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Information transmission in informationally linked markets: Evidence from US and Chinese commodity futures markets

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ABSTRACT

This paper investigates information transmission and price discovery in informationally linked markets within the multivariate generalized autoregressive conditional heteroskedasticity and information share frameworks. Based on both synchronous and non-synchronous trading information from Chinese futures/spot markets, the New York Mercantile Exchange (NYMEX), Chicago Board of Trade (CBOT), and CME Globex futures markets for copper and soybeans, we show that there is a bidirectional relationship in terms of price and volatility spillovers between US and Chinese markets, with a stronger effect from US to Chinese markets than the other way around. Additionally, the NYMEX and CBOT play a more important role than the CME Globex in the flow of information from US to Chinese markets. Moreover, we find that Chinese copper market adjusts more quickly than the NYMEX copper market to correct the disparity between both markets. However, the converse is true in the case of soybeans. Finally, our results highlight the remarkable role of Chinese futures markets in the price formation process, though NYMEX and CBOT futures markets are the main driving force in price discovery.

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1. Introduction

The term “informationally linked markets” refers to markets in which traded assets are fundamentally related to each other. Although these markets are interrelated, they have different information processing abilities and make different contributions to price discovery due to distinct transaction costs, regulations, liquidities, and other institutional factors. It is important for us to understand the dynamic nature of the price discovery process, because it reflects information transmission across markets, thereby providing an indication of price efficiency.

Price discovery and information transmission in informationally linked markets have been extensively examined in the literature. In their seminal paper, Garbade and Silber (1979) first propose the concepts of dominant and satellite markets and analyze the short-run price behavior of an identical asset traded in two different markets: the New York Stock Exchange and regional stock exchanges. Subsequently, a number of studies have investigated the lead–lag relationship between two informationally linked markets, such as spot and futures markets, and domestic and overseas futures markets (Ding et al., 1999; Hasbrouck, 1995; Lihara et al., 1996; Roope and Zurbruegg, 2002; Tse, 1999; Xu and Fung, 2005). Grammig et al. (2001) examine price discovery in international equity trading by analyzing quotes originating in New York and Frankfurt for internationally-traded firms. On the other hand, some research focuses on the case of three markets. For example, Booth et al. (1996) document the linkages and information transmission of similar Nikkei 225 stock index futures traded on the Osaka Securities Exchange, the Singapore Exchange, and the Chicago Mercantile Exchange, and find that none of the markets can be considered the main source of information flow. Chu et al. (1999) explore the price discovery function in three S&P 500 index markets: the spot index, the futures index, and S&P Depositary Receipts (SPDRs) markets by using matched synchronous intraday trading data. Their results suggest that the futures market serves a dominant role in price discovery, and imply that price adjustments take place in the spot index and SPDRs markets, but not in the futures market. So and Tse (2004) investigate price discovery relations among the Hang Seng Index, Hang Seng Index futures, and the tracker fund using the Hasbrouck (1995) and Gonzalo and Granger (1995) common-factor models as well as the multivariate generalized autoregressive conditional heteroskedasticity (M-GARCH) model. They conclude that futures markets contain the most information, followed by the spot market, while the tracker fund does not contribute to price discovery. Covrig et al. (2004) assess intraday information revelation and price discovery for the Nikkei 225 spot index traded on the Tokyo Stock Exchange (TSE), Nikkei 225 futures traded simultaneously on the Osaka Securities Exchange (OSE) and the Singapore Exchange (SGX), and confirm the dominant role of futures markets in price discovery.

This paper investigates price discovery and information transmission across Chinese commodity spot/futures markets and US futures markets. In particular, for Chinese markets we consider copper and soybean spot contracts, copper futures on the Shanghai Futures Exchange (SHFE), and soybean futures on the Dalian Commodity Exchange (DCE). For US markets, we consider copper futures on the New York Mercantile Exchange (NYMEX), soybean futures on the Chicago Board of Trade (CBOT), and CME Globex copper/soybean futures. Our research represents a significant contribution to the literature in a number of ways.

First, previous studies on this subject focus mainly on spot and futures markets or the domestic and overseas futures markets that have the same or overlapped trading hours. However, our research is based on both synchronous and non-synchronous trading information in three markets. While the regular trading hours of the NYMEX and CBOT do not overlap at all with those in Chinese markets, CME Globex copper and soybean futures trade throughout the entire Chinese trading session and also trade when Chinese markets are closed. Information flows rapidly between US and Chinese markets, but may exhibit different characteristics during the overlapped and non-overlapped trading periods. It is documented that, as a result of different rates of information flow, asset price volatilities are higher during exchange trading hours than at other times (French and Roll, 1986). Liu et al. (2011) further show that the information accumulated during non-trading hours contributes substantially to integrated risks of Chinese commodity futures markets. Apparently, the trading activity in the US NYMEX/CBOT and CME Globex futures markets represents an important part of this non-trading period information in Chinese markets. Our research serves as an important step toward understanding characteristics of information flow across markets with both overlapped and non-overlapped trading hours, as well as understanding the relative importance of NYMEX/CBOT and CME Globex trading in information transmission between US and Chinese futures markets.

Second, we provide a comprehensive analysis of the price discovery process and the contribution of each market to price discovery. Using the M-GARCH model, we investigate lead–lag relationships among the Chinese futures, Chinese spot, and US futures markets for both copper and soybean contracts. We also investigate volatility spillovers among these markets to further describe the information transmission process. Importantly, we assess the contribution of each market to price discovery using a new measure that properly accounts for both synchronous and non-synchronous trading information. Specifically, in the case of synchronous trading in Chinese and CME Globex markets, the modified information share (MIS) model proposed by Lien and Shrestha (2009) is directly adopted. In the non-synchronous trading case, we use two orderings of the price sequence to capture the interactions between Chinese and NYMEX/CBOT markets, and define the weighted average of the MISs implied by the two sequences as the information share of a particular market. The overall contribution of the market to price discovery is obtained based on the MISs in these two cases.

Third, we analyze daily information flows. To analyze both overlapping and non-overlapping trading information, we utilize daily closing data for regular trading in Chinese and NYMEX/CBOT markets and the data from CME Globex that matches Chinese market data. Moreover, we employ commodity futures data as opposed to market index or financial futures data used in most previous work. This is especially interesting, given that individual commodity futures markets are more volatile than are index futures markets. Additionally, while previous studies provide insightful findings in information transmission across financial futures markets, there is little research on commodity futures in this area. By focusing on copper and soybean futures, we are able to evaluate their relative informational roles in international commodity futures markets.

Finally, we document the international role of Chinese markets in price discovery and information transmission relative to developed futures markets (US markets). From an empirical perspective, examining information transmission between emerging markets and mature markets and their relative information processing abilities is of particular importance. This is because emerging markets are typically more volatile, less liquid, and less informationally efficient than mature markets such as those in the US and Europe. With the dramatic growth of Chinese economy over the past three decades, Chinese financial markets have become increasingly important in international markets. According to the Futures Industry Association (FIA), in 2008 the trading volume of Chinese commodity futures was 36.5% of the world's total trading volume, and China's is now the second largest commodity futures market in the world, with the US market being the largest.[1] However, there are significant structural and institutional differences between Chinese markets and developed markets. Consequently, Chinese markets present themselves as an interesting case for research.

Most previous work on price discovery focused primarily on mature markets rather than emerging markets. Due to the aforementioned and other reasons, more and more research on Chinese informationally linked markets has been conducted with an emphasis on the interrelation between Chinese futures and US/European futures markets. Using a cointegration analysis and the bivariate EGARCH model, Hua and Chen (2004) and Gao and Liu (2007) show that there are indeed significant cointegration relationships and bidirectional lead–lag relationships between the SHFE and LME copper and aluminum futures markets, and a cointegration relationship between the DCE and CBOT soybean futures markets. Overall, US/European futures markets play a dominant role in information transmission between US/European and Chinese markets. In addition, Xia and Cheng (2006) study the relationships among the DCE futures market, CBOT futures market, and Chinese spot market using the vector autoregressive (VAR) and vector error-correction models (VECM). They also find that there are long-run equilibrium and lead–lag relationships between one another. This paper extends these studies by examining how information is transmitted across Chinese spot/futures markets and US futures markets for copper as well as soybeans, and by quantifying the contributions of each market to the price discovery process based on both synchronous and non-synchronous futures trading

[1] Source: *Futures Daily*, August 17, 2009.

information. Our study provides further insight into the dynamic nature of price discovery and information transmission between emerging and mature financial markets.

