1-2003

Effects of Electronic Trading on the Hang Seng Index Futures Market

Joseph FUNG
Hong Kong Baptist University

Donald LIEN
University of Texas at San Antonio

Yiuman TSE
University of Texas at San Antonio

Yiu Kuen TSE
Singapore Management University, yktse@smu.edu.sg

SMU ECONOMICS & STATISTICS
WORKING PAPER SERIES

Effects of Electronic Trading on the Hang Seng Index Futures Market

Joseph Fung
Donald Lien
Yiuman Tse
Yiu Kuen Tse

January 2003

Paper No. 2-2003

Effects of Electronic Trading on the Hang Seng Index Futures Market

Joseph Fung
Hong Kong Baptist University

Donald Lien
University of Texas at San Antonio

Yiuman Tse
University of Texas at San Antonio

Yiu Kuen Tse
Singapore Management University

Abstract: This paper investigates the effects of the migration of the Hang Seng Index futures from open-outcry trading to electronic trading. Using trade data over a window of six months we find evidence that, after the migration, the bid-ask spread of the futures contract decreases and the contribution of the futures price in information transmission increases. Furthermore, the asymmetry in volatility spillover reduces and the open interests of the futures market become smaller. These results suggest that the anonymity in trading and the higher speed of order execution in the electronic trading system attract informed traders to the futures market and increase the information flow.

1. INTRODUCTION

Advances in information technology prompt exchanges to consider electronic trading systems as an alternative to open-outcry systems. To evaluate and compare the two systems, one often relies upon the concept of market quality. From the perspective of market operation, posted bid-ask spread and its modification reflect market frictions and serve as a measure of transaction cost (albeit somewhat imprecisely). Thus, a system with a smaller bid-ask spread should be preferred. Earlier studies by Grossman and Miller (1986) and Miller (1991) suggest that open-outcry system leads to a more liquid market and is therefore less expensive to trade. The anonymity prevailing in the electronic trading system depletes the information floor traders may otherwise observe in an open-outcry system. Concerns for adverse selection produce a larger bid-ask spread. Coval and Shumway (2002) confirmed that "sound" in trading pits is more than "noise"; it carries information value.

Recent works by Blennerhasset and Bowman (1998) and Frino, McInish and Toner (1998) provide empirical support for a smaller bid-ask spread in the electronic trading system. Pirrong (1996) argued that a priori there is no reason to suppose one system to be better than the other, as the sources of liquidity provision are different under the two systems. Vila and Sandmann (1996) concurred with this conclusion. Gilbert and Rijken (2002) found that the determinants of bid-ask spread are quite different across the two systems. The results suggest that the effects of electronic trading on bid-ask spread may vary case by case. Indeed, simulation studies by Domowitz (1990) found that stocks and options display poor properties of liquidity provisions under electronic trading whereas encouraging evidence is found in the futures markets.

As a derivative security, a futures contract is expected to fulfill a price-discovery function. Domowitz (1993) suggested that electronic trading has the potential to outperform the open-outcry system with respect to the speed of convergence to competitive equilibrium. When the market is inactive, floor traders have little to observe. On the other hand, electronic order book continues to inject information to the market and therefore speeds up the equilibrium convergence rate. Electronic trading in futures markets improves the price-discovery function. As a result, under the electronic trading system, the lead-lag relationship between the futures and spot markets is strengthened, the contemporaneous correlation between the spot and futures prices is improved, and the asymmetric response to good/bad news is less evident. Furthermore, volatility spillover is expected to be stronger and more prominent.

On the other hand, in an electronic trading system concerns for adverse selection may discourage trading and reduce the speed of price convergence during periods of high volatility (which also display high information intensity) due to trader anonymity. The delays reduce the information transfer from the futures to the spot markets, as well as the contemporaneous correlation between the two. Overall, the effects of electronic trading on the price-discovery function of the futures market depend upon the trading intensity in the market. Beelders and Massey (2002) found that the index futures market becomes more informative after the introduction of electronic trading on the Johannesburg Stock Exchange. The opposite, however, is true in the gold futures contracts.

