Study on stock market volatility spillover effect based on TVP-VAR model

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Abstract. Utilizing time-varying VAR model and impulse response analysis, we examine the dynamic impact of volatility from foreign companies listed and their contribution to the main stock market in Japanese, Korean, Hong Kong and Singapore markets during the period of 2000-2018. We find that the host markets have a positive response to volatility effects of foreign companies, more specifically, the increase of the foreign company volatility will cause the increase of the host market volatility. Results show that volatility of foreign companies from mature markets did not cause more volatility in host markets. Interestingly, foreign companies from emerging markets will bring stronger volatility spillover to host markets.

1. Introduction

Along with the development of the global stock market and the increase of the correlation between stock market, the competition is increasingly intensified. Under the background of economic globalization, international capital flows become more frequent and important, many of the market, no matter size, are racing to attract foreign company listings [1]. The opening of the stock market will improve the efficiency of market information [2], for example, foreign portfolio investment has a positive and significant impact on information efficiency [3], but it may also affect the quality of the market because the company provides false information. Karolyi [4] studied the growth and expansion dynamics of emerging stock markets around the world through ADRs cross-listing and assessed the impact of this trend on the development of emerging markets and integration with world markets. He believed that the availability of ADR to global investors enhances the liquidity, visibility and credibility of the home market, but the shunt effect may also lead to the deterioration of the home market quality, while the impact on the quality of the host market is not significant.

Since cross-listing is an effective bridge for geographical segmentation of the market, these transmission channels are more direct and feasible to list through foreign companies, leading to greater and faster contagion effects between the home market and the host market. American investors prefer ADR over non-ADR stocks, which has a crowding out effect on local American companies (see [5] and [6]). If a foreign company's shares at a discount and speculative stronger and attract investors, then the original host crowding out company [7], at the same time also will attract more international investors to invest in the host market, the balance will not significantly negative effects on the quality of the host
market, but will cause the international market spillover effect [8]. If there is less heterogeneous information about foreign companies' stocks, negative spillover effects may be generated on the market of the host market. However, if the scale and business nature of foreign companies are completely different from that of host market, it may contribute to the reduction of volatility of host market [9].

For Asia's four major two-way open markets, Japan's economy developed rapidly in the early stage when it launched International Board (International Board refers to the market plate formed by foreign companies' stocks listed on domestic stock exchanges and traded in local currency). Since the 1990s, with a large number of foreign companies delisted from the Tokyo stock exchange and the serious loss of high-quality foreign companies' resources, the International Board failed, and Japan fell into a long-term economic downturn. The rapid economic development of Hong Kong, China is also related to policies that encourage mainland companies to list and strengthen the stock market. Ho [10] believed that the listing and trading of H-shares in Hong Kong in July 1993 was of strategic significance, which rapidly enhanced the competitiveness of the Hong Kong stock exchange. Compared with the end of 1992, the market value at the end of 1996 increased by 10.46 times, the Hang Seng Index increased by 2.44 times, the turnover rate for the whole year increased by 2.02 times, the turnover rate of overseas institutions increased from 22.68% to 29.49%, and the turnover rate of h-shares was 5 times that of local stocks. Just four years to make Hong Kong Asia's second-largest market after Japan, and attracted more and more overseas institutions to participate in. South Korea and Singapore have also achieved great success in the internationalization of their stock markets. The Korean securities market entered the era of direct opening in 1992, gradually easing the restrictions on foreign investors. Korea's exchange rate regime has also been boosted, moving from a fixed rate to a basket of currencies to a market average, until it adopted a floating exchange rate in December 1997. The internationalization of the Korean stock market has made a great contribution to the economic development. Due to the small territory and shortage of natural resources, the economic development of Singapore must be connected with the external economy through foreign trade and other ways. Therefore, the government of Singapore attached great importance to the opening of its securities market at the very beginning of its establishment. After decades of development, Singapore has become the fourth largest financial center in the world, providing valuable experience for other Asian countries in financial liberalization.

As the influence of Asian market is growing rapidly, to provide reference and advice for China and other emerging markets, we have selected four major open markets in Asia as our research objects. In the process of market opening, the volatility risk caused by allowing foreign companies to be listed and the formulation of relevant standards and policies have become an important research topic. The purpose of this paper is to measure the impact of foreign companies on the volatility of host markets, and to explore whether foreign companies from emerging markets and mature markets make market volatility different. In terms of methods, many scholars adopt multivariate GARCH model, multivariate SV model and VAR model to solve the problem of volatility spillover. These methods are mainly used to describe and test the spillover effect and transmission mechanism from the perspective of a full sample, but they cannot describe the time-varying characteristics of the volatility spillover effect. Therefore, we use the time-varying VAR model to study the impact of foreign companies on the host market volatility. On the basis of the model, the parameters were estimated by MCMC algorithm, then we performed impulse response analysis at different lead times and different time points.

