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# High frequency volatility spillover effect based on the Shanghai-Hong Kong Stock Connect Program


## Abstract

The authors explore the influence of the Shanghai-Hong Kong Stock Connect Program (SHSCP, begun on November 17, 2014) on the one-minute intraday high frequency volatility spillover between the two markets. The program is a strategic movement of the Chinese capital market opening up to the rest of world, which has milestone implications for the development of China's financial market (enhancing the financial center status for both Shanghai and Hong Kong, the internationalization of Chinese currency, and enhancing its economic strength in the world economy). The authors apply asymmetric BEKK-GARCH and adopt the VAR approach as a robustness test. The results indicate that while there is no volatility spillover in the pre-connect period, strong bi-directional volatility spillover exists in the connected period. The statistic test results support the assumption that the program does increase the capital linkage between these two markets.


**Keywords:** Shanghai-Hong Kong Stock Connect Program, volatility spillover, asymmetric BEKK-GARCH, VAR approach, Mainland China capital market's opening-up policy.
**JEL Classification:** G15.

## Introduction

Current studies indicate that there exists a dynamic volatility spillover effect between two linked financial markets (So and Tse, 2004; Chen et al., 2004; Johansson and Ljungwall, 2009), commonly called volatility spillover or the transmission process. One important reason to explore this dynamic volatility process is to determine the direction of new information flow. According to Fama's (1970) efficient market hypothesis, in an efficient market, all price movements are caused by new information. That is, if two highly linked financial markets are efficient, then bi-directional volatility transmission will be expected, as all new information should be reflected in both markets simultaneously. The current market price is based on all past information, and represents an equilibrium relationship between buyers and sellers. Once new information flows into the market, the old equilibrium will break and the price moves to a new equilibrium level.

Outstanding new information will cause a dynamic price movement process among highly relative markets, since investors will have similar expectations of this new shock, which will lead to similar new equilibrium prices among highly relative markets. However, some empirical evidence shows that information flows into highly linked markets at different speeds (Bhar and Nikolova, 2009; Johansson and Ljungwall, 2009). That is, in an inefficient market, if volatility transmits from one market to the other, then the lead market can acquire new information more quickly than the lag market, and vice versa. Chan et al. (1991) also examine the intraday relationship between returns and returns volatility in the stock index and stock index futures markets. The results indicate a strong intermarket dependence in the volatility of the case and futures returns, meanwhile they point out that investigating the lead-lag relationship between return volatility in two linked markets can shed light on how information flows between the two markets.

Since the economic revolution in 1979, China's economy has undergone significant development and is currently the second largest economy in the world, according to the World Bank's GDP data. One of the key concepts of the economic revolution is to open up China's economy to the global economic system. Specific to the stock market, there are two significant open-door policies – the Qualified Foreign Institutional Investors regime (QFII, introduced on July 7, 2003) and the SHSCP (SHSCP, introduced on November 17, 2014). The QFII regime saw the Chinese government allowing qualified foreign investors to invest in Chinese stock markets. Before the QFII regime, the Chinese stock market was open only to domestic investors. Under the SHSCP, investors in the Hong Kong stock market can now invest in mainland China's market. As the Hong Kong stock market is wide open, and a global capital market, a significant increase in the level of openness of mainland China's stock market will be expected from this program.

The SHSCP will significantly increase the level of openness of mainland China's financial market, which has milestone implications for China's capital market development (enhancing the financial center status for both Shanghai and Hong Kong; the internationalization of Chinese currency; and enhancing its economic strength in the world



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economy). This program has been underway for nearly one and half months, and until now, no paper discusses the effect of this program on both mainland China and Hong Kong's stock markets. This paper aims to focus on the volatility aspect in these markets; it will examine whether this program significantly changes the volatility spillover effect in these two markets. This paper will contribute to the current literature in the following three ways: first, this paper is the first to investigate the SHSCP's effect on the dynamic linkage of volatility between these two markets. The study results will shed light on the volatility relationship between these two stock markets and provide risk management guidelines for the two markets' investors. Second, this study applies current one-minute high frequency data from October 17, 2014 to December 17, 2014. Nowadays, an investigation into volatility spillover on a daily level cannot capture the dynamic misconstruction volatility influence, while intraday high frequency data will provide an inside view of these two markets' volatility spillover processes. Third, we apply BEKK-GARCH to investigate volatility spillover and adopt the VAR approach as a robustness test.