On June 6, 2000, trading in the Hang Seng Index (HSI) futures contracts migrated from floor open-outcry to electronic trading. This paper investigates the effects of electronic trading on the bid-ask spread and the price-discovery function of the HSI futures market. We find that, after the migration to electronic trading, the bid-ask spread of the futures market decreases and the contribution of the futures price in information transmission (both information share and volatility spillover) increases. Furthermore, the asymmetry in volatility spillover reduces and the open interests of the futures market become smaller. These results suggest that the anonymity in trading and the higher speed of order execution in the electronic trading system attract informed traders to the futures market and increase the information flow.

The balance of this paper is as follows. In Section 2 we describe the data set we are analyzing. The methodology and the results are given in Section 3. Section 4 concludes the paper.

2. DATA

The Hong Kong stock market was ranked 12th in the world in 2000 by total market capitalization, and was second only to Japan in the Asia-Pacific region. Exchange-listed stocks in Hong Kong have been traded onscreen via the Automatic Matching and Execution System (AMS) since November 1, 1993. The system was expanded to allow for the installation of off-the-floor terminals on January 25, 1996. The Hang Seng Index (HIS) futures contract was ranked 7th worldwide in total volume in year 2000 with over 4 million contracts traded. It was traded in the pit via the conventional open-outcry method until June 5, 2000. Effective from 6 June, the futures trading migrated to an electronic trading platform – the Hong Kong Futures Automatic Trading System (HKATS). Contracts for the spot month, the next two calendar months, and the next two quarterly months, are available. However, trading is mostly concentrated on the spot-month contract, although the trading volume of the next-month contract exceeds that of the spot-month contract on the latter's last trading day most of the time.

We collected data on the cash index and the index futures covering an event window of six months before and after the change. The period of November 1, 1999 to April 30, 2000 (Period 1 hereafter) represents pre- migration, and the period of July 1, 2000 to December 30, 2000 (Period 2 hereafter) represents post-migration. There are 123 and 125 trading days in Period 1 and Period 2, respectively. Data for the month of May and June have been deleted to avoid potential data problem that may be caused by the market's unfamiliarity with the new system. We use the data to analyze the potential impact of the migration of futures to electronic trading on the relative informational role between the cash and the index futures markets,

The cash index data consist of the minute-by-minute index value provided by the Hang Seng Index Services Ltd. Tick-by-tick transaction records of the Hang Seng Index futures for the period is provided by the Hong Kong Futures Exchange (HKFE). We focus on the spot-month contract. However, since liquidity is dominated by the next-month contract on the last trading day of the spot contract, the price data of the next-month contract is substituted for that of the spot month on the latter's last trading day. To enhance the comparison between the dynamics of the cash index and of the index futures returns, we adopt a futures price series that is synchronous with the cash index series. The high level of synchronicity between the two price series is achieved by matching the stamped time of the futures price with the sampling time interval of the cash index. The minute-by-minute frequency results in a sample of 29,427 observations for Period 1 and 29,837 observations for Period 2.

Daily data on the open interest and volume of all traded contracts are retrieved from the HKFE website. To examine the potential impact of the switch in the trading system on the bid-ask spread of the futures contract, a complete record of the bid and ask futures price quotes for the study period are obtained from the HKFE. The comparison focuses on the spot-month contract but the quotes of the next-month contract are substituted for those of the spot-month contract on its last trading day.

3. METHODOLOGY AND RESULTS

As a preliminary analysis of the effects of the switch in the trading system on the data, we apply Chow's test for structural break. The result shows that there is no significant structural break due to the migration to electronic trading. Chow's test, however, examines the change in the unconditional distribution and may provide weak evidence if structural change prevails in the conditional distribution. We shall analyze the effects of the switch in the trading system with parametric models that incorporate possible changes in the parameter values. Our analysis covers the following aspects. First, we examine the changes in the spread, volume and open interests in the futures market. Next, we examine the pattern of price-discovery and informational shares of the index and the futures under the two trading system. Finally, we investigate the volatility spillover between the index and futures markets pre- and post-migration.

