.4224]							
γ_{21}	ZCE_t			0.0455 [0.2589]					
γ_{22}, ϕ_{21}	EU_{t-1}			0.1585*** [0.0000]	0.1872*** [0.0000]				
γ_{23}, ϕ_{22}	KCB_{t-1}			0.1944*** [0.0000]	0.1718*** [0.0000]				
γ_{31}, ϕ_{31}	ZCE_t					−0.0285 [0.5403]	−0.0154 [0.7339]		
γ_{32}	SAF_t					0.1225*** [0.0003]			
γ_{33}, ϕ_{32}	KCB_{t-1}					0.0846*** [0.0009]	0.1147*** [0.0000]		
γ_{41}, ϕ_{41}	ZCE_t							−0.0126 [0.7930]	−0.0441 [0.4298]
γ_{42}, ϕ_{42}	SAF_t							0.0311 [0.3458]	0.1562*** [0.0000]
γ_{43}	EU_t							0.6639*** [0.0000]	
R^2		0.0020	0.0027	0.1440	0.1381	0.0320	0.0199	0.2998	0.0141

Notes: Regression solutions for wheat daily returns in equations (6)–(9) are compared to equations (10)–(13). The second set of equations excludes the market that had most recently closed. The sample for each market covers the period December 2003 through September 2013. The parentheses give respective p-values. Significance is given by ***, ** and * for 1%, 5% and 10% levels, respectively.

and KCB_{t-1}. The parameters to be estimated are $\gamma_{10,\dots\dots\dots}\gamma_{43}$ and the error terms are $u_{1t},\dots\dots u_{4t}$. Table 6 presents the results of running the initial regressions in equations (6)–(9). The results show ZCE wheat returns are generally not dependent on the wheat returns of the other three markets. SAFEX wheat returns are significantly influenced by Euronext and KCBT wheat returns at the 1% level and Euronext wheat returns have significant relationships at 1% level with SAFEX and KCBT returns. It is noted that KCBT wheat returns are highly influenced only by Euronext wheat returns.

In Peiró *et al.* (1998), it was found that removing the regressor of the most-recently closed stock market substantially increased the significance and magnitude of the influence of the remaining variables. Following a similar approach, regression equations were solved after excluding the wheat market with the most recent closing with respect to endogenous variables in (6)–(9). The most recently closed market is expected to have a more significant regressor compared to a market closing earlier. Excluding most-recently closed regressors gives:

$$ZCE_t = \varphi_{10} + \varphi_{11} SAF_{t-1} + \varphi_{12} EU_{t-1} + \varepsilon_{1t} \quad (10)$$

$$SAF_t = \varphi_{20} + \varphi_{21} EU_{t-1} + \varphi_{22} KCB_{t-1} + \varepsilon_{2t} \quad (11)$$

$$EU_t = \varphi_{30} + \varphi_{31} ZCE_t + \varphi_{32} KCB_{t-1} + \varepsilon_{3t} \quad (12)$$

$$KCB_t = \varphi_{40} + \varphi_{41} ZCE_t + \varphi_{42} SAF_t + \varepsilon_{4t} \quad (13)$$

Wheat returns for ZCE, SAFEX, Euronext/Liffe and the KCBT in equations (10)–(13) are respectively ZCE_t, SAF_t, EU_t and KCB_t. Parameters to be estimated in the above regressions are $\varphi_{10,\ldots\ldots,}\varphi_{42}$ and the error terms are ε_{1t}, ε_{2t}, ε_{3t} and ε_{4t}.