The rest of this paper is arranged as follows: the second part introduces the data and describes the trend and volatility of the market index, and introduces the TVP-VAR model. In the third part, we performed the impulse response at different lead times and different time points. The fourth part is the robust test. The fourth part is the main conclusions of this paper.

2. Data and methodology

2.1. Data
This paper selected four major markets of Japan, South Korea, Hong Kong, Singapore and foreign companies listed in these markets from 2000 to 2018 as the research objects. In order to study the
different effects of foreign companies from emerging and mature markets on the host market, we divide foreign companies listed in the host market into those from overseas mature markets and those from overseas emerging markets. For foreign companies listed in Hong Kong and South Korea, we only selected those from overseas emerging markets. Meanwhile, for foreign companies listed in Japan and Singapore, we only selected those from overseas mature markets. The sample market indexes include Japan’s Nikkei 225 index, South Korea’s KOSPI index, Hong Kong’s Hang Seng index (HSCI), Singapore’s FTSE straits times index and world index. Because the trading time of different markets is inconsistent, this paper adopts weekly data for analysis. Every stock index includes the high (H), the low (L), the opening (O) and the closing (C) prices. There are 991 time series data in each sample. Due to the Korean market was late in allowing foreign companies to list, the selected sample data span from May 29, 2009 to December 28, 2018. The data comes from Wind and Datastream.

2.2. Methodology

2.2.1. Volatility measurement. We first refer to the study of Garman and Klass [11], and calculate the weekly range volatility by using the high, the low, the opening and the closing prices, the formula is as follows (In practical calculation, it is to take the natural logarithm of each exponential data and then put it into the formula. For the sake of brevity, the logarithm sign is omitted):

$$RV_t = 0.511(H_t - L_t)^2 - 0.0199(C_t - O_t)(H_t + L_t - 2O_t) - 2(H_t - O_t)(L_t - O_t) - 0.383(C_t - O_t)^2$$

(1)

Where $H_t$ is the weekly high price at time $t$, $L_t$ is the low price, $C_t$ is the closing price and $O_t$ is the opening price.

Then, formula (2) is used to convert weekly range volatility into percentage annual volatility. After giving the stock price index trend in Figure 1, we show the weekly volatility time series of each stock market in Figure 2.

$$\hat{\sigma}_t = 100 \times \sqrt{52 \times RV_t}$$

(2)

We assume that the weighted average of individual stocks constitutes the volatility of the foreign companies listed in the host market. First, the weighted average method is used to calculate the price data of foreign companies. As shown in formula (3):

$$O_{i,g,t} = \sum w_i \sum w_i O_{i,t}$$

(3)

Where $O_{i,t}$ is the opening price of company $i$ at time $t$, $w_i$ is the weight of the company $i$, we use the market value of the company to estimate. And $O_{i,g,t}$ ($H_{i,g,t}, L_{i,g,t}, C_{i,g,t}$ are the same) is the weighted average of foreign companies listed in market $g$ at time $t$. Further, the weighted average of the company is substituted into the formula (1) and (2) to obtain the annual volatility of foreign companies.

Since the volatility is a second-order moment data, it obviously does not follow normal distribution. We take the logarithm of the original volatility before calculating it to ensure that the data is closer to the normal distribution. We call this "logarithmic volatility". Table 1 and Table 2 respectively show the descriptive statistics and unit root test results of logarithmic volatility in Korea (marKR), Hong Kong (marHK), Singapore (marSG) and Japan (marJP) markets and foreign companies (comKR, comHK, comSG and comJP). As can be seen from Table 1, the volatility of Japanese stock market is the lowest in terms of mean and median, while Hong Kong and South Korea are more volatile. From the extreme value, the volatility range of Japan and Hong Kong is relatively large. Combined with Figure 2, it can also be seen that the volatility of Japan and Hong Kong market changed greatly, especially during the American Subprime Crisis in 2008. The KPSS test results show that the logarithmic volatility of both market and foreign companies is stable. The results of kurtosis, skewness and JB test show that the data still have the characteristic of "sharp peak and thick tail".
Table 1. Descriptive statistics of logarithmic volatility for markets.