## 1. Literature review

Volatility spillover effects comprise two categories: (1) the domestic market spillover effect, and (2) international markets spillover effects. Within the domestic market category, Kang et al. (2013) examine the volatility spillover effect between the Korean stock index futures and spot markets. The results indicate a strong bi-directional causality relationship between the spot and futures markets, which means new information flows into the two markets simultaneously. Zhong et al. (2004) investigate the price discovery function and volatility spillover effect in the Mexican stock index futures and spot markets. The results indicate that volatility transmits from the futures market to the spot market, which leads to an increase in volatility for the spot market.

Concerning research on international market spillover effects, Johansson and Ljungwall [2009] explore the linkages among the different stock markets in China, Hong Kong, and Taiwan. The empirical findings show that there is no long-run relationship among the markets. However, the researchers find short-run spillover effects in both returns and volatility in the region. Mean spillover effects from Taiwan affect both China and Hong Kong. Volatility in the Hong Kong market spills over into Taiwan, which in turn affects the volatility in the Mainland China market. Overall, the study shows significant interdependencies and volatility spillover effects among the three markets. On the other hand, Liu and An (2011) investigate information transmission and price discovery in informationally linked markets. The results show a bidirectional relationship in terms of price and volatility spillover between American and Chinese markets, with a stronger effect from American to Chinese markets than the other way around.

Specific to Asian markets, Yang et al. (2012) investigate intraday price discovery and volatility transmission between the Chinese stock index and the newly established stock index futures markets. The results indicate that the cash market plays a more dominant role in the price discovery process, and there is no strong evidence of a volatility transmission effect between the futures and spot markets. In et al. (2001) examine dynamic interdependence, volatility transmission, and market integration across selected stock markets during the Asian financial crisis periods. The results indicate reciprocal volatility transmission between Hong Kong and Korea, and unidirectional volatility transmission from Korea to Thailand. Hong Kong played a significant role in volatility transmission to the other Asian markets.

In terms of methodologies, a variety of volatility spillover models have been applied, including the VECM, co-integration analysis, BEKK-GARCH, VECH-GARCH, and CCC-GARCH models. Comparing VECH-GARCH and BEKK-GARCH, the advantage of BEKK over VECH is that it requires fewer parameters to estimate and ensure the positive definiteness of conditional covariance matrices, which is the most important issue for the estimation of the multivariable GARCH models (Iltuzer and Tas, 2012). However, Wu et al. (2013) point out three major disadvantages of the BEKK model: the large number of parameters in BEKK and local maxima in the likelihood function often lead to overfitting; financial markets are dynamic, and market conditions change with time, but BEKK does not naturally capture these shifts in market conditions; and the maximum likelihood fit of the BEKK parameters involves solving a non-linear optimization process, which is computationally expensive and infeasible in high dimensions. Caporin and McAleer (2012) compare two multivariate conditional volatility models − BEKK and DCC − and discuss the similarities and dissimilarities of these two models. They conclude the following: BEKK possesses asymptotic properties under untestable moment conditions, whereas DCC's asymptotic properties have simply been stated under a set of untestable regularity conditions; and BEKK could be used to obtain consistent estimates of DCCs, with a direct link to the indirect DCC model.

