The Financial Contagion between the Chinese Stock Market and Bond Market: Based On MVMQ-CAViaR Model

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Abstract

In 2015-2016, the Chinese stock market experienced severe price fluctuations. This paper studies the extreme risk spillover effect between stock price and bond price by constructing MVMQ-CAViaR model and analyzes the dynamic impact of market shock on the tail risk of market using quantile impulse response. The study finds that the stock market and the bond market have asymmetric financial contagion effects. Specifically, the stock market has a significant risk spillover effect on the bond market, the stock price and the bond price change in the opposite direction, which is consistent with the "flight-to-quality" effect. The impact of the bond market on the stock market is very weak, only the increase in the risk of national bonds, causing the stock market prices to decline, there is a co-movement between the two market prices. The conclusion of this paper provides an important theoretical basis for promoting the further development of China's stock market and bond market.

Keywords: Stock market; Bond market; MVMQ-CAViaR model; Financial contagion

1 Introduction

From 2015 to 2016, the stock market in China has experienced drastic price fluctuations. Due to the CSRC's inspection to the informal gray market of margin trading, the CSI 300 (Hushen300) index plummeted 114 points a day from of 5335 points on June 15, 2015, after which the stock market experienced successive falls, further broke the important mark, and even thousands of stocks came to the daily limit. Until to July 8th, CSI 300 index went below 3663 points, the market value had evaporated 3.5 trillion US dollars. Figure 1 shows the changes of the CSI 300 Index and the China Aggregate Bond Index in 2013-2017. It can be seen that the stock market has experienced three sharp declines since June 15th, 2015, while in the bond market, the China Aggregate Bond Index had a slow upward trend. Stock market and bond market are the two most important financial market in China. According to the definition of financial contagion, the correlation between different financial markets tends to increase significantly during the period of abnormal fluctuations. Then, this paper tried to answer whether the sharp stock price plunges has any impact on the bond prices and further examined the relationship between the two markets. The study of the correlation between the stock market and the bond market not only helps investors to allocate assets rationally and prevents market risks, but also facilitates the establishment of effective financial regulatory policies to safeguard the stability of the financial system.