|                | marKR | marHK | marSG | marJP | world |
|----------------|-------|-------|-------|-------|-------|
| Sample         | 991   | 991   | 991   | 991   | 991   |
| Mean           | 2.743 | 2.683 | 2.614 | 2.610 | 1.950 |
| Median         | 2.706 | 2.634 | 2.645 | 2.614 | 1.927 |
| Std            | 0.558 | 0.509 | 0.566 | 0.505 | 0.671 |
| Range          | 3.455 | 3.898 | 3.507 | 3.919 | 3.901 |
| Skewness       | 0.345 | 0.438 | -0.043| 0.133 | 0.158 |
| Kurtosis       | 2.964 | 3.628 | 2.662 | 3.880 | 3.109 |
| JB test a      | 19.722***| 47.975***| 5.023* | 34.894***| 4.640* |
| KPSS test      | 0.9588***| 1.6546***| 2.0644***| 0.8847***| 0.8024***|

* *, **, *** represent a significance level of 10%, 5%, and 1%, respectively.

Table 2. Descriptive statistics logarithmic volatility for foreign companies.

|                | comKR | comHK | comSG | comJP |
|----------------|-------|-------|-------|-------|
| Observations   | 594   | 991   | 991   | 991   |
| Mean           | 3.781 | 2.960 | 3.438 | 3.163 |
| Median         | 3.838 | 2.926 | 3.450 | 3.098 |
| Std. Dev.      | 0.585 | 0.525 | 0.430 | 0.387 |
| Skewness       | -1.146| 0.330 | -0.173| 0.645 |
| Kurtosis       | 7.326 | 3.212 | 3.732 | 3.373 |
| JB test        | 593.338| 19.798| 27.045| 74.248|
| Probability    | 0.00000| 0.00005| 0.00001| 0.00000|
| KPSS test      | 0.8185***| 1.6429***| 3.2596***| 1.2746***|

2.2.2. *TVP-VAR model.* Traditional VAR models cannot depict the characteristics of financial market volatility that change with time. While roll-out VAR can explore time-varying spillovers, roll-out estimation is too dependent on the choice of window width. If the window width is too short, the in-sample estimation will be unreliable, there will be more outliers and mutation results. If the window width is too long, the in-sample estimation will be smooth and some sudden changes will not be captured. Moreover, the roll-out VAR will inevitably lose the sample of the initial window, and the resulting time-varying spillovers effect will lose a sample of a window width. Cogley and Sargent [12] first proposed the time-varying VAR (TVP-VAR) model and obtained better results than the traditional VAR model. Then, the time-varying model which only considers the coefficient is extended to the VAR model which considers both the coefficient time-varying and variance time-varying. We refer to the TVP-VAR model of Primiceri [13], where coefficients, variance and covariance all change with time, and use Bayesian method to realize Markov Chain Monte Carlo (MCMC) estimation. Based on this model, impulse response and variance decomposition are carried out to obtain the impact of foreign companies on the host market.

Based on the research of Primiceri [13] and Nakajima [14], the TVP-VAR model was firstly simplified as follows:
\[ y_t = \Phi_{0,t} + \Phi_{1,t}y_{t-1} + \Phi_{2,t}y_{t-2} + \cdots + \Phi_{p,t}y_{t-p} + \varepsilon_t \]  

(4)

Where, \( t=p+1, p+2, \cdots, t \), \( p \) is the order of hysteresis, \( t \) is the sample length, \( y_t \) represents the \( N+1 \) dimensional observation vector, \( \Phi_{0,t} \) is \( N \times 1 \) dimension intercept term, \( \Phi_{p,t} \) is \( N \times N \) dimension time-varying hysteresis coefficient matrix, \( \varepsilon_t \) is the random disturbance term with variable variance.

\[ \Phi_t = \{ \Phi_{0,t}, \Phi_{1,t}, \Phi_{2,t}, \cdots, \Phi_{p,t} \} \]

\( \beta_t \) represents the packing of the columns of the matrix \( \Phi_t \), that is \( \beta_t = vecr(\Phi'_t) \), where \( vecr(t) \) is column stacking operator, \( \beta_t \) is \( (N^2P + N) \times 1 \) dimension coefficient vector. Suppose \( \beta_t \) obeys the random walk process:

\[ \beta_t = \beta_{t-1} + v_t \]  