## 2. Shanghai and Hong Kong stock exchange

The most important difference in regulations between the Shanghai and Hong Kong stock exchanges is the price limits on the Shanghai stock exchange. This price limit is equal to 10% of the last trading day's settlement price. Kim (2001) made the following interesting point: more (less) restrictive on price limits will lead higher (lower) volatility in stock market. In contrast, Phylaktis et al. (1999) examined the effects of price limits on stock volatility on the Athens stock exchange. They concluded that price limits give investors time to reassess the information they have and reduce stock volatility. Table 1 indicates that, for the Mainland China and Hong Kong stock exchanges, a price limit rule causes higher volatility during a pre-crisis period and lower volatility in a crisis period. Overall, a clear conclusion cannot be achieved on the effect of price limits on the volatility of a stock index.

The Shanghai stock index was compiled by the Shanghai stock exchange, and it adopted December 19, 1990, as the date from which to calculate the base point, starting with a base value of 100. The volume of shares is used as a weighting mechanism in the calculation of the index as follows:

$$Index\ value = market\ total\ value/base\ day\ market\ value \times 100,$$

$$Market\ total\ value = listed\ stocks'\ close\ price \times volume\ of\ share.$$

The Hong Kong stock index was compiled by Heng Sheng Bank, and is also weighted by share volume. The base date was selected as July 1, 1964, and the base value was 100 points. The index calculation formula is the same as the formula for the Shanghai stock index. The calculation method for these two indexes shows that a listed company with a larger share volume has a more significant influence on the index. These two indexes are the most actively traded stock indexes in Mainland China and Hong Kong, and generally represent the economic atmosphere of their respective regions.

The trading hours for the Shanghai index are divided into three parts. The first part is the auction period, from 9:15 to 9:25, and the second and third parts are continuous trading periods, from 9:30 to 11:30 and from 13:00 to 15:00. The Hong Kong index trades during four periods, including two auction periods from 9:30 to 10:00 and 16:00 to 16:10. The two continuous trading periods are 10:00 to 12:30 and 14:30 to 16:00. As of March 5, 2012, the Hong Kong stock index trading hours were modified to approach that of the Mainland China market. The first stage advanced from 9:30 to 12:00, and the second stage advanced for 13:00 to 16:00. The Hong Kong index has a total of five and a half continuous trading hours, or one and a half hours longer than that of the Mainland China market. The Hong Kong index uses the last 10 minutes of the auction period to form settlement prices, and the Shanghai index applies the volume weighted average price from the last 15 minutes of the continuous trading time to conform the settlement price. The quotation currency for Shanghai stocks is the Chinese RMB, and Hong Kong stocks have adopted the Hong Kong dollar. In this study, we do not apply a complex exchange rate to evaluate the relative value of the two markets. A continuous compound return, which represents a percentage change in stock prices, is applied to solve this currency issue.

## 3. Data description

The aim of this paper is to investigate the effect of the SHSCP on volatility spillover between these two markets. We select two representative stock indexes: the Shanghai Composite Index (Mainland China) and the Hang Seng Index (Hong Kong). We select and match intraday 1min high frequency data; the time range is from October 17, 2014 to December 17, 2014, totally two months. The overall sample is broken into two sub-periods: pre-connect program period (October 17, 2014 to November 16, 2014) and after-connect program period (November 17, 2014 to December 17, 2014). The time stamped interval for both two indexes are 1mins. Both two indexes are widely traded and have very high liquidity; hence almost there have price movements in every second. Therefore, there should be no time stamps missing issues. The Bloomberg dataset is the data source.

The intraday 1min returns are calculated as $R_t = 100 \times (\log P_t - \log P_{t-1})$. The jump period samples are eliminated from the total sample, which include 11:30 to 13:00 and 15:00 to next day 9:30. Figure 1 shows the returns of two markets. It clearly shows that after connect program Mainland China market has higher volatility. Both two markets show significant intraday volatility jump process. Table 1 represents the basic statistical description of returns and volatility. The statistical results clearly show that after-connect program period generates higher volatility than the pre-connect period; Mainland China shows increased average returns significantly after connect program, whereas Hong Kong turns positive average returns to negative values. Meanwhile, returns and volatility are significantly different from normal distribution in the JB statistics results.