3.1 Spreads, Volume, and Open Interest of the Futures Market

We define the relative bid-ask spread as

$$\text{Relative Bid-Ask Spread} = \frac{A_t - B_t}{M_t} \times 100\%, \tag{1}$$

where A_t and B_t are the quoted ask and bid prices, respectively, and $M_t = (A_t + B_t)/2$ is the mid-quote. The daily average relative spread in Period 1 is 0.038%. It reduces significantly to 0.032% in Period 2 (the *t*-statistics is −16.43). This result is consistent with the notion that trading costs decrease under electronic trading. Tse and Zabotina (2001) also reported a decrease in the spreads when the London International Financial Futures and Options Exchange (LIFFE) transferred the FTSE 100 Index futures contracts from open-outcry to electronic trading in May 1999. This is an indication that the lower transaction cost (proxied by the bid-ask spread) in the electronic trading system is able to attract more informed traders

During the open-outcry trading period, the daily average open interest and trading volume of the futures contracts were 37,925 and 16,361 contracts, respectively. The daily average open interest and trading volume for the electronic trading period were 35,453 and 16,811 contracts, respectively. The decrease in the open interest after migration to electronic trading is statistically significant with a *t*-statistic of −4.98, while the increase in the trading volume is insignificant with a *t*-statistic of 0.57.

Bessembinder and Seguin (1993) pointed out that the open interest is a proxy for the amount of uninformed trading because open interest reflects hedging activity. The decrease in open interest after electronic trading in the Hong Kong futures market may suggest that electronic trading attracts informed traders and, accordingly, the proportion of uninformed trading becomes smaller. We shall provide more evidence on this suggestion in the following sub-section.

3.2 Price Discovery and Information Shares

We follow the time series analysis employed in Tse (1999a) to investigate price discovery and volatility spillover between the Hong Kong index and futures markets. Many papers, e.g., Wahab and Lashgari (1993) and Koutmos and Tucker (1996), have found that the index and futures prices are cointegrated with a common stochastic factor or implicit efficient price. These results are expected because of the cost-of-carry relationship between the index and futures markets. Arbitrage prevents the two prices from diverging. We confirm the cointegration relationship (not reported here but available upon request) in the current study using the Johansen (1991) test.

The bivariate cointegrated series, $X_t = (s_t, f_t)'$, can be represented by the following vector error correction model (VECM):

$$\Delta X_t = bz_{t-1} + \sum_{i=1}^{p} A_i \Delta X_{t-i} + e_t \ , \tag{2}$$

where s_t and f_t are the logarithm of the index and futures prices, respectively, z_{t-1} is the differential between the two prices (i.e., the error correction term), b is a 2×1 vector of parameters, A_i are 2×2 matrices of parameters, and e_t is the vector of unautocorrelated innnovations/residuals. The constant terms are omitted for simplicity.

Hasbrouck (1995) transformed the VECM in equation (2) into the following common-factor model:

$$X_t = \begin{bmatrix} 1 \\ 1 \end{bmatrix} \Theta \sum_{\tau=1}^{t} e_\tau + \Phi^*(L) e_t \tag{3}$$

where Θ is a 1×2 row vector and $\Phi^*(L)$ is a matrix polynomial in the lag operator L. Hasbrouck showed that the increment Θe_t in equation (3) is the permanent component of price changes and is driven by new information. He described the common factor as the efficient price. Equation (3) is closely related to the following common factor representation of Stock and Watson (1988):

$$X_t = h_t + G_t, \tag{4}$$

where h_t is the common factor (analogous to e_t in Hasbrouck's model) and G_t is the temporary component that does not have a permanent impact on X_t.

Hasbrouck (1995) defined a market's contribution to price discovery – the process of impounding new information into the price – as its information share, or the proportion of the efficient price innovation variance that can be attributed to that market. The higher the information share, the more the market contributes in the price discovery process. See Hasbrouck for the detailed analysis of the model.

Hasbrouck (1995) showed that the information shares estimated depend on the order the variables are represented in the model if the innovations e_t are correlated such that $\mathrm{Corr}(e_{1t}, e_{2t}) \neq 0$. More specifically, the results depend on the order of the variables in the Cholesky decomposition of the residual covariance matrix in the VECM of equation (1). The upper (lower) bound of the information share for f_t is associated with f_t (s_t) being the first variable in the decomposition. Baillie et al. (2002) investigated this issue in detail and showed that the average of the upper and lower bounds provides a sensible estimate. Marten (1998), Tse (1999b), and Booth et al. (2002) also used the average to interpret their information-share results in various empirical studies.