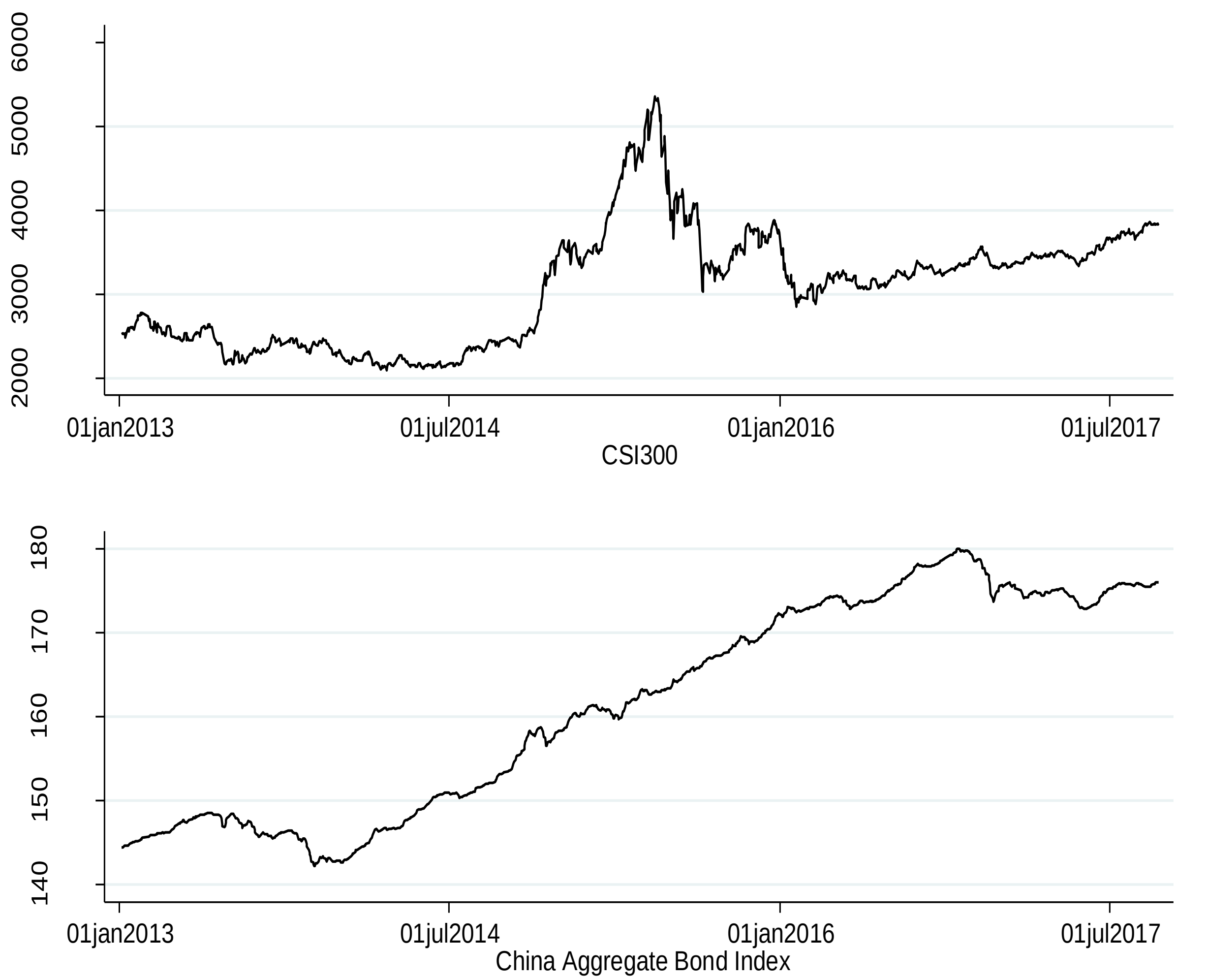


Fig1. CSI 300 and China Aggregate Bond Index trends

Market relevance studies include linear correlation studies and nonlinear correlation studies. Earlier linear correlation studies used the Pearson correlation method to study the correlation between two markets (King and Wadhwani, 1990; Calvo and Reinhart, 1996). Forbes and Rigobon (2002) argued that the Pearson correlation test did not consider the heteroscedasticity of market returns and leads to biased estimates, hence they proposed a conditional correlation method of adjusting heteroskedasticity to study the financial contagion during the 1997 Asian flu, 1994 Tequila crisis, and 1998 U.S. market crash. However, the linear correlation study is not enough for analyzing financial market for the distribution of assets returns has the characteristics of leptokurtic, thick tails and volatility clustering. Financial researchers pay more attention to the tail risk spillover effect between the two markets, so GARCH models (Engle, 2000), Copula functions (Hu, 2006; Ye and Miu, 2009), quantile regression (Baur, 2013; Park et al., 2015) and extreme value theory (Hartmann et al., 2004) and other nonlinear correlation research methods are introduced into the research of financial contagion. The GARCH model mainly studies the second-order correlation of two sequences and focuses on the contagion effect of external shock on the market. The Copula function and the quantile regression method study the high-order correlation of two sequences and describe the changes of the degree and structure of association of the two markets. Hu (2006) proposed a financial contagion test of stock market based on the mixed Copula function, and used nonparametric method to estimate the marginal distribution of asset returns. Baur (2013) used quantile regression method to test the asymmetric and nonlinear relationship of financial time series, but did not take full account of the autocorrelation of financial time series. This paper studies the financial contagion effects between the stock market and the bond market. Compared with the previous studies, it has the following contributions: Firstly, this paper adopted the modeling approach proposed by White et al. (2015), constructed the multivariate multi-quantile conditional auto-regression (MVMQ-CAViaR) model to research financial contagion effects between stock markets and bond markets.