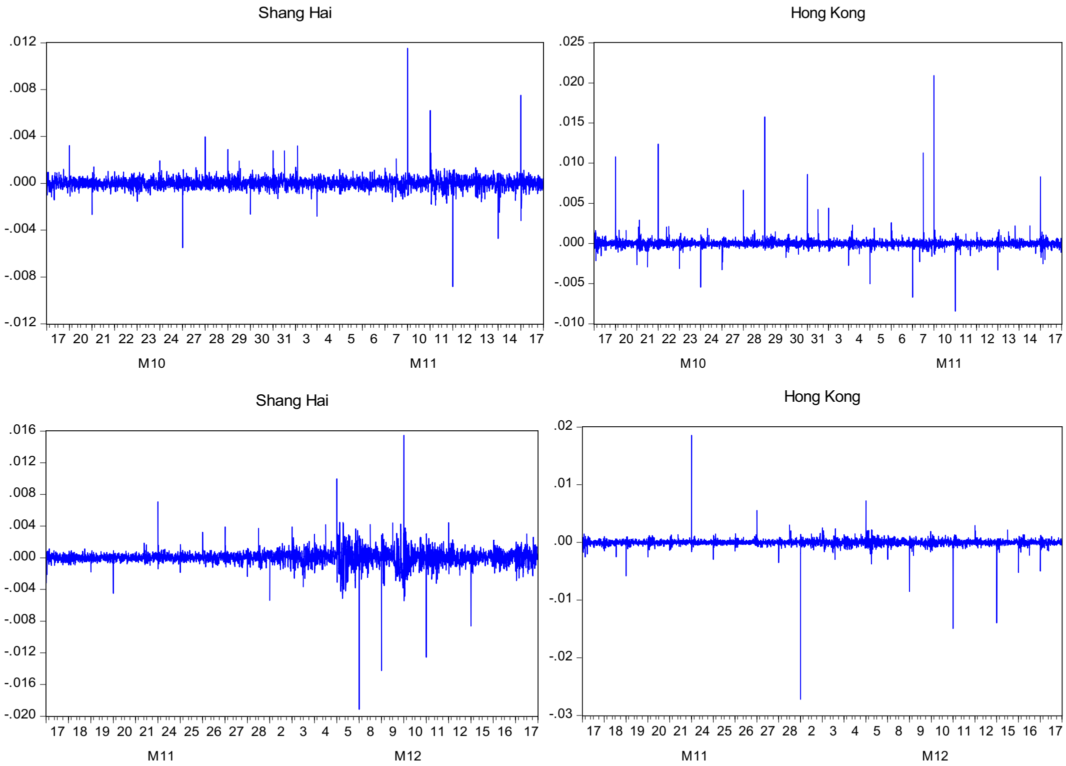


**Fig. 1. High frequency returns of two stock indexes**

Table 1. Basic statistics

| | Pre-connect program | | | | |
|---|---|---|---|---|---|
| | Mean | Variance | Skewness | Kurtosis | JB |
| Stock returns | | | | | |
| Mainland China | 9.32e-06 | 0.000488 | 2.040238 | 104.6881 | 2272095 |
| Hong Kong | 6.99e-06 | 0.000638 | 13.15931 | 376.4165 | 30718218 |
| Volatility | | | | | |
| Mainland China | 0.000307 | 0.000380 | 11.13963 | 246.4733 | 13113278 |
| Hong Kong | 0.000261 | 0.000583 | 18.96398 | 507.7824 | 56170785 |
| | After-connect program | | | | |
| | Mean | Variance | Skewness | Kurtosis | JB |
| Stock returns | | | | | |
| Mainland China | 3.85e-05 | 0.000981 | -1.708270 | 31.20366 | 747712.9 |
| Hong Kong | -1.31e-05 | 0.000708 | -10.92747 | 577.5996 | 72727537 |
| Volatility | | | | | |
| Mainland China | 0.000592 | 0.000784 | 7.458716 | 123.5460 | 3245234 |
| Hong Kong | 0.000302 | 0.000640 | 23.87882 | 818.1110 | 1.47e+08 |