The information shares can be derived from the results of the VECM (see Hasbrouck (1995) and Baillie et al. (2002)). We estimate the VECM with 10 lags; results are similar for 15 lags. Table 1 reports the results of the information shares of Hasbrouck

(1995). Because the correlations between the innovations are highly significant (0.674 in Period 1 and 0.535 in Period 2) the lower and upper bounds of the information shares are considerably different as shown in the table. Using the average values, we find that during the open-outcry trading system, the information shares attributed to the index and futures market are 43.5% and 56.5%, respectively, suggesting that the futures market contributes more in the price-discovery process.

The dominance of the futures in impounding information is more pronounced during the electronic trading system with an information share of 65.6%, while the index's share drops to 34.4%. The increase in the futures market's information share during Period 2 suggests that the HKATS attracts a higher percentage of informed orders compared to the uninformed orders. Informed traders are attracted by the anonymity and immediate execution offered by the electronic trading in the futures market.

3.3 Volatility Spillover

We now analyze the information transmission mechanism between the Hong Kong index and futures markets by examining the volatility spillover process between the two markets. Understanding the volatility process is important because, as shown by Ross (1989), the variance of price changes (not the price change itself) is related directly to the rate of information flow. We use the following bivariate EGARCH(1,1)-*t* model to investigate the volatility spillover mechanism:

$$e_t = \begin{bmatrix} e_{1t} \\ e_{2t} \end{bmatrix} \Big| Q_{t-1} \sim \text{Student-}t(0, H_t, v), \quad H_t \equiv \begin{bmatrix} \sigma_{1t}^2 & \rho\sigma_{1t}\sigma_{2t} \\ \rho\sigma_{1t}\sigma_{2t} & \sigma_{2t}^2 \end{bmatrix} \tag{5}$$

$$\sigma_{1t}^2 = \exp\{\omega_1 + \alpha_1 F_{1,t-1} + k_1 F_{2,t-1} + \beta_1 \ln(\sigma_{1,t-1}^2)\} \tag{6a}$$

$$\sigma_{2t}^2 = \exp\{\omega_2 + \alpha_2 F_{2,t-1} + k_2 F_{1,t-1} + \beta_2 \ln(\sigma_{2,t-1}^2)\} \tag{6b}$$

$$F_{it} = |u_{it}| - E|u_{it}| + \delta_i u_{it}, \quad u_{it} = e_{it} / \sigma_{it}, \quad i = s \text{ or } f \tag{7}$$

$$E|u_{it}| = \sqrt{2/\pi}\ \Gamma[(v-1)/2] / \Gamma(v/2) \tag{8}$$

The innovations e_t in equation (5) are obtained from the VECM in equation (2) and Q_{t-1} is the information set at time $t-1$. Overnight innovations are excluded. Equation (5) assumes constant conditional correlation ρ as in, e.g., Bollerslev (1990) and Chan, Chan, and Karolyi (1991), and Tse (1999b). To account for excess kurtosis, we assume e_t follows a conditional Student-t distribution with v degree of freedom (Bollerslev, 1987). In the conditional-variance equations (6a) and (6b), α_i and β_i represent the market-specific volatility clustering. The coefficient k_1 (k_2) describes the volatility spillover from the futures (index) market to the index (futures) market. That is, k_1 and k_2 measure the volatility spillovers between the two markets and are the focus of the model. In equations (7) and (8), u_{it} is the standardized innovation and the coefficient δ_i captures the asymmetry in volatility transmission. If δ_i is negative, a negative innovation (or bad news) will increase the volatility more than a positive innovation (good news) of the same magnitude. The univariate EGARCH model was introduced by Nelson (1991) and its multivariate version has been extensively applied in the literature.

We estimate equations (5) to (8) simultaneously by maximizing the log likelihood function $L(\theta)$ using the BHHH algorithm. $L(\theta)$ is given by

$$L(\theta) = \sum_{t=1}^{T} \frac{\Gamma[(2+v)/2]}{\Gamma(v/2)[\pi(v-2)]} |H_t|^{-1/2} \left[1 + \frac{e_t' H_t^{-1} e_t}{v-2}\right]^{-(2+v)/2}, \tag{9}$$

where θ is the parameter vector of the model. As Tse (1999b) has pointed out, this two-step approach (the first step for the VECM in equation (2) and the second step for the bivariate EGARCH model in equations (5) to (9)) is asymptotically equivalent to a joint estimation of equations (4) to (9). Tables 2 and 3 present the results of the volatility spillovers in Periods 1 and 2, respectively. The diagnostic checks (including the Engle and Ng (1993) tests) of the standardized innovations show that the bivariate EGARCH model is well specified.