Our results indicate that Chinese futures/spot and US futures markets for both copper and soybeans are interrelated, and that information flows rapidly from one market to others. However, there are asymmetric relationships between futures and spot markets as well as between Chinese and US futures markets in terms of price transmission and volatility spillovers, with a stronger effect from futures markets to spot markets and a stronger effect from US to Chinese futures markets than the other way around. In addition, the NYMEX/CBOT plays a more important role than the CME Globex in information transmission between Chinese and US markets. Moreover, we find that the Chinese copper market adjusts more quickly than the NYMEX copper market to correct the disparity between both markets, and it interprets shocks to the long-run relation as particularly important information that needs to be quickly reflected in price movements. However, the converse is true in the case of soybeans. The information share based on non-synchronous trading information accounts for 65.05% of the overall price discovery in copper markets, while it accounts for 90.24% in soybean markets. The contributions of the Chinese futures, Chinese spots, and US futures to price discovery are 38.58%, 17.89%, and 43.53% for copper, respectively, and 40.33%, 17.52%, and 42.15% for soybeans, respectively. The results imply that about 47%–49% of the total information share of futures markets comes from Chinese futures markets. It follows that the NYMEX and CBOT are still the main driving force in information transmission and price discovery, but the informational role of Chinese markets is remarkable.

The remainder of this paper is organized as follows. Section 2 describes the models for price transmission, volatility spillovers, and price discovery measures. Section 3 discusses the data used for our analysis. Section 4 analyzes the empirical results, and Section 5 concludes this paper.

2. M-GARCH and information share models

This section presents the M-GARCH model and the information share model used in this paper for analyzing information transmission and price discovery in informationally linked markets with both synchronous and non-synchronous trading periods.

2.1. M-GARCH model

To examine patterns of price transmission across various markets, we use the following vector error-correction model (VECM) to specify conditional mean returns of spots and futures:

$$r_{1,t}=\mu_1+\sum_{i=1}^{p}\alpha_{1,i}r_{1,t-i}+\sum_{j=1}^{q}\beta_{1,j}r_{2,t-j}+\sum_{m=1}^{r}\gamma_{1,m}r_{3,t-m}+\sum_{n=1}^{s}\varphi_{1,n}r_{4,t-n}+\kappa_1(P_{2,t-1}-P_{1,t-1}) +\theta_1(P_{3,t-1}-P_{1,t-1})+\tau_1(P_{4,t-1}-P_{1,t-1})+\varepsilon_{1,t} \quad (1)$$

$$r_{2,t}=\mu_2+\sum_{i=1}^{p}\alpha_{2,i}r_{1,t-i}+\sum_{j=1}^{q}\beta_{2,j}r_{2,t-j}+\sum_{m=1}^{r}\gamma_{2,m}r_{3,t-m}+\sum_{n=1}^{s}\varphi_{2,n}r_{4,t-n}+\kappa_2(P_{1,t-1}-P_{2.t-1}) +\theta_2(P_{3,t-1}-P_{2,t-1})+\tau_2(P_{4,t-1}-P_{2,t-1})+\varepsilon_{2,t} \quad (2)$$

$$r_{3,t}=\mu_3+\sum_{i=1}^{p}\alpha_{3,i}r_{1,t-i}+\sum_{j=1}^{q}\beta_{3,j}r_{2,t-j}+\sum_{m=1}^{r}\gamma_{3,m}r_{3,t-m}+\sum_{n=1}^{s}\varphi_{3,n}r_{4,t-n}+\kappa_3(P_{1,t}-P_{3,t-1})+\theta_3(P_{2,t} -P_{3,t-1})+\tau_3(P_{4,t}-P_{3,t-1})+\varepsilon_{3,t} \quad (3)$$

$$r_{4,t}=\mu_4+\sum_{i=1}^{p}\alpha_{4,i}r_{1,t-i}+\sum_{j=1}^{q}\beta_{4,j}r_{2,t-j}+\sum_{m=1}^{r}\gamma_{4,m}r_{3,t-m}+\sum_{n=1}^{s}\varphi_{4,n}r_{4,t-n}+\kappa_4(P_{1,t-1}-P_{4,t-1}) +\theta_4(P_{2,t-1}-P_{4,t-1})+\tau_4(P_{3,t-1}-P_{4,t-1})+\varepsilon_{4,t} \quad (4)$$

where $P_{1,t}$, $P_{2,t}$, $P_{3,t}$, and $P_{4,t}$ are the logarithmic prices of Chinese futures, Chinese spots, NYMEX/CBOT futures, and CME Globex futures on date t, respectively. In addition, $r_{1,t} = P_{1,t} - P_{1,t-1}$, $r_{2,t} = P_{2,t} - P_{2,t-1}$, $r_{3,t} = P_{3,t} - P_{3,t-1}$, and $r_{4,t} = P_{4,t} - P_{4,t-1}$ correspond to the respective returns of these futures. We further assume that

$$\varepsilon_t = \left(\varepsilon_{1,t}, \varepsilon_{2,t}, \varepsilon_{3,t}, \varepsilon_{4,t}\right)^T \Big| \Omega_{t-1} \sim t(0, \Sigma_t),$$

where Ω_{t-1} is the information set at $t - 1$, $\Sigma_t = \{\rho_{i,j}\sigma_{i,t}\sigma_{j,t}\}$ is the 4×4 time-varying conditional covariance matrix, and $\rho_{i,j}$ is the conditional correlation coefficient between error terms ε_i and ε_j.

This approach is widely used in the literature to describe price interactions among various informationally linked markets (Booth et al., 1999), as it captures both the short- and long-term effects of information flow across markets. In particular, short-term effects are reflected by cross-market lagged returns in these equations, and long-term effects are captured by long-run equilibrium errors, defined as the difference in the last period's market prices between any two markets.

Given the fact that volatility is a source of information (Chan et al., 1991; Ross, 1989), an examination of volatility spillovers can help us further understand the information transmission process across markets. To this end, we consider the multivariate GARCH (1,1) model, in which conditional variance equations are specified as follows:

$$\sigma^2_{1,t} = \omega_1 + \lambda_1\sigma^2_{1,t-1} + \iota_1\varepsilon^2_{1,t-1} + \psi_1\varepsilon^2_{2,t-1} + \xi_1\varepsilon^2_{3,t-1} + \nu_1\varepsilon^2_{4,t-1} \quad (5)$$

$$\sigma^2_{2,t} = \omega_2 + \lambda_2\sigma^2_{2,t-1} + \iota_2\varepsilon^2_{2,t-1} + \psi_2\varepsilon^2_{1,t-1} + \xi_2\varepsilon^2_{3,t-1} + \nu_2\varepsilon^2_{4,t-1} \quad (6)$$

$$\sigma^2_{3,t} = \omega_3 + \lambda_3\sigma^2_{3,t-1} + \iota_3\varepsilon^2_{3,t-1} + \psi_3\varepsilon^2_{1,t-1} + \xi_3\varepsilon^2_{2,t-1} + \nu_3\varepsilon^2_{4,t-1} \quad (7)$$

$$\sigma^2_{4,t} = \omega_4 + \lambda_4\sigma^2_{4,t-1} + \iota_4\varepsilon^2_{4,t-1} + \psi_4\varepsilon^2_{1,t-1} + \xi_4\varepsilon^2_{2,t-1} + \nu_4\varepsilon^2_{3,t-1} \quad (8)$$

The unautocorrelated terms $\varepsilon_{1,t}$, $\varepsilon_{2,t}$, $\varepsilon_{3,t}$, and $\varepsilon_{4,t}$ in Equations (5)–(8) are the residuals from Equations (1)–(4). In Equations (5)–(8), the asset's conditional volatility is influenced not only by past residual shocks from its own markets, but also by those from other markets. As a result, this model can capture both volatility clustering (represented by coefficients λ_i and ι_i) in each market and volatility spillovers (measured by coefficients ψ_i, ξ_i, and ν_i) across these markets.