## 4. Study methodology

We apply the asymmetric BEKK-GARCH model to examine the volatility spillover effect. The advantage of the BEKK-GARCH model is that it ensures the conditional variance-covariance matrix and is always positively definite (Engle and Kroner, 1995). The empirical evidence (Black, 1976; Christie, 1982) shows that financial market volatility has asymmetric effects, combined with the leptokurtic and fat tail distribution of asset returns. Volatility asymmetry refers to a negative relationship between stock returns and future volatility. This effect can be explained by two points: first, treating equity as a call option on the value of the firm's assets, when the asset value falls below liabilities, the option becomes worthless (Black, 1976; Christie, 1982); and, second, assuming a rational investor paradigm, rising volatility pushes the expected return higher, which in turn lowers the stock price, contributing to the asymmetric effect in volatility (Bollerslev et al., 1988).

The volatility spillover test models are based on bivariate VAR (1) as follows:

$$R_{i,t} = u_i + \varphi_i R_{i,t-1} + \varepsilon_{i,t}, \tag{1}$$

where $R_{i,t}$ is a [2×1] vector referring to the two markets' returns at time $t$; $u_i$ is a [2×1] vector representing the long-term coefficient drift; and $\varepsilon_{i,t}$ is a

[2×1] vector referring to the random uncorrelated error terms of these two markets at time $t$. Thus, the equation defines $H_t$ as the [2×2] conditional variance-covariance matrix of $\varepsilon_{i,t}$, and $\varepsilon_{i,t} \mid \psi_{t-1} \sim N(0, H_t)$ with $\psi_{t-1}$ represents the information set at time $t$-1. Consequently, the conditional variance-covariance matrix $H_t$ can be written as:

$$H_t = C'C + A'\varepsilon_{t-1}\varepsilon'_{t-1}A + B'H_{t-1}B + D'\eta_{t-1}\eta'_{t-1}D, \quad (2)$$

In the conditional variance-covariance equation, $C$ is a [2×2] upper triangular matrix; $A$ is a [2×2] matrix representing the degree of $H_t$ relative to the past error term in the mean equation; $B$ is a [2×2] matrix referring to the relationship between current conditional variance and past conditional variance; coefficient matrix $D$ is used to measure the impact degree of the asymmetric effect between positive and negative shocks; and asymmetric item $\eta_{t-1}$ is defined as $\eta_{t-1} = \max\,[0, -\varepsilon_{t-1}]$.

Alternatively, we can expand the conditional variance-covariance matrix $H_t$ as follows:

$$H_t = \begin{bmatrix} c_{11} & c_{12} \\ 0 & c_{22} \end{bmatrix}' \begin{bmatrix} c_{11} & c_{12} \\ 0 & c_{22} \end{bmatrix} + \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix}' \varepsilon_{t-1}\varepsilon'_{t-1} \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} + \begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{bmatrix}' H_{t-1} \begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{bmatrix} + \begin{bmatrix} d_{11} & d_{12} \\ d_{21} & d_{22} \end{bmatrix}' \eta_{t-1}\eta'_{t-1} \begin{bmatrix} d_{11} & d_{12} \\ d_{21} & d_{22} \end{bmatrix}. \quad (3)$$

We use the maximum likelihood estimation method to estimate the models, and the Berndt, Hall, Hall, and Hausman (BHHH) algorithm to optimize the method. We can represent the likelihood function $L(\theta)$ as follows:

$$L(\theta) = -\frac{TN}{2}\log 2\pi - -\frac{1}{2}\sum_{t=1}^{T}(\log|H_t| + \varepsilon'_t H_t^{-1}\varepsilon_t), \quad (4)$$

where $\theta$ denotes all the unknown parameters to be estimated; $N$ is the number of assets; and $T$ is the number of observations. Meanwhile, the $\theta$ in the maximum likelihood estimation is asymptotic to normal distribution.