Secondly, through studying the risk contagion between the stock market and the bond market under the low quantile level from an extreme risk perspective, this paper reflects the market's impact in the worst condition such as the stock market crash, and also helps to reveal the relationship of stock market and bond market in China. Thirdly, the quantile regression method, as a semi-parametric estimation method, does not make any parameter distribution assumptions about regression model, thus effectively avoid the problem of misspecification in Copula function. The study finds that there is an extreme risk spillover effect between the stock market and the bond market. From the perspective of the stock market's impact on the bond market, the decline in the stock market is to promote bond prices, which is in line with the investor's risk hedging and "flight-to-quality" effect, but it will differ with types of bonds. From the perspective of the bond's impact on the stock market, the decline in national bond prices tends to lower the stock market prices, which means the stock market and the national bond market have the same directional interaction effect. The remaining part of this paper is arranged as follows: The second part is the literature review, in the third part, a MVMQ-CAViaR model is established, the fourth part is an empirical research including model coefficient estimation, extreme risk spillover test and quantile impulse response analysis and so on, the last part is the conclusion and suggestions.

2 Literature Review

Scholars at home and abroad have conducted extensive researches on the correlation effects of stock market and bond market. There are mainly two types of viewpoints in foreign studies: one type of view holds that common information simultaneously affects investors' expectation on the stock market and the bond market, resulting in changes in the prices of the two markets in the same direction, i.e. the co-movement (Campbell and Ammer, 1993; Fleming et al., 1998; Baur and Lucey, 2009). Another view is that as the stock market and the bond market are two different asset markets, the investors' cross-market-hedging strategy makes the price changes in the opposite direction, which is called "flight-to-quality" (Merton, 1973; Barsky, 1989; Yang et al., 2010). In terms of co-movement, Li et al. (2002) argued that the correlation between stock and bond prices are mainly determined by the uncertainty of expected inflation, followed by unexpected inflation and real interest rate. Goeij and Marquering (2002) argued that the impact of good news and bad news on the correlation of the stock market and the bond market will be different. Yang et al. (2009) thought that higher short-term interest rate or inflation rate will make the stock market and the bond market more relevant. In the cross-market-hedging influences, Kodres and Pritsker (1998) argued that under the given macroeconomic condition, due to the wealth effect and substitution effect, the shock on one market may make investors hedging asset risk with the unaffected asset market. Fleming et al. (1998) argued that there is full cross-market information spillover effect in a frictionless market and cross-market spillover effects will be weakened once transaction costs, institutional constraints and other hedge-trade restrictions are considered. Veronesi (2001) introduced the concept of "uncertainty aversion" and found that investors were exceptionally sensitive to external information due to their aversion to the state uncertainty. When the stock price fluctuates at a premium or abnormal volatility, investors would increase their bond asset allocation. Stivers et al. (2015) used the implied volatility and the detrended stock turnover to study the impact of stock market uncertainty on the dynamic correlation change of the stock and bond yields, and found that the rising uncertainty in the stock market will lead to the increase of the current bond yield and the negative correlation between the stock price and the bond price.

In domestic researches, Yuan et al. (2008) used the asymmetric dynamic conditional correlation model to study the correlation between China's stock market and bond market from 2003 to 2006 and found that the correlation between them will be affected by external uncertainties such as the economic performance and macroeconomic policies, and joint negative shock will cause both stock prices and bond prices to fall, a joint positive shock will lead to rise of the price, both result in the increase of the correlation coefficient of two markets, but the effect of the combined negative impact is greater. Wang and Fang (2010) studied the liquidity spillover effect of China's stock market and bond market in 2003-2008 and the effect of macroeconomic variables on the liquidity of the two markets by VAR model. They found that there are significant lead-lag relationship and bi-directional Granger causality between the liquidity of the two markets. Hu and Ma (2011) used the BEKK-MGARCH model to study the volatility spillover effect of China's stock market and bond market from 2006 to 2011 based on the different stock market condition (bull, bear, rebound, shock), they found that the volatility spillover effect between the two markets has obvious different characteristic when the stock market in different conditions. When the stock market is in a bull market or a bear market, the stock market has a unidirectional volatility over the bond market. When the stock market is in the rebounding condition, there is no volatility spillover effect between the two markets.