It is important to note that trading activities in both the Chinese spot and futures markets are concurrent. However, Chinese markets and US futures markets have both overlapped and non-overlapped trading periods. During the regular trading period of the NYMEX and CBOT on day t, Chinese markets on day t are closed, whereas the NYMEX and CBOT close their regular hours trading on day t before Chinese markets start trading on day $t + 1$. Non-synchronous trading causes the "daylight" issue of non-overlapped data. On the other hand, there is some overlap in trading between Chinese markets and the CME Globex trading session. For this reason, the measures for the long-term return and volatility spillover effect in our VECM–GARCH model are modified to account for both synchronous and non-synchronous trading information. Specifically, the long-run equilibrium error $P_{2,t-1} - P_{1,t-1}$ in Equations (1) and (2) represents the synchronous interactions between the Chinese futures and spot markets. The long-run equilibrium errors $P_{3,t-1} - P_{1,t-1}$ and $P_{4,t-1} - P_{1,t-1}$ in Equation (1) reflect the impact of US futures on Chinese futures, whereas both $P_{1,t} - P_{3,t-1}$ and $P_{1,t-1} - P_{4,t-1}$ in Equations (3) and (4) capture the effect of the Chinese futures on the US futures. Following So and Tse (2004) and Tse (1999), we first estimate the VECM to obtain the residuals, and then estimate Equations (5)–(8) simultaneously by maximizing the following log-likelihood function:

$$L(\Theta) = -\sum_{t=1}^{N}\left(\ln\left|\textstyle\sum_t\right| + \varepsilon_t^T \textstyle\sum_t^{-1} \varepsilon_t\right) \quad (9)$$

where Θ is the parameter vector.

To enhance the accuracy of our estimates, we adopt the BHHH algorithm (Berndt et al., 1974) with no constraints on parameters to maximize the log-likelihood function based on the Akaike information criterion (AIC).

2.2. Information share model

We first present a brief review of the information share (IS) measure of price discovery defined by Hasbrouck (1995) and the modified information share (MIS) measure proposed by Lien and Shrestha (2009). Then, we apply the MIS method to quantify a market's price discovery based on both synchronous and non-synchronous trading information.

Denote Y_t as a column vector of n cointegrated price series at time t. To illustrate the information share model, we consider the following Engle and Granger's (1987) VECM:

$$\Delta Y_t = \Pi Y_{t-1} + \sum_{i=1}^{k} A_i \Delta Y_{t-i} + \varepsilon_t \tag{10}$$

where $\Pi = \alpha\beta^T$, and α and β are $n \times (n-1)$ matrices. Each column of α is the error-correction terms, and matrix β consists of the n − 1 cointegrating vectors. The residuals ε_t are serially uncorrelated and have a covariance matrix denoted by Σ. Stock and Watson (1988) show that Equation (10) can be written as:

$$Y_t = Y_0 + \Psi(1)\sum_{i=1}^{t} \varepsilon_i + \Psi^*(L)\varepsilon_t \tag{11}$$

where $\beta^T\Psi(1) = 0$, $\Psi(1)\alpha = 0$, and Ψ^* is a polynomial in the lag operator.

Let $\psi=(\psi_1, \psi_2,\ldots, \psi_n)$ be the identical row of $\Psi(1)$. If covariance matrix Σ is diagonal, Hasbrouck (1995) defines the IS of market j as:

$$IS_j = \psi_j^2 \sigma_{jj} / \psi \Sigma \psi^T \tag{12}$$

If the covariance matrix is not diagonal, then the IS is given by

$$IS_j = \left([\psi F]_j\right)^2 / \psi \Sigma \psi^T \tag{13}$$

where F is the Cholesky factorization of Σ, and it is a lower triangular matrix. $[\psi F]_j$ is the jth element of the row vector ψF. The information share defined by Hasbrouck (1995) is based on the contributions of innovations in each market to the total variance. The major problem of this model is that it does not generate a unique measure of price discovery when the innovations are correlated, as the Cholesky factorization depends on the particular ordering of data series.

To solve this non-uniqueness problem, Lien and Shrestha (2009) propose an MIS model, which leads to a unique measure of price discovery. Specifically, the MIS of market j is defined as:

$$MIS_j = \left([\psi F^*]_j\right)^2 / \psi \Sigma \psi^T \tag{14}$$

where $F^* = [G\Lambda^{-1/2}G^T V^{-1}]^{-1}$. Λ is a diagonal matrix with diagonal elements being the eigenvalues of the innovation correlation matrix, and G is a matrix in which the columns are the corresponding eigenvectors. V is a diagonal matrix with diagonal elements being the innovation standard deviations. It is obvious that $\Sigma = F^*(F^*)^T$. Note that this factor structure involves a full matrix instead of a lower triangular matrix, thereby yielding a unique price discovery measure.

The MIS model provides a sensible measure of price discovery in synchronous trading markets. In our analysis, MIS_j is calculated for Chinese futures, Chinese spot, and CME Globex futures markets based on synchronous trading prices $Y_t = (P_{1,t}, P_{2,t}, P_{4,t})$. To quantify a market's price discovery in non-synchronous trading markets, we propose a new method based on the MIS approach. Specifically, let $n \times 1$ price series Y_t^d represent the price sequence for the case in which a group of markets trades before the other group as per calendar time, and $n \times 1$ series Y_t^f represents the data for the case in which the former group of markets is seen to follow the latter. In particular, in our analysis, trading in Chinese markets occurs prior to the NYMEX/CBOT market on day t; therefore, $Y_t^d = (P_{1,t}, P_{2,t}, P_{3,t})$. On the other hand, if day $t+1$ trading in Chinese markets is considered to follow the NYMEX/CBOT market on day t, then $Y_t^f = (P_{1,t+1}, P_{2,t+1}, P_{3,t})$ represents another possible ordering of the price sequence within 24 h.

Using both sequences, we calculate two MISs for market j, denoted by MIS_j^d and MIS_j^f, respectively. Then, the information share of market j in the non-synchronous (NIS) trading case is defined as the weighted average of both MISs:

$$NIS_j = \alpha \cdot MIS_j^d + \beta \cdot MIS_j^f \tag{15}$$

where $\alpha + \beta = 1$.

In Equation (15), the weights of MIS_j^d and MIS_j^f are determined based on the information contained in data series Y_t^d and Y_t^f, respectively. Since variances are directly related to information transmission (Ross, 1989), the series with a higher variance should carry a higher weight. For this reason, we use the rate between the variances of series Y_t^d and Y_t^f to calculate their respective weights. If V_d is the sum of the variance and covariance of Y_t^d, and V_f is the sum of the variance and covariance of Y_t^f, then the weights in Equation (15) are given as

$$\alpha = V_d / \left(V_d + V_f\right)$$

$$\beta = V_f / \left(V_d + V_f\right) \tag{16}$$

Based on MIS_j and NIS_j, we are able to properly measure the integrated information share (IIS) of market j, accounting for both synchronous and non-synchronous trading information.

$$IIS_j = w_S MIS_j + w_N NIS_j \tag{17}$$

where w_S and w_N are the percentages of synchronous and non-synchronous trading volumes in total trading volume, and $w_S + w_N = 1$.

3. Data

In this paper, we consider Chinese copper futures traded on the SHFE and soybean futures traded on the DCE. The copper spot contracts are traded in the Shanghai Metal Market, and the soybean spots are from www.dadou.com. The US commodity futures markets under consideration are copper futures traded on the NYMEX, soybean futures traded on the CBOT, and both futures in the CME Globex trading session.

Note that Chinese and US markets are in different time zones. In China, these futures markets trade from 9:00 a.m. to 3:00 p.m., while the NYMEX trades from 8:10 p.m. to 1:00 a.m. (Beijing time, BT) and the CBOT trades from 10:30 p.m. to 2:15 a.m. (Beijing time, BT) on the next day. This indicates that the regular trading hours of Chinese markets do not overlap at all with those of the NYMEX/CBOT markets. At the same time, the CME Globex copper futures trading period extends from 6:00 p.m.–5:15 p.m. (US Eastern time, ET), while the CME Globex soybean futures trading is from 6:00 p.m.–7:15 a.m. and 9:30 a.m.–1:15 p.m. (US Central time, CT). Therefore, CME Globex copper/soybean futures are traded throughout the entire trading period of Chinese markets, and are also traded when Chinese markets are closed. The trading periods for Chinese markets, NYMEX, CBOT, and CME Globex futures markets are depicted in Fig. 1, which clearly shows that there are overlapping and non-overlapping trading hours between Chinese and US futures markets. Electronic Globex trading of copper/soybean futures is believed to play an important role in information transmission, given the extended trading period and large trading volume relative to that of Chinese futures markets. This can be clearly seen in Fig. 2, which depicts Globex trading volumes of copper and soybean futures and trading volumes of SHFE copper and DCE soybean futures from November 9 to 13, 2009.