Two aspects influence the volatility of market $i$: its own pervious terms, including volatility $h_{ii,t-1}$, residue $\varepsilon_{i,t-1}$, and the asymmetric term $\eta_{i,t-1}$; and market $j$'s pervious influence and the covariance between the two markets, including covariance $h_{ij,t-1}$, residue $\varepsilon_{j,t-1}$, and the asymmetric term $\eta_{j,t-1}$. Therefore, if:

$$a_{ij} = b_{ij} = d_{ij} = 0, (i \neq j), \quad (5)$$

then only market $i$'s own pervious terms influence its volatility, and no volatility spillover effect exists. Applying the constraints of coefficients $a$, $b$, and $d$ to test the two markets' volatility spillover effect, we propose the following hypotheses:

Hypothesis 1: No volatility spillover exists between market 1 and market 2:

$$a_{12} = b_{12} = a_{21} = b_{21} = 0. \quad (6)$$

Hypothesis 2: No volatility spillover exists from market 1 to market 2:

$$a_{21} = b_{21} = 0. \quad (7)$$

Hypothesis 3: No volatility spillover exists from market 2 to market 1:

$$a_{12} = b_{12} = 0. \quad (8)$$

Hypothesis 4: No asymmetric effect exists between market 1 and market 2:

$$d_{12} = d_{21} = 0. \quad (9)$$

## 5. Study results

We present the asymmetric BEKK-GARCH estimated results in Table 2.

Table 2. Asymmetric BEKK-GARCH estimated results

| | Pre-connect program period | | | After-connect program period | | |
|---|---|---|---|---|---|---|
| | Coefficient | *t*-statistic | *p*-value | Coefficient | *t*-statistic | *p*-value |
| Mean(1) | 0.000010 | 0.51829 | 0.60425467 | 0.000026793 | 3.25721 | 0.00112513 |
| Mean(2) | 0.000007 | 0.29964 | 0.76445017 | -0.000016004 | -1.81845 | 0.06899491 |
| C(1,1) | 0.000488 | 93.47339 | 0.00000000 | 0.000137199 | 21.43030 | 0.00000000 |
| C(2,1) | 0.000244 | 46.27104 | 0.00000000 | 0.000490399 | 111.07298 | 0.00000000 |
| C(2,2) | 0.000590 | 399.07041 | 0.00000000 | 0.000000815 | 0.01101 | 0.99121198 |
| A(1,1) | 0.223607 | 2.90991 | 0.00361532 | 0.122065200 | 23.67679 | 0.00000000 |
| A(1,2) | 0.000000 | 0.00000 | 1.00000000 | -0.014142207 | -1.32408 | 0.18547512 |
| A(2,1) | 0.000000 | 0.00000 | 1.00000000 | -0.029197920 | -7.32726 | 0.00000000 |
| A(2,2) | 0.223607 | 23.68877 | 0.00000000 | 0.024152007 | 2.23932 | 0.02513482 |