Table 2 shows that the estimated coefficient of the futures-to-index volatility spillover, k_1, is 0.077 with a *t*-statistic of 7.02, and the coefficient of the index-to-futures volatility, k_2, is 0.083 with a *t*-statistic of 8.20, suggesting highly significant bidirectional volatility spillover during Period 1. In Table 3, estimates of both k_1 and k_2 are also highly significant. Rather interestingly, while the estimate of k_1 remains unchanged at 0.077, the estimate of k_2 decreases to 0.066. This shows that since the implementation of HKATS, the volatility spillover from the index market to the futures market has diminished. In contrast, the volatility spillover from the futures market to the index market has become more prominent. These results are consistent with the information-share results that the HKATS has enhanced the role of the futures markets in information transmission.

Table 2 also shows that the asymmetric volatility coefficient for the index market is insignificant (estimate of δ is 0.054 with a *t*-statistic of 1.07), while it is negative and highly significant for the futures market (estimate of δ is −0.162 with a *t*-statistic of −4.49). These results may be explained by the short-sale restrictions in the stock market but not in the futures market. When a negative innovation (or bad news) impounds on the stock market, investors find it difficult to sell short when the price is decreasing. However, investors in the futures market can short futures contracts. As a result, the futures market would experience a greater impact of negative innovations on volatility than the index market would.

It is interesting to note that the asymmetric volatility coefficient in the futures market is only marginally significant (estimate of δ is −0.09 with a *t*-statistic of −2.17) during Period 2, suggesting that the HKATS has decreased the extent of asymmetric volatility. Based on the Sentana-Wadhwani (1992) model, Antoniou, Holmes, and Priestley (1998) argued that "with a model of feedback traders who have access to less information than their informed counterparts, responses to bad news (price falls) lead to greater volatility than do responses to good news." (p.155). From this perspective, the decrease in the asymmetric volatility implies that the proportion of uninformed (informed) traders becomes smaller (larger) in the futures markets after the HKATS.

4. CONCLUSIONS

Anonymity in an electronic trading system raises traders' concerns of possible adverse selection. As a result, the bid-ask spread in the futures market may increase and the price-discovery function of the market may become less effective. In spite of these concerns, our empirical results are favorable to the electronic trading system in the Hang Seng index futures markets. After the migration to electronic trading of the Hong Kong futures market, the bid-ask spread of the futures market decreases, the contribution of the futures price in information transmission (both information shares and volatility spillovers) increases, and the asymmetric volatility and open interests of the futures market are smaller. The overall evidence suggests that the anonymity in trading and the higher speed at which orders are executed attract informed traders to the futures market and increase the information flow.

References

Antoniou, A., P. Holmes, and R. Priestley, 1998. The effects of stock index futures trading on stock index volatility: An analysis of the asymmetric response of volatility to news. Journal of Futures Markets 18, 151-166.

Baillie, R.T., G.G. Booth, Y. Tse, and T. Zabotina, 2002. Price discovery and common factor models. Journal of Financial Markets 5, 309-321.

Beelders, O. and J. Massey, 2002. The relationship between spot and futures index contracts after the introduction of electronic trading on the Johannesburg Stock Exchange, working paper, Emory University, Atlanta, The United States.

Blennerhassett, M. and D. G. Bowman, 1998. A change in market microstructure: the switch to electronic screen trading on the New Zealand Stock Exchange. Journal of International Financial Markets 8, 261-276.

Bollerslev, T., 1987. A conditional heteroskedastic time series model for speculative prices and rates of return. Review of Economics and Statistics 69, 542-547.

Bollerslev, T., 1990. Modelling the coherence in short-run nominal exchange rates: A multivariate generalized ARCH model. The Review of Economics and Statistics 72, 498-505.

Booth, G.G., J.-C. Lin, T. Martikainen, and Y. Tse, 2002. Trading and pricing in upstairs and downstairs stock markets. Review of Financial Studies 15, 1111-1136.