Of interest is to compare the initial regressions with the set that excludes the market most-recently closed, which usually has the most significant coefficient. Doing this allows the element of collinearity to be taken out of the explanatory variables while focus is placed on positions occupied by respective markets in the trading sequences. Results for equations (10)–(13) are also given in Table 6, side-by-side with those for equations (6)–(9). This makes it easier to check changes in the coefficients across the two sets of models. In Table 6, ZCE did not have any relationship with any of the markets at the first regression stage (equations (6)–(9)). After removal of KCBT from the ZCE wheat return equation, still no significant influence on ZCE can be discerned from the other markets. When ZCE wheat return is removed from the SAFEX relation (equation (7)), the magnitude of the coefficient of the lagged Euronext return increases while that of the lagged KCBT wheat return decreases slightly. For Euronext, the removal of SAFEX wheat returns from equation (8) increases the significance and influence of KCBT wheat returns. In the KCBT wheat returns situation, excluding Euronext as a regressor substantially increases the relationship between the former and SAFEX wheat returns. In fact, the effect of SAFEX on KCBT changes from insignificant to significant at 1%. The above findings would suggest that trading times play an important part in the relationships between the various wheat markets.

Finally, the main model used for the empirical analysis is presented below and is similar to the one used in Peiró *et al.* (1998) for the analysis of stock markets.

$$ZCE_t = \alpha_{ZCE} + \beta_{SAF}\lambda_{ZCE}SAF_{t-1} + \beta_{EU}\lambda_{ZCE}EU_{t-1} + \beta_{KCB}\lambda_{ZCE}KCB_{t-1} + u_{ZCE,t} \quad (14)$$

$$SAF_t = \alpha_{SAF} + \beta_{ZCE}\lambda_{SAF}ZCE_t + \beta_{EU}\lambda_{SAF}EU_{t-1} + \beta_{KCB}\lambda_{SAF}KCB_{t-1} + u_{SAF,t} \quad (15)$$

$$EU_t = \alpha_{EU} + \beta_{ZCE}\lambda_{EU}ZCE_t + \beta_{SAF}\lambda_{EU}SAF_t + \beta_{KCB}\lambda_{EU}KCB_{t-1} + u_{EU,t} \quad (16)$$

$$KCB_t = \alpha_{KCB} + \beta_{ZCE}\lambda_{KCB}ZCE_t + \beta_{SAF}\lambda_{KCB}SAF_t + \beta_{EU}\lambda_{KCB}EU_t + u_{KCB,t} \quad (17)$$

The wheat price return series for ZCE, SAFEX, Euronext/Liffe and KCBT are denoted by ZCE_t, SAF_t, EU_t and KCB_t, respectively. SAF_{t-1}, EU_{t-1} and KCB_{t-1} are lags for wheat returns on SAFEX, Euronext and KCBT, respectively. The size of β determines the level of influence that one market has on the other markets. In the system of equations (14)–(17), λ_{ZCE}, λ_{SAF}, λ_{EU} and λ_{KCB} are measures of the sensitivity of each wheat market to global factors. Constant terms for each equation are α_{ZCE}, α_{SAF}, α_{EU} and α_{KCB}. The error terms are $u_{ZCE,t}$, $u_{SAF,t}$, $u_{EU,t}$ and $u_{KCB,t}$. The order of the equations and variables allows for the current return of one market to be linked to latest available returns from the other three markets.

Specifically, this model takes into account the non-synchronous trading amongst the wheat futures markets with the closing prices of each market potentially influenced by the other three markets. For example, SAFEX can potentially be influenced by ZCE on the same day. No time overlap occurs between these markets. A time overlap of 1 hour and 15 minutes, however occurs between SAFEX and Euronext/Liffe. This means that the closing price for Euronext/Liffe can be influenced by the SAFEX closing price of the same

Table 7. Joint estimation of models (14)–(17)

Market	$\hat{\beta}$	$\hat{\lambda}$
ZCE	−0.0009 [0.8936]	0.1420 [0.1231]
SAFEX	0.0042 [0.4106]	1.6607*** [0.0000]
Euronext/Liffe	0.0981*** [0.0028]	1.0000 [–]
KCBT	0.1166*** [0.0000]	6.6286*** [0.0030]

Notes: Estimation of models (14)–(17) is presented in this table. Joint estimation is carried out using non-linear least squares or seemingly unrelated regression with data covering the period December 2003 to September 2014. As a restriction λ_{EU} is fixed as 1. The sample for each market covers the period December 2003 through September 2013. Parentheses present the p-values. Significance at 1%, 5% or 10% is shown as ***, ** or *, respectively.

day, while the KCBT closing price can be influenced by the closing prices of Euronext/Liffe and SAFEX of the same day. Euronext/Liffe and KCBT overlap in trading time for about 2 hours.