Table 2 (cont.). Asymmetric BEKK-GARCH estimated results

| | Pre-connect program period | | | After-connect program period | | |
|---|---|---|---|---|---|---|
| | Coefficient | *t*-statistic | *p*-value | Coefficient | *t*-statistic | *p*-value |
| B(1,1) | 0.670820 | 78.02511 | 0.00000000 | 1.006841787 | 868.57923 | 0.00000000 |
| B(1,2) | 0.000000 | 0.00000 | 1.00000000 | 0.061238615 | 15.15910 | 0.00000000 |
| B(2,1) | 0.000000 | 0.00000 | 1.00000000 | -0.074408843 | -16.71611 | 0.00000000 |
| B(2,2) | 0.670820 | 358.86629 | 0.00000000 | 0.677843580 | 247.48225 | 0.00000000 |
| D(1,1) | 0.000000 | 0.00000 | 1.00000000 | 0.023314262 | 2.88117 | 0.00396200 |
| D(1,2) | 0.000000 | 0.00000 | 1.00000000 | 0.066666684 | 7.85426 | 0.00000000 |
| D(2,1) | 0.000000 | 0.00000 | 1.00000000 | -0.009774723 | -1.86742 | 0.06184340 |
| D(2,2) | 0.0000000 | 29289.21835 | 1.00000000 | -0.022671856 | -3.84705 | 0.00011955 |

| Wald joint coefficient test | Pre-crisis period | | Crisis period | |
|---|---|---|---|---|
| | Chi-squared value | *p*-value | Chi-squared | *p*-value |
| A(1,2)=A(2,1)=0 | 0.0000 | 1.0000 | 63.6647 | 0.0000 |
| B(1,2)=B(2,1)=0 | 0.0000 | 1.0000 | 902.3785 | 0.0000 |
| D(1,2)=D(2,1)=0 | 0.0000 | 1.0000 | 117.0843 | 0.0000 |

In the pre-connect period, both Mainland China and Hong Kong show significant positive ARCH and GARCH effects, but no significant asymmetric effect. In the after-connect period, the GARCH effects remain significant for both markets; Mainland China market remains significant ARCH effect, but Hong Kong market's ARCH effect is not significant at 1% confidence level. ARCH effect refers to consistency of short term volatility; the results mean Mainland China shows stronger consistency in short term volatility compared to Hong Kong market. All the ARCH and GARCH coefficients are positive, which indicates the first lag term shock has a positive effect on current short term and long term volatility. The short term volatility consistency effect can explain this phenomenon; that is, high volatility means another high volatility the next trading 1min for both two markets. Meanwhile, this volatility consistency effect is also found in long term point of view.

The asymmetric effect changes from not significant in the pre-connect period to significant in the connected period, which indicates investors become more risk averse. In the pre-connect period, investors react to positive and negative shocks equally, but in the connected period, negative shock creates more investor panic, which is reflected in negative shocks, creating larger volatility in the next trading minute. The Wald joint coefficient test indicates no bi-directional volatility spillover for ARCH or GARCH and no asymmetric effect in the pre-connect period. We find significant bi-directional volatility spillover for GARCH and asymmetric effects in the connected period. Volatility spillover reflects information flows; strong volatility spillover indicates two markets are highly linked. The results indicate that the connect program increased linkage between the Mainland China and Hong Kong markets. Another interesting point is found, that is the A(1,2) term is not significant at even 10% level. This means short term volatility does not transmit from Hong Kong to Mainland China market. The strong significance of A(2,1) indicates that Mainland China dominates in short term volatility transmission.

## 6. Robustness test

We apply the bivariate VAR approach and Granger causality tests as robustness tests to confirm the result. We divide the total sample period into two sub-periods: the pre-connect period and the connected period. We treat the intraday 1min squared logarithm return as proxy of intraday high frequency volatility. We can note the bivariate VAR as follows:

$$\begin{bmatrix} y_{1t} \\ y_{2t} \end{bmatrix} = \begin{bmatrix} c_1 \\ c_2 \end{bmatrix} + \begin{bmatrix} \alpha_{11} & \alpha_{12} \\ \beta_{21} & \beta_{22} \end{bmatrix} \begin{bmatrix} y_{1,t-1} \\ y_{2,t-1} \end{bmatrix} + \begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \end{bmatrix}. \quad (10)$$

We apply the ADF test to the two sub-periods' data stationarity and present the test results in Table 3.