The SHFE currently trades futures on aluminum, copper, gold, zinc, natural rubber, and fuel oil. These commodities are considered by the Chinese government to be strategically important industrial inputs and thus are subject to no import quotas or duties. However, export of these commodities is restricted, though export duties have been significantly reduced since 1999. The DCE was founded in 1993 and primarily trades soybean futures. The trading volume of soybean futures on the DCE is now 23% of that on the Chicago Mercantile Exchange (CME), the largest soybean futures market in the

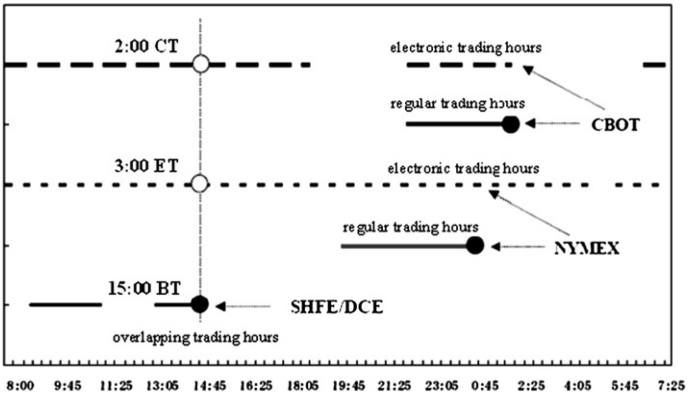

Fig. 1. Market trading hours in Chinese markets, NYMEX, and CBOT. This figure depicts trading hours of Chinese markets, the New York Mercantile Exchange (NYMEX), and the Chicago Board of Trade (CBOT) in terms of Beijing time. CT, ET, and BT stand for US Central time, US Eastern time, and Beijing time, respectively.

world, and 13 times the trading volume of the third largest market, Tokyo Grains Exchange.[2] Therefore, Chinese copper and soybean futures markets are the most dramatically expanding emerging markets in the world and have a significant influence on international markets. However, Chinese futures markets are still relatively immature and differ from developed markets in many respects. Relative to developed markets, there are only a limited number of futures products actively traded in Chinese markets, and most traders are individual, not institutional, investors. The futures contracts traded on the SHFE/DCE relative to spot contracts are smaller than those on mature exchanges. For instance, the ratio of the total trading volume of soybean futures on the CME to the spot trading volume was 59 in year 2008, while it was only 21 on the DCE for the same year.[3] Chinese futures markets exhibit strong regional characteristics, and have low liquidity compared with developed markets, such as the NYMEX and CBOT.

Table 1 displays institutional characteristics of Chinese and US markets for copper and soybean contracts, including trading locations and trading hours. Note that the daily price limit in the Chinese futures markets is 3% of the previous settlement price, while there is no such a price limit that halts trading in both the NYMEX and CBOT markets. Imposing price limits may lower the market's capability of quickly and accurately incorporating new information into futures prices. The trading mechanism for copper and soybean futures on the SHFE and DCE is a continuous computerized trading system, whereas the trading mechanisms for the two futures contracts in the US include both open outcry and electronic trading. As we know, the trading mechanism, contract size, and tick size greatly affect transaction costs and trading activities in markets. Thus, these institutional distinctions between Chinese and US markets may help explain their different roles in information transmission and price discovery.

The futures data are daily closing prices obtained from the corresponding exchanges, while the daily spot closing prices for soybean spots are obtained from http://www.dadou.cn.[4] The sample period is from January 2, 2004 to December 31, 2009.

Each futures price series is constructed by rolling over the nearby futures contract on the first trading day of the next month (for copper contracts) or the contract's expiration month (for soybean contracts). The nearby futures contracts are used, as these are the most liquid and actively traded

2 Source: *Shanghai Securities News*, August 18, 2009.

3 Source: *Futures daily*, August 17, 2009.

4 http://www.dadou.cn provides the most comprehensive, accurate, and updated information about the Chinese soybean market.

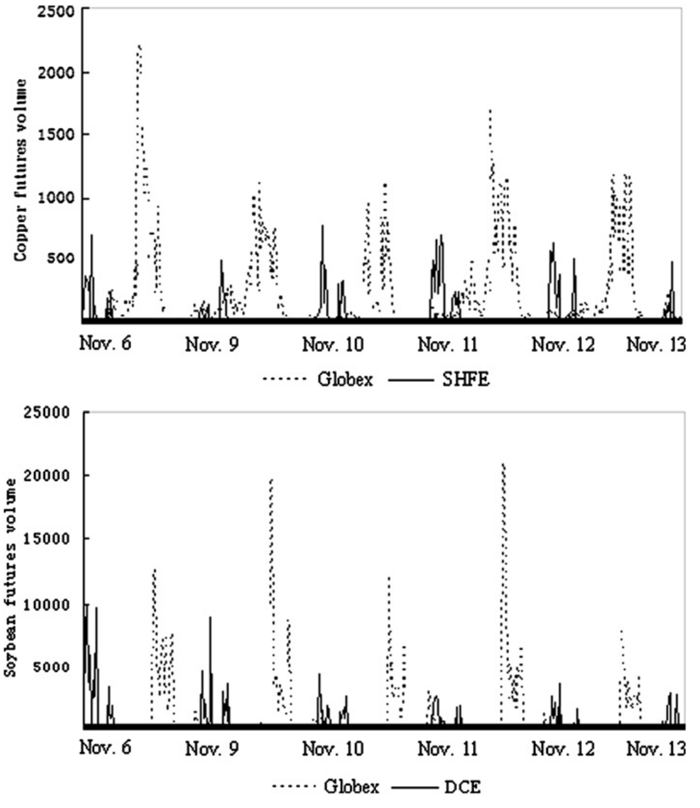

Fig. 2. Trading volumes of copper and soybean futures on the SHFE, DCE, and CME Globex. This figure displays 5-min trading volumes of copper and soybean futures on the SHFE, DCE, and CME Globex for the period from November 6, 2009 to November 13, 2009. SHFE and DCE stand for Shanghai Futures Exchange and Dalian Commodity Exchange, respectively.

contracts in markets.[5] To make the data for Chinese markets and the data for US futures prices comparable, we use the Lagrange polynomial interpolation method to estimate those data that are not available due to holidays or non-trading days in a particular market. Consequently, we end up with a total of 1559 observations in our data sample for each price series.

For the purpose of comparison, the daily closing prices of copper futures traded on the NYMEX and those of soybean futures traded on the CBOT are converted into Chinese dollars (RMB) using the daily RMB/USD exchange rate provided by the Bank of China for this sample period. Moreover, the quotation units for futures contracts are also adjusted so that all are expressed in terms of RMB/ton.

Fig. 3 plots the price moving trends of the Chinese futures, Chinese spots, and US futures for copper and soybean data. In general, the moving trends of these prices exhibit similar patterns, indicating that a long-run dynamic relationship exists among them.

The descriptive statistics for the futures and spot returns are given in Panel A of Table 2. The returns for all data series are negatively skewed with excess kurtosis, indicating that they are not normally distributed. The Ljung-Box Q and Q-squared tests with 6 and 12 lags show that there is a strong auto-correlation in each series. The daily volatilities for the US copper and soybean futures data are higher than the values for their corresponding Chinese futures data, which in turn are higher than those for the

[5] Note that the most active futures in one market may be exposed to certain shocks that do not affect the most active futures in another market. Therefore, the data constructed using the most active futures may not accurately reflect interrelations among markets. We are grateful to the reviewer for pointing this out.

Table 1
Contract specifications for copper and soybean futures.