Chan, K., K.C. Chan, and A.G. Karolyi, 1991. Intraday volatility in the stock index and stock index futures markets. Review of Financial Studies 4, 657-684.

Coval, J. D. and T. Shumway, 2002. Is sound just noise? Journal of Finance, forthcoming.

Domowitz, I., 1990. The mechanics of automated trade execution systems. Journal of Financial Intermediation 1, 167-194.

Domowitz, I., 1993. Equally open and competitive: regulatory approval of automated trade execution in futures markets. Journal of Futures markets 13, 93-113.

Engle, R.F. and V.K. Ng, 1993. Measuring and testing the impact of news on volatility. Journal of Finance 48, 1749-1778.

Frino, A., T. McInish and M. Toner, 1994. The liquidity of automated exchanges: New evidence from German bond futures. Journal of International Financial Markets, Institutions and Money 8, 225-241.

Gilbert, C. L. and H. A. Rijken, 2002. How is futures trading affected by the move to a computerized trading system? Lessons from the LIFFE FTSE 100 contract, working paper, Vrije Universitei, Amsterdam, The Netherlands.

Grossman, S. and M. Miller, 1986. The economic costs and benefits of the proposed one-minute time bracketing regulation. Journal of Futures Markets 6, 141-166.

Hasbrouck, J., 1995. One security, many markets: Determining the contributions to price discovery. Journal of Finance 50, 1175-1199.

Johansen, S., 1991. Estimation and hypothesis testing of cointegration vectors in Gaussian vector autoregressive models. Econometrica 59, 1551-1580.

Koutmos, G. and M. Tucker, 1996. Temporal relationships and dynamic interactions between spot and futures stock markets. Journal of Futures Markets 16, 55-69.

Martens, M., 1998. Price discovery in high and low volatility periods: open outcry versus electronic trading. Journal of International Financial Markets, Institutions and Money 8, 243-260.

Miller, M., 1991. *Financial Innovation and Market* Volatility, Oxford, Blackwell.

Nelson, D.B., 1991. Conditional heteroskedasticity in asset returns: A new approach. Econometrica 59, 347-370.

Pirrong, C., 1996. Market liquidity and depth on computerized trading systems: a comparison of DTB and LIFFE bond contracts. Journal of Futures Markets 16, 519-543.

Ross, S., 1989. Information and volatility: The no-arbitrary martingale approach to timing and resolution irrelevancy. Journal of Finance 44, 1-17.

Sentana, E. and Wadhwani, S., 1992. Feedback traders and stock return autocorrelations: Evidence from a century of daily data. Economic Journal 102, 415-425.

Stock, J.H. and M.W. Watson, 1988. Testing for common trends. Journal of the American Statistical Association 83, 1097-1107.

Tse, Y., 1999a. Round-the-clock market efficiency and home bias: Evidence from the International Japanese Government Bonds futures markets. Journal of Banking and Finance 23, 1831-1860.

Tse, Y., 1999b. Price discovery and volatility spillovers in the DJIA Index and futures markets. Journal of Futures Markets 19, 911-930.

Tse, Y. and T. Zabotina, 2001. Transaction costs and market quality: Open outcry versus electronic trading. Journal of Futures Markets 21, 713-735.

Vila, A. F. and G. Sandmann, 1996. Floor trading versus electronic screen trading: An empirical analysis of market liquidity in the Nikkei stock index futures markets, working paper, London School of Economics, London, The United Kingdom.

Wahab, M. and M. Lashgari, 1993. Price dynamics and error correction in stock index and stock index futures markets: A cointegration approach. Journal of Futures Markets 13, 711-742.

Table 1. Information shares

	First Period		Second Period	
	Index	Futures	Index	Futures
Lower bound	76.71	23.29	59.26	40.74
Upper bound	10.33	89.67	9.53	90.47
Average	43.52	56.48	34.40	65.60

This table presents the information shares derived from Hasbrouck's (1995) model. The information share of a market is defined as the proportion of the efficient price innovation variance that can be attributed to that market. The average information share is the average of the lower and upper bounds of the information shares. The upper (lower) bound is obtained when the market is the first (second) variable in the Cholesky decomposition of the innovation matrix of the VECM.