Table 3. ADF stationarity test results

| | Pre-connect period | | Connected period | |
|---|---|---|---|---|
| | *t*-statistic | *p*-value | *t*-statistic | *p*-value |
| Shanghai | -19.7637 | 0.0000 | -7.5693 | 0.0000 |
| Hong Kong | -67.3122 | 0.0001 | -45.9091 | 0.0001 |

The test results indicate all the datasets are stationary at the 1% confidence level; hence, we can conduct the VAR approach and Granger causality tests. We represent the Granger causality test result in Table 4.

Table 4. Granger causality test results

| Pre-connect period | | | | | |
|---|---|---|---|---|---|
| | Shanghai | | | Hong Kong | |
| | Chi-squared | *p*-value | | Chi-squared | *p*-value |
| Hong Kong | 5.5589 | 0.0039 | Shanghai | 0.3025 | 0.7390 |
| Connected period | | | | | |
| | Shanghai | | | Hong Kong | |
| | Chi-squared | *p*-value | | Chi-squared | *p*-value |
| Hong Kong | 4.5195 | 0.0109 | Shanghai | 7.1498 | 0.0008 |

From the test results, slightly different conclusions are found: in the pre-connect period, there is strong volatility transmission from Hong Kong to Shanghai market, no volatility spillover is found from Shanghai to Hong Kong market. In the previous BEKK-GARCH results, no volatility spillover is found in pre-connect period. The reason to lead this inconsistence conclusion may be due to that BEKK-GARCH test has stricter test statistic compared to Granger causality test. In the connected period, we find strong bi-directional volatility spillover between these two markets, this result confirms the previous BEKK's conclusion. In overall, Granger causality robustness test shows slightly conflict with BEKK in pre-connect period, but both two tests indicate that connect program enhance volatility spillover between these two markets. The purpose of this connection program is to reinforcement informational linkage between these two markets. From the empirical results, the program is successful achieving this target.

## Study conclusion

The SHSCP is an important step for the Chinese capital market to open up to the rest of the world; the program will significantly increase the linkage between these two capital markets. The program promotes both capital markets' level of openness, and has three important positive influences: 1. This new cooperation mechanism can enhance the overall strength of Mainland China's capital market. The program can deepen exchange and cooperation, while also expanding the investment channels and enhancing the market competitiveness for both sides. 2. The program will enhance the financial center status for both Shanghai and Hong Kong, and improve their attractiveness to international investors. The program also helps to improve investors' structure in the Shanghai market, further promoting the international financial center construction of Shanghai; it is also conducive for Mainland China investors to create overseas investments through the Hong Kong stock market, which will consolidate and enhance Hong Kong's international financial center status. 3. The program can promote the internationalization of Mainland China's currency (RMB), and support Hong Kong as an offshore center for RMB business. These benefits show the strategic value of this program, which will significantly enhance China's economic strength in the world economy. The program can facilitate mainland investors using RMB to invest in the Hong Kong stock market, while increasing the investment channels for offshore RMB funds and facilitating the orderly flow of RMB between these two markets.

From a statistics point of view, this program enhances the two markets' high frequency volatility linkage. Before the program, BEKK evidence indicates no intraday high frequency volatility spillover (ARCH, GARCH, and asymmetric effects) was found between the two markets, but Granger causality shows some significant level of volatility spillover from the Hong Kong to Shanghai market. This inconsistent conclusion is because the BEKK-GARCH test has stricter test statistics as compared to Granger causality. After the launch of the program, there is strong evidence of volatility spillover (ARCH, GARCH, and asymmetric effects) between the two markets from both BEKK and Granger causality results. However, BEKK shows that the ARCH short-term volatility spillover from Hong Kong to Shanghai is not significant, the reason for this slightly different conclusion is that the Hong Kong market itself does not show a strong ARCH effect. This means that, after the program, the Hong Kong markets' short-term volatility shows characteristics of low consistency. Overall, both BEKK and Granger causality support the conclusion that the SHSCP does increase the capital linkage between these two markets, and the purpose of this program is successfully achieved.

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