	Copper				Soybeans			
	Chinese futures	Chinese spots	US futures (regular trading)	US futures (electronic trading)	Chinese futures	Chinese spots	US futures (regular trading)	US futures (electronic trading)
Trading exchange	Shanghai Futures Exchange	www.smm.com.cn	New York Mercantile Exchange	New York Mercantile Exchange	Dalian Commodity Exchange	www.dadou.cn	Chicago Board of Trade	Chicago Board of Trade
Trading hours	9:00–11:30 a.m. 1:30–3:00 p.m. (Beijing time)	8:00 a.m.–5:30 p.m. (Beijing time)	8:10 a.m.–1:00 p.m. (US eastern time)	6:00 p.m.–5:15 p.m. (US eastern time)	9:00–11:30 a.m. 1:30–3:00 p.m. (Beijing time)	8:00 a.m.–5:30 p.m. (Beijing time)	9:30 a.m.–1:15 p.m. (US central time)	6:00 p.m.–6:00 a.m. 9:30 a.m.–1:15 p.m. (US central time)
Trading unit	5 tons/lot	Tons	25,000 pounds/lot	25,000 pounds/lot	10 tons/lot	Tons	5000 bushels/lot	5000 bushels/lot
Quotation unit	RMB/ton	RMB/ton	Dollar/pound	Dollar/pound	RMB/ton	RMB/ton	Dollar/bushel	Dollar/bushel
Tick size	10 RMB/ton	NA	0.05cents/pound	0.05cents/pound	1 RMB/ton	NA	0.25 cents/bushel	0.25 cent/bushel
Daily price limit	<3% of the previous settlement price	None	None	None	<3% of the previous settlement price	None	<50 cents/bushel	<50 cents/bushel
Contract months	Jan.–Dec.	Jan.–Dec.	Jan.–Dec.	Jan.–Dec.	Jan., March, May, July, Sept., Nov.	Jan.–Dec.	Jan., Mar., May, Jul., Aug., Sep., Nov.	Jan., Mar., May, Jul., Aug., Sep., Nov.
Trading system	Computer automated trading	Argy-bargy	Open outcry	CME Globex	Computer automated trading	Argy-bargy	Open outcry	CME Globex

Source: Shanghai Futures Exchange, Dalian Commodity Exchange, New York Mercantile Exchange, Chicago Board of Trade, www.smm.com.cn, and www.dadou.cn.

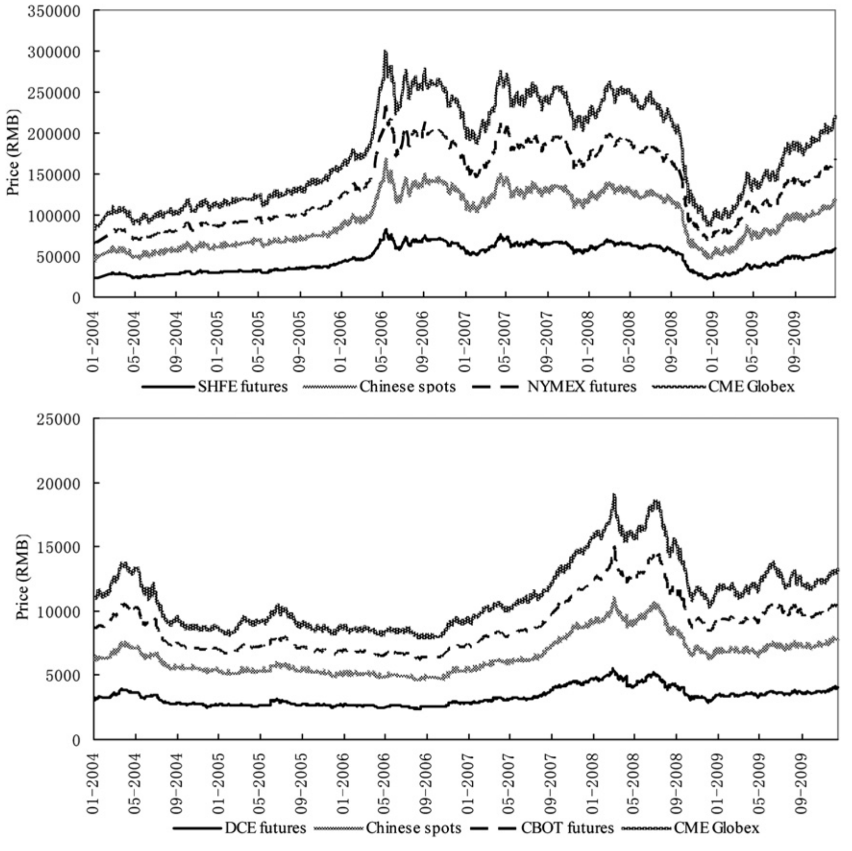

Fig. 3. Price moving trends of Chinese futures, Chinese spots, US futures for copper and soybeans. This figure displays price trends of Chinese futures, Chinese spots, and synchronously and non-synchronously traded US futures for copper (top) and soybean (bottom) contracts for the sample period from January 2, 2004 to December 31, 2009. SHFE, DCE, NYMEX, and CBOT stand for Shanghai Futures Exchange, Dalian Commodity Exchange, New York Mercantile Exchange, and Chicago Board of Trade, respectively.

Chinese spot contracts. The differences in volatilities among these markets reflect their different roles in information transmission. Panel B of Table 2 presents the correlations among the Chinese futures, Chinese spots, and US futures for both copper and soybean data. These markets are significantly positively correlated, with the highest correlation between the Chinese futures and spot markets and the lowest correlation between the Chinese spot and NYMEX/CBOT futures markets. In addition, it seems that Chinese futures are more correlated with synchronously traded futures in the Globex session than with non-synchronously traded futures in the NYMEX/CBOT. Panel C of Table 2 reports the unit root test results for all log-price series. Based on the augmented Dickey-Fuller (Dickey and Fuller, 1981) tests, we conclude that all log-price series are nonstationary, while the first differences of these series are stationary. Hence, all the data series are indeed integrated of order one, or I(1) series.

4. Empirical results

4.1. Cointegration tests

We employ the cointegration analysis to detect long-run and short-run dynamic relationships among these price series before examining the information transmission pattern and the price discovery mechanism. To this end, we first identify the optimal lag length in the cointegration

Table 2
Descriptive statistics of returns of Chinese futures, Chinese spots, NYMEX/CBOT futures, and CME Globex futures for copper and soybeans.

	Copper				Soybeans			
	$r_{1,t}$	$r_{2,t}$	$r_{3,t}$	$r_{4,t}$	$r_{1,t}$	$r_{2,t}$	$r_{3,t}$	$r_{4,t}$
Panel A: Summary statistics of daily returns								
Mean	6.07E-04	5.99E-04	5.98E-04	6.05E-04	1.52E-04	1.35E-04	5.18E-05	5.67E-05
S.D.	0.0197	0.0185	0.0231	0.0233	0.0152	0.0104	0.0195	0.0315
Skewness	−0.2035	−0.0282	−0.2384	−0.3608	−0.6684	−1.3441	−0.9258	−0.3246
Kurtosis	4.3654	7.1479	5.4264	7.3036	22.8929	30.6544	9.9759	40.2919
Maximum	0.1134	0.1032	0.1165	0.1233	0.1413	0.0888	0.0638	0.3088
Minimum	−0.075	−0.0999	−0.1141	−0.1594	−0.1817	−0.1252	−0.1886	−0.2855
LB(6)	27.701**	23.934**	21.215**	20.914**	21.611**	29.612**	118.17**	287.11**
LB(12)	34.093**	34.373**	24.918*	28.546**	32.699**	50.935**	256.54**	411.16**
$LB^2(6)$	520.60**	544.86**	322.01**	417.08**	69.791**	38.719**	73.862**	287.11**
$LB^2(12)$	909.23**	944.29**	648.80**	796.96**	173.423**	193.44**	204.90**	411.16**
Panel B: Correlations of returns								
$r_{1,t}$		0.7627**	0.2515*	0.4977**		0.5132**	0.2022**	0.2715**
$r_{2,t}$			0.1190**	0.4609**			0.0644*	0.1786**
$r_{3,t}$				0.3342**				0.1439**
Panel C: Stationarity tests								
ADF of $P_{i,t}$	−1.6995	−1.7869	−1.7184	−1.6705	−1.1531	−0.6714	−1.5038	−1.7007
ADF of $r_{i,t}$	−20.4855**	−38.3409**	−43.5826**	−44.1374**	−43.6410**	−38.2118**	−39.5643**	−13.1456**

This table reports summary statistics for daily return series of Chinese futures, Chinese spot, and US futures prices for copper and soybean contracts for the period from January 2, 2004 to December 31, 2009. Ljung-Box Q (LB) and Q-squared (LB^2) statistics with 6 and 12 lags for returns and squared returns are also provided. Correlations among these return series for copper and soybeans are presented in Panel B. Augmented Dickey-Fuller (ADF) test statistics for level and return series are reported in Panel C. ** and * indicate significance at the 1% and 5% levels, respectively.

equations based on the AIC criterion and find that the model has the lowest AIC at five lags. Next, we test for the cointegration relationships among these data series and the number of cointegrating vectors in the cointegration system using the methodology proposed by Johansen (1988, 1991) based on the trace and maximal eigenvalue statistics.