Table 2. Volatility spillovers: Bivariate EGARCH model, Period 1

$$e_t = \begin{bmatrix} e_{1t} \\ e_{2t} \end{bmatrix} \left| Q_{t-1} \right. \sim \text{Student-}t(0, H_t, v), \quad H_t \equiv \begin{bmatrix} \sigma_{1t}^2 & \rho\sigma_{1t}\sigma_{2t} \\ \rho\sigma_{1t}\sigma_{2t} & \sigma_{2t}^2 \end{bmatrix}$$

$$\sigma_{1t}^2 = \exp\{\omega_1 + \alpha_1 F_{1,t-1} + k_1 F_{2,t-1} + \beta_1 \ln(\sigma_{1,t-1}^2)\}$$

$$\sigma_{2t}^2 = \exp\{\omega_2 + \alpha_2 F_{2,t-1} + k_2 F_{1,t-1} + \beta_2 \ln(\sigma_{2,t-1}^2)\}$$

$$F_{it} = |u_{it}| - E|u_{it}| + \delta_i u_{it}, \quad u_{it} = e_{it} / \sigma_{it}, \qquad i = s \text{ or } f$$

$$E|u_{it}| = \sqrt{2/\pi}\ \Gamma[(v-1)/2]/\Gamma(v/2)$$

	Index	Futures
ω_i	−0.481 (-13.32)	−0.377 (−13.66)
α_i	0.217 (17.31)	0.175 (15.64)
δ_i	0.054 (1.07)	−0.162 (−4.49)
β_i	0.910 (121.7)	0.927 (155.6)
k_i	0.077 (7.02)	0.083 (8.20)
ρ	0.487 (65.64)	
v	0.153 (33.14)	

Diagnostic checking

p-values of Ljung-Box Q(24) statistics

	Index	Futures
u_{it}	0.733	0.999
u_{it}^2	0.939	0.999

p-values of Engle and Ng (1993) diagnostic tests

	Index	Futures
Sign bias test	0.603	0.209
Negative size bias test	0.051	0.643
Positive size bias test	0.729	0.579
Joint test	0.170	0.627

Table 3. Volatility spillovers: Bivariate EGARCH model, Period 2

$$e_t = \begin{bmatrix} e_{1t} \\ e_{2t} \end{bmatrix} \left| Q_{t-1} \right. \sim \text{Student-}t(0, H_t, v), \quad H_t \equiv \begin{bmatrix} \sigma_{1t}^2 & \rho\sigma_{1t}\sigma_{2t} \\ \rho\sigma_{1t}\sigma_{2t} & \sigma_{2t}^2 \end{bmatrix}$$

$$\sigma_{1t}^2 = \exp\{\omega_1 + \alpha_1 F_{1,t-1} + k_1 F_{2,t-1} + \beta_1 \ln(\sigma_{1,t-1}^2)\}$$

$$\sigma_{2t}^2 = \exp\{\omega_2 + \alpha_2 F_{2,t-1} + k_2 F_{1,t-1} + \beta_2 \ln(\sigma_{2,t-1}^2)\}$$

$$F_{it} = |u_{it}| - E|u_{it}| + \delta_i u_{it}, \quad u_{it} = e_{it} / \sigma_{it}, \quad i = s \text{ or } f$$

$$E|u_{it}| = \sqrt{2/\pi}\ \Gamma[(v-1)/2] / \Gamma(v/2)$$

	Index	Futures
ω_i	−0.505 (−13.30)	−0.397 (−10.23)
α_i	0.226 (18.36)	0.150 (12.99)
δ_i	0.030 (0.96)	−0.090 (−2.17)
β_i	0.912 (128.2)	0.920 (110.4)
k_i	0.077 (6.90)	0.066 (6.47)
ρ	0.406 (50.00)	
v	0.172 (33.95)	

Diagnostic checking

p-values of Ljung-Box Q(24) statistics

	Index	Futures
u_{it}	0.560	0.983
u_{it}^2	0.547	0.981

p-values of Engle and Ng (1993) diagnostic tests

	Index	Futures
Sign bias test	0.407	0.890
Negative size bias test	0.977	0.554
Positive size bias test	0.801	0.655
Joint test	0.782	0.889