(5)

Where, the perturbation term \( v_t \) is independent of the white Gaussian noise with the same distribution, and \( v_t \sim N(0, \Sigma_v) \), \( \Sigma_v \) is the time-invariant diagonal matrix. \( I_{t-1} \) is denoted as the observable information of phase \( t-1 \), and \( e_t | I_{t-1} \sim N(0, \Sigma_t) \), \( \Sigma_t \) is the time-varying conditional covariance matrix. Re-parametric \( \Sigma_t \), you will get \( \Sigma_t = C_t^{-1}D_t(C_t^{-1})' \). Where, \( C_t \) is the lower triangular matrix whose diagonal element is 1, and \( D_t \) is the diagonal matrix. Arrange the off-diagonal elements of \( C_t \) to obtain the \( [N(N-1)/2] \times 1 \) dimension coefficient vector \( \alpha_t \), and arrange the diagonal elements of \( D_t \) to the \( N \) dimension variance vector \( h_t \), and \( h_t = \ln \sigma^2_t \). Suppose that both \( \alpha_t \) and \( h_t \) follow a random walk:

\[ \alpha_t = \alpha_{t-1} + \zeta_t, h_t = h_{t-1} + \xi_t \]  

(6)

Where, the disturbance terms \( \zeta_t \) and \( \xi_t \) are independent and identically distributed white Gaussian noise, and \( \zeta_t \sim N(0, \Sigma_{\zeta}) \), \( \xi_t \sim N(0, \Sigma_{\xi}) \), both \( \Sigma_{\alpha} \) and \( \Sigma_{h} \) are time-varying diagonal matrices. Suppose that the disturbance terms \( v_t \), \( \zeta_t \), and \( \xi_t \) are independent of each other and have no correlation with \( \varepsilon_t \).

The coefficient matrix \( \hat{\Phi}_{t,1}, \hat{\Phi}_{t,2}, \cdots, \hat{\Phi}_{t,p,t} \) can be obtained by rearranging the posterior estimation coefficients \( \hat{\beta}_t \). Use the recursive relation:

\[ A_{h,j} = \hat{\Phi}_{t,1} + \hat{\Phi}_{t,2} + \cdots + \hat{\Phi}_{t,p,t} \]

(7)

the coefficient matrix \( A_{h,j} \) of the TVP-VAR model is calculated.

Based on generalized impulse function available \( N \times N \) generalized variance decomposition matrix \( \Theta_t \). Each element in the matrix can be obtained by the following formula:

\[ \theta_{ij}(H) = \hat{\sigma}_{ij}^{-1} \sum_{h=0}^{H-1} (e'_hA_{h,j}^s)e_j \]  

(8)

Where \( \theta_{ij}(H) \) is the entry in row \( i \), column \( j \) of \( \Theta_t \), \( \hat{\sigma}_{ij}^{-1} \) is the variance of the \( j \)th perturbed term, and \( e_i \) is the \( i \)th column vector of the identity matrix, which is the selection vector. Directly according to the formula (7) to calculate the generalized variance decomposition of matrix \( \Theta_t \), the sum of the elements in each row of the matrix is not equal to 1. In order to match the economic meaning of the traditional variance decomposition, we normalize the matrix \( \Theta_t \) by rows and obtain the generalized variance decomposition matrix \( \hat{\Theta}_t \) after transformation. The calculation formula of matrix elements is:
\[
\tilde{\theta}_{j,r}(H) = \frac{\theta_{j,r}(H)}{\sum_{j=1}^{N} \theta_{j,r}(H)}
\]  

(9)

3. Empirical results

From the Figure 1, the overall trend of the four major markets of South Korea, Hong Kong, Singapore and Japan is very similar. They all experienced a sustained rise from 2003 to 2007 and 2009 to 2017, and a sharp short-term decline from 2000 to 2002 and 2008 to 2009. Affected by the Asian financial crisis from 1997 to 1999, the four major markets still showed a sustained short-term decline after 2000, among which the Singapore and Japan markets were relatively affected. From 2007 to 2008, the sub-prime mortgage crisis broke out in the United States, and the four major markets all saw significant declines.