Table 3 reports Johansen cointegration test results for the data series of copper and soybean contracts. From results in Panel A, we can see that both the trace and maximal eigenvalue tests

Table 3
Cointegration tests.

	Copper			Soybeans		
Panel A: Test for number of cointegrating relationships						
H_0	Eigenvalue	Trace test	Maximal eigenvalue test	Eigenvalue	Trace test	Maximal eigenvalue test
$\rho = 0$	0.0833	192.1992** (<0.001)	135.0385** (<0.001)	0.0346	111.8871** (<0.001)	54.4213** (<0.001)
$\rho = 1$	0.0217	57.1607** (<0.001)	34.0724** (<0.001)	0.0235	57.4658** (<0.001)	36.7505** (<0.001)
$\rho = 2$	0.0131	23.0883** (<0.001)	20.4415** (<0.001)	0.0127	20.7153** (<0.001)	19.7379** (<0.001)
$\rho = 3$	0.0017	1.6468 (>0.200)	1.6468 (>0.200)	0.0006	0.9774 (>0.300)	0.9774 (>0.300)
Panel B: Estimated values of cointegrating vectors (3 cointegrating vectors)						
	Vector 1	Vector 2	Vector 3	Vector 1	Vector 2	Vector 3
Beta 1 ($r_{1,t}$)	−5.4028	45.3508	9.4684	5.3942	17.2844	−13.7876
Beta 2 ($r_{2,t}$)	3.1381	−22.6546	−27.6566	−5.3702	−16.1758	−1.7192
Beta 3 ($r_{3,t}$)	−132.9859	−17.9092	1.2323	−35.1945	11.1249	6.8442
Beta 4 ($r_{4,t}$)	135.1853	−5.2687	14.7917	36.1400	−9.3263	6.5718
Sum	−0.0653	−0.4817	−2.1642	0.9695	2.9072	−2.0908

This table reports results for Johansen (1991) cointegration tests on logarithmic price series of Chinese futures, Chinese spot, NYMEX/CBOT futures, and CME Globex futures for copper and soybean contracts. Panel A contains the trace and maximal eigenvalue test results for the number of unique cointegrating vectors (ρ) in the system. P-values are in parentheses. Panel B contains values for estimated cointegrating vectors (betas) and the sum of these betas. The sample period is from January 2, 2004 to December 31, 2009. ** and * indicate significance at the 1% and 5% levels, respectively.

significantly reject the null hypothesis of none, one, or two cointegrating vectors in the system, whereas these tests fail to reject the null hypothesis of three cointegrating vectors. Thus, the prices of Chinese futures, Chinese spots, US futures, and US futures in the Globex session are cointegrated with three unique cointegrated relationships, and they are all driven by one common stochastic factor. It is also shown that these findings are robust with respect to the number of lags used in the cointegration equations. The aforesaid conclusions are true for both copper and soybean data. To further investigate this issue, we estimate the cointegrating vectors (betas), which are presented in Panel B of Table 3. This test confirms that these prices do not deviate far from their long-run equilibria, as the sum of betas of these cointegrating vectors is generally very small. These findings are in line with those in the literature (e.g., Covrig et al., 2004; Roope and Zurbruegg, 2002).

4.2. Lead–lag relationships and volatility spillovers

To estimate Equations (1)–(4), we employ the AIC method to determine the optimal lag lengths. Following Xu and Fung (2005), we check the model with one, two, and three lags and find that the model with two lags yields the lowest AIC. Consequently, we consider the two-lag model in our following analysis.

Estimation results for the multivariate VECM–GARCH model using copper data are reported in Table 4. The Ljung-Box Q and Q-squared statistics with 6 and 12 lags for the residuals indicate that the residuals are not serially correlated at the 1% significance level. This suggests that the model is adequate to describe the dynamics of these price movements.

A number of observations can be derived from the estimation results in Panel A of Table 4. First, focusing on Chinese markets, the coefficient of the first lagged spot return $\beta_{1,1}$ in Equation (1) is significant with a value of 0.0650 (t-statistic = 3.331), whereas the coefficient of the first lagged futures return $\alpha_{2,1}$ in Equation (2) is also significant with a value of 0.0767 (t-statistic = 4.989). Additionally, the coefficients of both the second lagged returns are not significant. Note that cross-market coefficients of lagged returns measure the short-term impact of one market on another. This observation suggests that information flows rapidly between Chinese copper futures and spot markets, and that trading information from one market can be impounded into the other within one trading day. This is not surprising, given that copper futures and spots in Chinese markets are highly correlated. However, changes in the Chinese futures market have a stronger impact on the Chinese spot market in terms of the size of the coefficients and their statistical significance. Thus, the Chinese copper futures market leads the Chinese copper spot market in a more significant way than the other way around.

Second, regarding Chinese and NYMEX copper futures markets, the coefficient of the NYMEX futures return at the first lag in Equation (1) $\gamma_{1,1}$ is significant with a value of 0.3754 (t-statistic = 8.284), while the coefficient of the Chinese futures return at the first lag in Equation (3) $\alpha_{3,1}$ is also significant with a value of 0.0701 (t-statistic = 2.180). Therefore, the NYMEX copper futures market affects the Chinese futures market more significantly than the Chinese futures market affects the NYMEX futures market. Similarly, we can see that there is bivariate feedback between NYMEX futures and Chinese spot markets with a stronger and faster effect running from NYMEX futures to Chinese spots. On the other hand, Globex trading in copper futures seems to have a lagged and large impact on the Chinese futures market compared with the effect of the latter on the former one, while there is only a one-way explanation about pricing running from the Globex to Chinese spot market. The above observations suggest that there exists a bidirectional but asymmetric lead–lag relationship between Chinese and US copper futures markets. We conclude that US markets contain more information regarding copper returns than do Chinese markets. In addition, we notice that Chinese markets are affected more significantly by NYMEX trading than by Globex trading, indicating that the NYMEX provides more information than the Globex for the pricing of Chinese copper futures and spots.

The coefficients of the error-correction terms κ, θ, and τ, in the VECMs reflect the price adjustment toward the long-run equilibrium relationship between any two of these markets. Our results show that all these error-correction coefficients are significant at the 1% or 5% level, suggesting that all these markets react with respect to each other to maintain equilibrium. In this sense, all the copper markets under consideration are informationally efficient. Since the magnitude of κ_1 is higher than that of κ_2, Chinese futures prices adjust faster to correct disparity than do Chinese spot prices. In other words,

Table 4
Lead–lag relationships and volatility spillovers for copper markets.