For resolution of the system in (14)–(17), a non-linear least squares modelling approach is applied making use of the Gauss–Newton method. Furthermore, as the above system of equations is not identified, there is need to incorporate some restrictions to enable a solution to be found. Following from Peiró *et al.* (1998), the value of λ_{EU} is set to 1. Joint estimation of the parameters is carried out to derive the required coefficients.

Essentially, we seek to isolate the information transmitting effect of a given market regardless of the order of timeframes involved between the markets. The equations are resolved simultaneously as a joint system using the seemingly unrelated regression approach. Joint estimation results for system of equations (14)–(17) are given in Table 7.

As shown in Table 7, KCBT and Euronext are the only influential markets. KCBT is the most influential market and, at the same time, the most sensitive market. This result is consistent with KCBT's size within the global futures markets. SAFEX is more sensitive to receiving market information than Euronext, but is only a receiver of information while not influencing other markets. This finding is consistent with SAFEX's relatively small size and with the fact that South Africa is a net importer of wheat, securing approximately half of its wheat requirements from the international system (DAFF, 2012). Finally, ZCE appears as the least influential and least sensitive of the four markets.

3.4. Out of Sample Estimations

Finally, it is imperative to find out which relations (6)–(9) or (14)–(17) would be more useful and appropriate for econometric use. It may therefore be prudent to test the out-of-sample predictive potential of the two sets of equations. Comparison of equations (6)–(9) with equations (14)–(17) is provided in Table 8. Forecasts are generated by these

Table 8. Out-of-sample forecasts and root mean squared errors

Market	Models (6)–(9)	Models (14)–(17)
ZCE_i	0.9994	0.8199
SAF_t	0.8206	0.6215
EU_t	1.0186	0.8206
KCB_t	1.1980	0.9286

Notes: Root-mean squared errors evaluate out-of-sample forecasts for models (6)–(9) compared to models (14)–(17). The forecast period is the one year commencing on 24 September 2013 to 23 September 2014.

set of equations to find out if the latter adds value to the former. Root mean squared errors are used as the measure of evaluating the forecasts of corresponding equations in the two groups.

Table 8 shows that out-of-sample forecasts were generated for the one-year period 24 September 2013 to 23 September 2014. Root mean squared errors calculated using models (14)–(17) are less than those for models (6)–(9). Modest improvements in the predictive power in respect of all the endogenous variables are registered. In addition to securing information on the levels of sensitivity and influence of each market, models (14)–(17) also enable us to secure more accurate forecasts. This finding is in agreement with Peiró *et al.* (1998) who also got better forecasts by using the joint system rather than the individual simple regression equations.

4. CONCLUSIONS

This article investigates international information flows across the SAFEX wheat futures market. Specifically, the wheat contracts examined are on the ZCE (China), SAFEX (South Africa), the Euronext/Liffe (Europe) and KCBT (USA). Cross-correlation analysis shows close linkages between Euronext/Liffe and KCBT and between these two markets and SAFEX. However, no cointegration relationships are found within the four markets. Variance decomposition analysis indicates that the Euronext/Liffe market is the most exogenous and also contributes the most to the prediction of the variance of the other three markets, while ZCE has the least amount of linkages with the other markets, and, as a consequence, can be considered as a net receiver of information.

To better understand the nature of information flows across the markets, we use the Peiró *et al.* (1998) approach which seeks to separate the influencing ability and the sensitivity or openness of a market to receiving information from other markets. We find the KCBT futures market is the most influential market of the four wheat markets examined. It may be obvious that KCBT prices drive most of the other markets; however, we have also found that KCBT is, at the same time, the most sensitive of the four futures markets. This fact does not occur with the Euronext/Liffe market, which appears as an influential market with low sensitivity to news coming from other markets. Regarding the ZCE market, it seems that market participation by state-owned entities in the Chinese food markets has eliminated wheat market linkages with the global system. Finally, we have also seen that the relative openness of the SAFEX wheat market supports information flows and linkages from KCBT and Euronext/Liffe. Therefore, our results suggest that more supportive policies to incentivise higher wheat production in South Africa are required to mitigate the impact of price shocks emanating from the global wheat markets.