When the stock market is in a shock, there is a two-way volatility spillover effect between them. Using the Copula function to study the risk spillover effect between Chinese stock market and bond market from 2002 to 2009, Shi et al. (2013) found that the linkage effect in the stock market and bond market is not significant, but the stock prices are negatively correlated with the price of inter-bank bond, which is also known as "see-saw effect". When the stock price drops abnormally, the risk spillover effect is the see-saw effect. When the stock price rises abnormally, the risk spillover effect changes from the see-saw effect to the co-movement effect, that is, the stock and bond market prices change in the same direction. Chen and Zeng (2016) using the data of the stock indexes and bond indexes about China and the USA, studied the extreme risk spillover effect between the two markets in different market conditions in 2004-2013. This paper constructed the MVMQ-CAViaR model by referring to White et al. (2015) to study the risk contagion between the Chinese stock market and the bond market during the stock market crash in 2015. Compared with the existing linear correlation method, tail risk spillover effects can be tested from a low quantile level. The method is easy to calculate and does not need to make any assumptions about the joint distribution of the returns, thus effectively avoid the problem of model misspecification.

3 MVMQ - CAViaR model

VaR (Value at Risk) indicates the maximum loss rate of a financial asset (or financial market) under a certain level of confidence. VaR is the standard measure of the extreme risk of financial markets. Many financial institutions use VaR to measure the risk of financial markets (Hong et al., 2009; Adrian and Brunnermeier, 2014). Engle and Manganelli (2004) introduced the time series relationship in the VaR model and proposed the conditional autoregressive risk value (CAViaR) model.

Based on the CAViaR model of Engle and Manganelli (2004), White et al. (2015) proposed a multivariate and multi-quantile conditional autoregressive value at risk (MVMQ-CAViaR) model that extended the quantile regression of single equations to vector auto-regression structured equation to more intuitively and clearly analyze the tail risk spillover effect of interconnected markets (Zeng et al., 2017; Hao et al., 2017). The construction idea of MVMQ-CAViaR model is as follows:

Suppose the random variable $\{(Y_t^{'}, \mathrm{X}_t^{'}) : t = 1, 2, ..., T\}$ is a stationary topological random process in probability space $(\Omega, \mathrm{F}, \mathrm{P}_0)$, where the dependent variable $Y_t^{'}$ is a $n \times 1$ vector and the independent variable $\mathrm{X}_t^{'}$ is the finite-dimensional vector with first element as 1.

F_{t-1} is σ -algebra generated by $Z^{t-1} := \{\mathrm{X}_t, (\mathrm{Y}_{t-1}, \mathrm{X}_{t-1}), (\mathrm{Y}_{t-2}, \mathrm{X}_{t-2}), ...\}$, i.e. $F_{t-1} := \sigma(\mathrm{Z}^{t-1})$, $i = 1, ..., n$. $F_{it}(\mathrm{y})$ is the cumulative distribution function (CDF) based on the F_{t-1}, $F_{it}(\mathrm{y}) := \mathrm{P}_0[\mathrm{Y}_{it}\ \mathrm{p}\ \mathrm{y} | F_{t-1}]$. For $0\ \mathrm{p}\ \theta_{i1}\ \mathrm{p}\ ...\ \mathrm{p}\ \theta_{ip}\ \mathrm{p}\ 1$, $j = 1, ..., p$, the θ_{ij} - quantile of Y_{it} based on F_{t-1} is defined as $q_{i,j,t}$,

$$q_{i,j,t} := \inf\{\mathrm{y} : \mathrm{F}_{it}(\mathrm{y}) \geq \theta_{ij}\} \qquad (1)$$