	Chinese futures	Chinese spots	NYMEX	CME Globex
Panel A: Conditional mean equations (pricing transmission parameters)				
μ	0.0044** (3.171)	0.0027* (2.100)	−0.0019** (−3.328)	−0.0016(−1.336)
$\alpha_{\cdot,1}$	−0.3128** (−7.773)	0.0767** (4.989)	0.0701* (2.180)	0.0085* (1.984)
$\alpha_{\cdot,2}$	−0.0940* (−2.514)	0.0530 (1.508)	0.0076 (0.126)	0.0106 (0.369)
$\beta_{\cdot,1}$	0.0650** (3.331)	−0.1600** (−4.165)	−0.0269* (−2.335)	0.0272 (0.860)
$\beta_{\cdot,2}$	0.0376 (0.961)	−0.1076** (−2.759)	0.0027 (0.979)	0.0569* (2.234)
$\gamma_{\cdot,1}$	0.3754** (8.284)	0.3417** (8.741)	−0.1175* (−2.099)	0.2185** (5.110)
$\gamma_{\cdot,2}$	0.1255** (3.341)	0.0330 (1.019)	−0.0430(−1.857)	0.0696* (2.046)
$\varphi_{\cdot,1}$	−0.0158(−0.372)	0.0495* (2.304)	0.0528* (2.340)	−0.1077** (−2.955)
$\varphi_{\cdot,2}$	0.0439* (2.039)	0.0498* (2.016)	−0.0127(−0.286)	−0.0361(−1.649)
κ	0.0213* (2.290)	−0.0165* (−2.009)	0.1028** (4.007)	0.0327* (2.191)
θ	0.1570** (3.354)	0.0944* (2.299)	−0.0089* (−2.306)	−0.0229* (−2.106)
τ	−0.1240** (−2.650)	−0.0802* (−1.981)	0.8014** (14.499)	−0.7250** (−17.032)
Panel B: Conditional variance equations (volatility spillover parameters)				
ω	4.96E-6* (2.474)	2.20E-6* (1.995)	2.80E-4** (3.540)	1.92E-6* (2.555)
λ	0.0600** (3.413)	0.0748** (4.978)	0.1261** (3.123)	0.1262** (9.649)
ι	0.8239** (29.509)	0.8149** (34.146)	0.7213** (8.809)	0.8664** (44.541)
ψ	0.0506** (3.208)	0.0595** (4.682)	−0.0288* (−2.207)	−0.0035* (−2.028)
ξ	0.0391** (3.908)	0.0501** (3.252)	−0.0275* (−1.982)	0.0102* (2.407)
ν	−0.0212** (−3.895)	0.0131** (3.710)	−0.0394** (−6.683)	0.0016** (5.337)
Panel C: Ljung-Box Q statistics				
LB(6)	9.0616 [0.170]	4.8425 [0.564]	5.2240 [0.561]	14.3383 [0.116]
LB(12)	13.5340 [0.331]	6.8316 [0.869]	15.0091 [0.217]	7.0042 [0.799]
$LB^2(6)$	4.5564 [0.602]	3.6398 [0.725]	4.0772 [0.642]	3.3923 [0.758]
$LB^2(12)$	6.0657 [0.913]	5.6984 [0.931]	6.2837 [0.890]	5.0028 [0.958]

This table reports estimation results for the VECM–GARCH models given by Equations (1)–(8) using data for copper contracts from January 2, 2004 to December 31, 2009. The *t*-statistics are in parentheses. Ljung-Box Q statistics with 6 and 12 lags for standardized residuals and squared residuals are insignificant at the 1% level, where probability values are in square brackets. ** and * indicate significance at the 1% and 5% levels, respectively.

Chinese copper futures update market information more efficiently than do Chinese copper spots. At the same time, a comparison between magnitudes of θ_1 and κ_3, as well as those of τ_1 and κ_4, indicates that the SHFE futures market seems to respond faster than US futures markets (NYMEX and Globex trading) when their cointegrating relationship is perturbed by the arrival of news. This demonstrates the leading role of US copper futures in processing information, as it is primarily the SHFE futures that need adjustments to maintain the long-run NYMEX–SHFE relation.

The estimated coefficients in conditional variance equations (5)–(8) are reported in Panel B of Table 4. First, we observe that volatilities spillover from one market to another, because all the estimated coefficients ψ, ξ, and ν in these markets are significant at the 1% or 5% level. However, different markets have different capabilities of spilling over their volatilities in terms of the size and statistical significance of the coefficients. For example, the coefficient for volatility spillover from the Chinese futures market to Chinese spot market is 0.0595 with a *t*-statistic of 4.682, while the spillover coefficient from the Chinese spot to Chinese futures markets is 0.0506 with a *t*-statistic of 3.208. Therefore, the spillover effect from Chinese futures to Chinese spots is stronger than in the other direction. While there is bidirectional spillover between Chinese and US futures markets, the effects from US futures to Chinese futures ($\xi_1 = 0.0391$with *t*-statistic $= 3.908$ for NYMEX, and $\nu_1 = -0.0212$ with *t*-statistic $= -3.895$ for Globex) are slightly stronger than those from Chinese to US futures markets ($\psi_3 = -0.0288$with *t*-statistic $= -2.207$ for NYMEX, and $\psi_4 = -0.0035$ with *t*-statistic $= -2.028$ for Globex). These findings confirm the informational role of US futures as an international leader in financial markets in the case of copper futures, which is expected. Interestingly, our analysis sheds light on the importance of the Chinese copper futures market in information transmission particularly in terms of volatility spillovers to the NYMEX, though the Chinese futures market is relatively immature compared with the NYMEX. This can be explained by the important status of the Chinese copper market in international markets. During the past 10 years, Chinese copper consumption has grown

Table 5
Lead–lag relationships and volatility spillovers for soybean markets.

	Chinese futures	Chinese spots	CBOT	CME Globex
Panel A: Conditional mean equations (pricing transmission parameters)				
μ	0.0043** (2.616)	0.0033** (3.139)	−0.0050* (−2.002)	−0.0047(−0.538)
$\alpha_{\cdot,1}$	−0.2115** (−6.863)	−0.0149** (−2.946)	−0.0381* (−2.187)	0.0299 (0.306)
$\alpha_{\cdot,2}$	−0.0226* (−2.201)	0.0079* (2.007)	−0.0239(−0.410)	0.0530* (2.208)
$\beta_{\cdot,1}$	−0.0049* (−2.163)	−0.0004* (−1.999)	−0.0241* (−2.278)	0.0561 (0.4002)
$\beta_{\cdot,2}$	−0.0497* (−2.147)	0.0436 (1.364)	−0.0057(−1.097)	0.0906 (0.6193)
$\gamma_{\cdot,1}$	0.2465** (8.892)	0.0427** (3.771)	0.0322* (2.166)	0.7394** (10.564)
$\gamma_{\cdot,2}$	0.0487 (1.658)	0.0317* (2.058)	−0.0351(−0.998)	0.4573** (4.568)
$\varphi_{\cdot,1}$	0.0069* (2.382)	0.0148* (1.977)	0.0025 (0.564)	−0.6022** (−9.912)
$\varphi_{\cdot,2}$	0.0276* (2.142)	0.0198** (2.915)	−0.0345* (−2.168)	−0.1940** (−3.668)
κ	0.0060* (1.968)	0.0063* (2.017)	0.0244* (1.967)	0.0080 (0.245)
θ	0.0027* (2.189)	0.0074* (1.992)	−0.0137* (−2.075)	0.0053 (0.1703)
τ	0.0066* (2.411)	0.0028* (2.359)	0.1576** (7.381)	0.1347** (5.248)
Panel B: Conditional variance equations (volatility spillover parameters)				
ω	1.86E-5** (8.749)	3.17E-6** (14.529)	2.83E-4* (1.965)	4.30E-4** (4.411)
λ	0.0276** (3.062)	0.1092** (14.920)	0.1139* (2.167)	0.1493** (2.807)
ι	0.7961** (23.507)	0.8340** (26.175)	0.7282** (12.271)	0.7557** (9.190)
ψ	−0.0071* (−1.973)	−0.0089** (−8.079)	−0.0253* (−2.249)	−0.0029* (−5.904)
ξ	0.0672** (8.856)	0.0307** (9.148)	−0.0210* (−2.001)	−0.0679** (−7.083)
ν	−0.0073** (−7.548)	0.0808** (−8.652)	0.0221* (2.174)	−0.0605** (−9.398)
Panel C: Ljung-Box Q statistics				
LB(6)	2.5478[0.863]	5.0383 [0.473]	3.9912 [0.730]	9.8830 [0.216]
LB(12)	8.3535 [0.757]	9.0372 [0.689]	11.8022 [0.451]	7.8842 [0.643]
$LB^2(6)$	1.4564 [0.967]	0.6901 [0.995]	0.6700 [0.994]	5.9005 [0.427]
$LB^2(12)$	2.4021 [0.999]	0.9600 [0.947]	2.9027 [0.959]	3.2346 [0.929]

This table reports estimation results for the VECM–GARCH models given by Equations (1)–(8) using data for soybean contracts from January 2, 2004 to December 31, 2009. The *t*-statistics are in parentheses. Ljung-Box Q statistics with 6 and 12 lags for standardized residuals and squared residuals are insignificant at the 1% level, where probability values are in square brackets. ** and * indicate significance at the 1% and 5% levels, respectively.

dramatically, about 2.4 times the world average. China is now the world's largest copper consumer at a rate of 5.2 million metric tons in 2008, accounting for more than 27% of the world supply for that year. In addition, over 28% of the copper consumed in China is imported. Accordingly, in terms of trading volume, the SHFE copper futures market is larger than the NYMEX and ranks second only behind the LME. The prices of copper futures traded on the SHFE, together with those on the LME and NYMEX, are an important indicator for the world's copper mining industry.