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APPENDIX A. WHEAT CLASSIFICATION AND IDENTIFICATION

Class	Category	Sub-class	Protein content	Products	Properties
Hard red spring	Hard	• Dark northern spring	12–15%	Bread	75% or more hard, vitreous kernels
	Hard	• Northern spring	12–15%	Bread	25–75% hard, dark, vitreous kernels
	Hard	• Red spring	12–15%	Bread	<25% hard, dark, vitreous kernels
Hard white	Hard	None	10–15.0%	Bread	
Hard red winter	Medium hard	None	9.5–13.5%	Bread	Medium to hard kernels
Durum	Extra hard	• Hard amber durum	11–15%	Pasta	75% or more hard, vitreous kernels
	Extra hard	• Amber durum	11–15%	Pasta	60–75% hard and vitreous kernels
	Extra hard	• Durum	11–15%	Pasta	<60% hard and vitreous kernels
Soft red winter	Very soft		8.0–11.0%	Cookies	
Soft white	Very soft	• Soft white	8.0–11.0%	Cookies	Soft, <10% white club wheat
		• White club	8.0–11.0%	Cookies	Soft, <10% other soft white
		• Western white	8.0–11.0%	Cookies	<10% white club, ≥10% other soft
Unclassed	Unclassed		–		Not classified, includes other colours
Mixed	Mixed		–		<90% one class, ≥10% other class

Notes: Appendix A has been included to assist with classification and harmonisation of wheat grading. Bread is made using hard wheat while confectionaries are made using soft wheat. This table is classifying USA wheat and has been used as a guide for making comparisons with other global markets. Triticum compactum falls under the soft wheats which include the club wheats shown in the table. Wheat classification in China has two major categories, strong gluten wheat and weak gluten wheat. Strong gluten wheat has crude protein content of at least 14.0% and test weight of 770 grams/Litre. Weak gluten wheat has crude protein content of at least 11.5% and test weight greater than 750 grams/Litre. Zhang (2008) contends that bread is produced using strong gluten wheat while cookies and confectionaries are produced using weak gluten wheat. Milling wheat is the name used on Euronext/Liffe to refer to wheat with bread making characteristics comparable to the hard wheat in the table. Sources: Own elaboration based on tables from Bushuk (1997) and Lukow *et al*. (2006).

APPENDIX B. WHEAT FUTURES CONTRACT SPECIFICATIONS FOR FOUR MARKETS

Futures Exchange	SAFEX	KCBT	NYSE Euronext Liffe	ZCE
Region	South Africa	USA	European Union	China
Reference point	Randfontein	Kansas	Rouen	Zhengzhou
Impurities (%)	2.0%	2.0%	2.0%	2.0%
Specific weight	76 kg/hl	78 kg/hl	76 kg/hl	76 kg/hl
Contract size	50 tons	50 tons	50 tons	50 tons
Trading hours	9:00 am to 12.00 pm	9:30 am to 1:15 pm	10:45 am to 6:30 pm	9:00 am to 3:00 pm
Maturity months	March, May, July, September, December	July, September, December, March, May	November, January, March, May, September	January, March, May, July, September, November
Foreign material	1.0%	0.7%	1.0%	1.0%
Broken grains	5%	5%	4%	8.0%
Protein content	11.0%	9.5–13.5%	11.0%	14–15.0%
Moisture	13.0%	13.5%	15.0% Max.	13.5%
ISIN Codes	WEA	KW	BL2	CPM & CWT
Quotation	Rands/ton	US Dollars/ton	Euro/ton	Yuan/ton
Data Source	www.jse.co.za	www.cmegroup.com	www.nyx.com/liffe	http://www.czce.com.cn
Wheat product	RSA bread milling wheat	No. 2 hard red winter	Milling wheat	Hard white and common wheat

Notes: SAFEX stands for the South African Futures Exchange; KCBT is the Kansas City Board of Trade; ZCE is China's Zhengzhou Commodity Exchange.