Where $q_{i,j,t}$ indicates the minimum y value to satisfy $\mathrm{F}_{it}(\mathrm{y}) \geq \theta_{ij}$. To estimate the conditional quantiles $q_{i,j,t}$ ($i = 1, ..., n$, $j = 1, ..., p$), suppose $q_t := (\mathrm{q}_{1,t}^{'}, \mathrm{q}_{2,t}^{'}, ..., \mathrm{q}_{n,t}^{'})^{'}$ and $q_{i,t} := (\mathrm{q}_{i,1,t}, \mathrm{q}_{i,2,t}, ..., \mathrm{q}_{i,p,t})^{'}$. For a given finite integer k and m, $k \times 1$ vector steady-state topological sequence $\{\psi_t\}$ is measurable on F_{t-1}. Suppose $\beta_{ij} := (\beta_{i,j,1}, ..., \beta_{i,j,k})^{'}$ and $\gamma_{i,j,\tau} := (\gamma_{i,j,\tau,1}^{'}, ..., \gamma_{i,j,\tau,n}^{'})$, where $\gamma_{i,j,\tau,k}$ is $p \times 1$ vector that satisfies

$$q_{i,j,t} = \psi_t^{'} \beta_{ij} + \sum_{\tau=1}^{m} \mathrm{q}_{t-\tau}^{'} \gamma_{i,j,\tau} \qquad (2)$$

where $i = 1, ..., n$, $j = 1, ..., p$. Model (2) is called MVMQ-CAViaR model. It is noteworthy that ψ_t included lagged term of Y_t, X_t and lagged term of X_t.

For a given θ_{ij}, β_{ij} and $\gamma_{ij} := (\gamma_{i,j,1}^{'}, ..., \gamma_{i,j,m}^{'})^{'}$ is the estimated parameters of model (2). Let $\alpha_{ij}^{'} := (\beta_{ij}^{'}, \gamma_{ij}^{'})$, $\alpha^* = (\alpha_{11}^*, ..., \alpha_{1p}^*, ..., \alpha_{n1}^*, ..., \alpha_{np}^*)^{'}$, α^* is $l \times 1$ dimension vector, and $l = np(\mathrm{k} + \mathrm{npm})$. We call α^* as the coefficient vector of MVMQ-CAViaR. α^* is derived from the quasi-maximum likelihood estimation, it is equivalent to the solution of the following optimization problem

$$\min_{\alpha \in \mathrm{A}} \bar{S}_T(\alpha) := \mathrm{T}^{-1} \sum_{t=1}^{T} \{\sum_{i=1}^{n} \sum_{j=1}^{p} \rho_{\theta_{ij}} (\mathrm{Y}_{it} - \mathrm{q}_{i,j,t}(\cdot, \alpha))\} \qquad (3)$$

Where $\rho_\theta(\mathrm{e}) = \mathrm{e}\varphi_\theta(\mathrm{e})$ is a standard check function, defined using the usual quantile step function $\varphi_\theta(\mathrm{e}) = \theta - 1_{[\mathrm{e} \leq 0]}$.

White et al. (2015) proved the asymptotic normal distribution and efficiency of $\hat{\alpha}_T$, which is the quasi-maximum likelihood estimate of α^*,

$$T^{1/2}(\hat{\alpha}_T - \alpha^*) \xrightarrow{d} N(0, \mathrm{Q}^{-1}\mathrm{V}\mathrm{Q}^{-1}) \qquad (4)$$

where $Q := \sum_{i=1}^{n}\sum_{j=1}^{p} E[f_{i,j,t}(0)\nabla \mathrm{q}_{i,j,t}(\mathrm{g}\,\hat{\alpha}_T)\nabla' \mathrm{q}_{i,j,t}(\mathrm{g}\,\hat{\alpha}_T)]$, $V := E(\eta_t\eta_t')$, $\eta_t := \sum_{i=1}^{n}\sum_{j=1}^{p}\nabla q_{i,j,t}(\cdot,\hat{\alpha}_T)\varphi_{\theta_{ij}}(\varepsilon_{i,j,t})$, $\varepsilon_{i,j,t} := Y_{it} - q_{i,j,t}(\cdot,\hat{\alpha}_T)$, $\varepsilon_{i,j,t}$ is distributed to the asymmetric Laplace distribution.