Table 5 reports the estimation results for the VECM–GARCH model using soybean data. Consistent with findings from copper contracts, we find that Chinese soybean futures and spot markets interact with each other, and the futures market has a stronger impact on the spot market than the other way around. However, these effects seem to be more persistent in soybean markets than those in copper markets, as both the coefficients on the second lagged returns are significant at the 5% level. In addition, the results suggest that there is bidirectional but asymmetric short-run causality between Chinese futures/spots and CBOT futures markets, with the stronger effect from CBOT futures to Chinese markets. We also notice that Globex trading of soybean futures has significant impacts on both Chinese futures and spot markets, whereas the impact of Chinese spots on Globex soybean futures returns is a negligible.

Based on error-correction coefficients κ, θ, and τ, we find that price adjustments take place to maintain equilibrium in almost all markets. However, Globex soybean futures do not directly react to temporary changes in its long-run relationship with Chinese markets. This is because the trading volume of Globex soybean futures is substantially lower than that of CBOT futures, and Globex futures are greatly affected by trading in the CBOT. Consequently, it is the task of the CBOT (not the Globex) to maintain equilibrium between US and Chinese markets. The Globex responds to changes in CBOT futures market directly. Contrary to the case of copper markets, CBOT futures respond more quickly to disequilibria than do Chinese markets. This illustrates that relative to Chinese markets, CBOT futures

Table 6
Price discovery weights in copper and soybean markets.

	Copper			Soybeans		
	Chinese futures	Chinese spots	US futures	Chinese futures	Chinese spots	US futures
Panel A: Information share based on non-synchronous trading information						
MIS^d (%)	37.00	19.51	43.49	39.57	19.40	41.03
MIS^f (%)	39.76	17.34	42.90	41.03	16.46	42.51
Weights of MIS^d	0.4529			0.5314		
Weights of MIS^f	0.5471			0.4686		
NIS (%)	38.51	18.32	43.17	40.26	18.02	41.72
Panel B: Information share based on synchronous trading information						
MIS (%)	38.70	17.08	44.22	40.99	12.90	46.11
Panel C: Integrated information share						
Weights of NIS	0.6505			0.9024		
Weights of MIS	0.3495			0.0976		
IIS (%)	38.58	17.89	43.53	40.33	17.52	42.15

This table reports the Lien and Shrestha's (2009) modified information share (MIS) measure of price discovery based on synchronous trading information, the non-synchronous trading information share (NIS) as per our method, and integrated information share (IIS) for each market. MIS^d corresponds to the MIS based on price series $(P_{1,t}, P_{2,t}, P_{3,t})$ and MIS^f corresponds to the MIS based on $(P_{1,t+1}, P_{2,t+1}, P_{3,t})$, where $P_{1,t}$, $P_{2,t}$, and $P_{3,t}$ are daily logarithmic prices for Chinese futures, Chinese spot, and NYMEX/CBOT futures for copper and soybean contracts on date t. The sample period is from January 2, 2004 to December 31, 2009.

market interprets changes in price differentials between both markets as particularly more important information that needs to be quickly reflected in price movements. The particularly important role that Chinese markets play in information flow across Chinese and US futures markets is primarily due to the fact that China is now the world's largest soybean importing country, while the US is the largest soybean producer and exporter. Consequently, changes in Chinese soybean spot and futures markets will have a stronger impact on the US soybean market.

The results in Panel B of Table 5 reconfirm that the Chinese futures, Chinese spot, and US futures markets for soybeans are indeed interrelated, in the sense that volatilities spillover from one market to others with a stronger effect from the US futures market to the Chinese futures market, and a stronger effect from the Chinese futures market to the Chinese spot market. This is in line with the findings in copper markets.

4.3. Contribution of price discovery

Table 6 presents the results for price discovery measured by the IIS defined in Equation (17). For the purpose of comparison, Lien and Shrestha's (2009) MIS and the NIS are also reported. We find that price sequence $Y_t^d = (P_{1,t}, P_{2,t}, P_{3,t})$ contains less information than price sequence $Y_t^f = (P_{1,t+1}, P_{2,t+1}, P_{3,t})$ for copper markets, while the converse is true for soybean markets. We also find that the weights of information share based on non-synchronous trading are approximately 65% and 90% for copper and soybean markets, respectively. As a result, the NYMEX/CBOT futures trading plays a primary role in the price discovery process compared with the Globex futures trading. This is particularly pronounced in soybean futures markets, as approximately 90% of the total trading occurs in the CBOT.

The total proportions of the information share attributed to the Chinese futures, Chinese spots, and US futures are 38.58%, 17.89%, and 43.53%, respectively for copper, while the corresponding numbers for soybeans are 40.33%, 17.52%, and 42.15%, respectively. Based on these findings, we conclude that US futures markets contribute most to the price discovery process, followed by Chinese futures, and that Chinese spots contribute least. It is noteworthy that the information share commanded by SHFE futures represents 46.99% of the futures market's contribution (both Chinese and US futures) for the case of copper, whereas almost half (48.90%) of the soybean futures market's share comes from the DCE market. This highlights the remarkable role of Chinese futures markets in the price formation process relative to US futures, although US futures markets are the main driving force in price discovery. The international role of Chinese soybean futures in price discovery and information transmission seems to be relatively greater than that of Chinese copper futures.

Furthermore, for both copper and soybean markets, futures markets typically account for 82% of the information share, while spot markets account for only 18%, approximately. In Chinese markets, the futures market contributes 68% to the total information share in the case of copper and 70% in case of soybeans. It follows that futures markets play a dominant role in the price discovery process, which is consistent with the findings in the literature. Our analysis provides further evidence in favor of the trading cost hypothesis proposed by Fleming et al. (1996), based on both synchronous and non-synchronous trading information.

5. Conclusions

This paper examines patterns of information transmission in informationally linked markets based on synchronous trading information from Chinese futures/spot markets and CME Globex, as well as non-synchronous trading information from NYMEX and CBOT futures markets for copper and soybeans. In particular, we investigate the lead–lag relationships and volatility spillover effects among these markets in the VECM–GARCH model framework, and explore the contribution of each market to price discovery using a new method.

The results show that the price series for Chinese futures, spots, and US futures are cointegrated with one common stochastic factor. There exist bidirectional but asymmetric lead–lag relationships between Chinese futures and spot markets as well as between Chinese and US futures markets in terms of information transmission. Overall, US futures markets lead Chinese futures markets, which in turn lead Chinese spot markets in the short run. Additionally, Chinese markets are affected more significantly by NYMEX/CBOT trading than by CME Globex trading. These observations are true for both copper and soybeans. However, copper and soybean markets interpret the long-run equilibrium relationship between Chinese and US markets differently. For copper contracts, Chinese markets react more quickly to changes in the cointegrating relationship between Chinese and US markets, while the converse is true for the soybean contracts. This demonstrates the particularly important role that Chinese soybean markets play in information transmission between Chinese and US markets. In addition, volatilities spillover from one market to others, and the spillover effects from the US futures market to the Chinese futures market, and those from the Chinese futures market to the Chinese spot market, are stronger than in the other direction.

In terms of price discovery measured by integrated information share, we find that price discovery mostly occurs in US futures markets, then in Chinese futures markets, and lastly in Chinese spot markets. Interestingly, the contribution of Chinese futures markets to the price discovery process is remarkable, though these markets are immature relative to NYMEX and CBOT futures markets. Our findings provide insights into the informational role of emerging markets relative to mature markets.

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