Can be seen from the Figure 2, South Korea, Hong Kong, Singapore and Japan have very similar volatility characteristics, and there's a difference with the world index, this is consistent with the price index chart. It can also be found from the analysis that the volatility of each stock market in different periods is different, and there is an obvious volatility clustering phenomenon. During the subprime crisis in the United States in 2008, the four major stock markets all showed a sharp increase in volatility, which was highly correlated. After the Asian financial crisis in 1997, South Korea and Singapore still had sharp volatility for a period of time, while Hong Kong and Japan had small volatility.

3.1. Impulse response with different period ahead

Figure 3 shows the impulse response of the host market with 4, 8 and 12-period ahead respectively when facing a positive impact of foreign companies and world index. From the response of the Korean market,
it can be seen that market response of 4-period ahead to the impact of foreign companies is positive and gradually tends to smooth, close to the zero-line fluctuation. The response of 8 and 12 periods are negative. The response of the market to the impact of the world index is positive with the different periods ahead, and the trend of response is highly correlated. This suggests that in the short term, the volatility of foreign companies will cause more volatility in the Korean stock market, but the overall impact is gradually reduced. In the long run, the volatility of foreign companies has a stable impact on the Korean market, which plays a role in stabilizing the market. For Hong Kong, Singapore and Japan, the response to the foreign company shock are positive. There was a brief negative response from the Hong Kong and Singapore markets to the world index shock, while the Japan market has a positive response. From the perspective of different sources of foreign companies, the volatility impact of foreign companies from emerging markets makes the Korea and Hong Kong markets more volatile, volatility impact of foreign companies from mature markets has not made Singapore and Japan markets more volatile.

3.2. Impulse response at different time points
In order to further investigate the fluctuation state of each market during the economic crisis, we select three time points for impulse response. As shown in Figure 4, t = 366, 575, 805 respectively represent the American Subprime Crisis in January 2007 (Since the sample time of the Korean market started from 2009, the impulse response only included the European debt crisis at time t = 85 and the Chinese stock market crisis at time t = 315), the European Debt Crisis in January 2011 and the Chinese stock market crisis in June 2015. At three time points, the response of the Korean market to the impact of foreign companies fluctuates around the zero line, finally tends to be stable and negative near the zero line, while the response to the impact of the world index is positive with the same trend. The response of Hong Kong, Singapore and Japan to the impact of foreign companies is also positive at three time points, reaching a maximum in the first few periods and then gradually leveling off to zero. The response of the
Japanese market to the impact of world index is positive in January 2007, while in January 2011 and June 2015, the response is negative after the third period. The American Subprime Crisis has a great impact on the markets of Hong Kong, Singapore and Japan, which indicates that the more interconnected the market with a greater degree of openness to the outside world is with the international market, the more vulnerable it is to the impact of the world financial crisis.

**Figure 4.** Impulse response at different time points.

4. **Robust test**
In order to make the empirical results more robust, we used the MCMC method for parameter estimation after the model was built. It mainly uses the MCMC algorithm to iterative sampling of random samples, through which the conditional posterior distribution of time-varying parameters is simulated, and the statistical inference of related parameters is realized. In order to ensure the convergence of posterior distribution, when running the MCMC algorithm of TVP-VAR model, we sampled a total of 11,000 times, discarded the "pre-burned" sampling of the previous 1,000 times, and used the sampling of the following 10,000 times for calculation.

5. **Conclusions**
This paper employs the time-varying VAR model to study the volatility impact of foreign companies on the host market. First, we use MCMC method to estimate parameters on the basis of the model, and then carry out impulse response analysis at different lead times and different time points. We found that the host market has a positive response to the fluctuations of foreign companies listed locally. Volatility of foreign companies from mature markets did not cause more volatile in host markets. In contrast, volatility of foreign companies from emerging markets had a stronger positive correlation with host markets. For China and other emerging markets to open their markets, attract high-quality companies from mature markets to go public is more conducive to the positive impact of the stock market. However, TVP-VAR model also has some disadvantages. Because the VAR model is an over-parameterization model, there are many parameters to be estimated, and the "dimension disaster" is likely to occur in the case of limited sample size. TVP-VAR model is a direct extension of the traditional VAR model, and it
cannot avoid the problem of over-parameterization. If the time-varying parameters are set as AR process, the parameters to be estimated will be greatly increased, which will inevitably lead to the degree of over-parameterization. On the basis of this study, we will conduct a follow-up study on the influencing factors of the volatility spillover effect. We can combine the time-varying VAR model with the construction method of the volatility spillover index by Diebold and Yilmaz [15] to calculate the time-varying volatility spillover index and further discuss how the listing of foreign companies affects the host market volatility.

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