The MVMQ-CAViaR model has the following advantages. First, there is no need to make any assumptions about the joint distribution of returns and avoid the biased estimation problem caused by model misspecification (Zeng et al., 2017). Second, the introduction of quantile auto-regression reflects the volatility clustering of the financial time series data. Third, the relevance of returns can be described from different quantile levels and that is robust to outliers of financial data. Fourth, it is not necessary to calculate the first and second moment of the model, and the direct measurement of the upper moment tail risk contagion of the relevant market can greatly simplify the parameter estimation process (Hao et al., 2017). Next, in order to study the financial contagion between the stock market and the bond market, suppose the returns of market 1 and market 2 are respectively expressed as Y_{1t} and Y_{2t}, and the MVMQ-CAViaR (1,1) model is established as follows:

$$q_{1t} = c_1(\theta) + a_{11}(\theta)|Y_{1t-1}| + a_{12}(\theta)|Y_{2t-1}| + b_{11}(\theta)q_{1t-1} + b_{12}(\theta)q_{2t-1},$$
$$q_{2t} = c_2(\theta) + a_{21}(\theta)|Y_{1t-1}| + a_{22}(\theta)|Y_{2t-1}| + b_{21}(\theta)q_{1t-1} + b_{22}(\theta)q_{2t-1}, \qquad (5)$$

Equation (5) can be simplified as

$$q_t = c + A|Y_{t-1}| + Bq_{t-1} \qquad (6)$$

Where $c = \begin{pmatrix} c_1 \\ c_2 \end{pmatrix}$, $A = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix}$, $B = \begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{bmatrix}$, q_{it} represents the VaR of market i (i = 1, 2) at time t, which satisfies the condition $\Pr[\mathrm{Y}_{it} \le \mathrm{q}_{it} | F_{t-1}] = \theta$. The coefficients of equations (5) and (6) are derived from the quasi-maximum likelihood estimation. If the non-diagonal coefficients a_{12}、a_{21}、b_{12} and b_{21} of the two markets are significantly different from zero, the two random variables have a tail risk contagion effect. The null hypothesis is $H_0 : a_{12} = a_{21} = b_{12} = b_{21} = 0$. If a_{12} and b_{12} are significantly different from 0 , then there is a risk spillover from market 2 to market 1, and if a_{21} and b_{21} are significantly different from 0 , there is a risk spillover from market 1 to market 2. If the diagonal coefficients a_{11}、a_{22}、b_{11} and b_{22} are not significantly equal to 0, there are volatility clustering effects.

Let R be the constraint matrix, β is the matrix of estimated coefficients. For the null hypothesis $H_0 : R\beta = r$, by referring to the construction idea of Wald statistics, this paper establishes Wald statistics of the MVMQ-CAViaR (1,1) model to test whether there is a significant tail risk contagion between the two markets,

$$(\mathrm{R}\hat{\beta} - r)'[\mathrm{R}\times \mathrm{VC}_T \times \mathrm{R}']^{-1}(\mathrm{R}\hat{\beta} - r) \xrightarrow{d} \chi^2(q)$$

Where VC_T is the variance covariance matrix of the coefficient, $VC_T = \frac{1}{T}Q^{-1}VQ^{-1}$, and Q and V are the same as in equation (4). If we examine whether market 1 and market 2 have a significant tail risk spillover effect, then the value of q = 4, r = 0. When the Wald statistic is greater than the critical value of a given significance level, then the two markets have significant tail risk contagion, on the contrary, the conclusion is the opposite.

4 Empirical results and analysis

4.1 The basic characteristics of the data

According to the types of bonds, we separately study the risk spillover effect between the stock price and the prices of total bonds, national bonds, enterprise bonds and corporate bonds. National bonds are issued by the central government, usually as a tool for the central government to raise funds from the society. Enterprise bonds are issued by large-scale corporations, and the issuers can either be listed companies or non-listed companies, while corporate bonds are issued by listed companies. Although enterprise bonds and corporate bonds are the means of directly financing from the society of the corporations, enterprise bond is unique in China which requires bond issuers to have large-scale national projects or projects in line with national industrial policies.

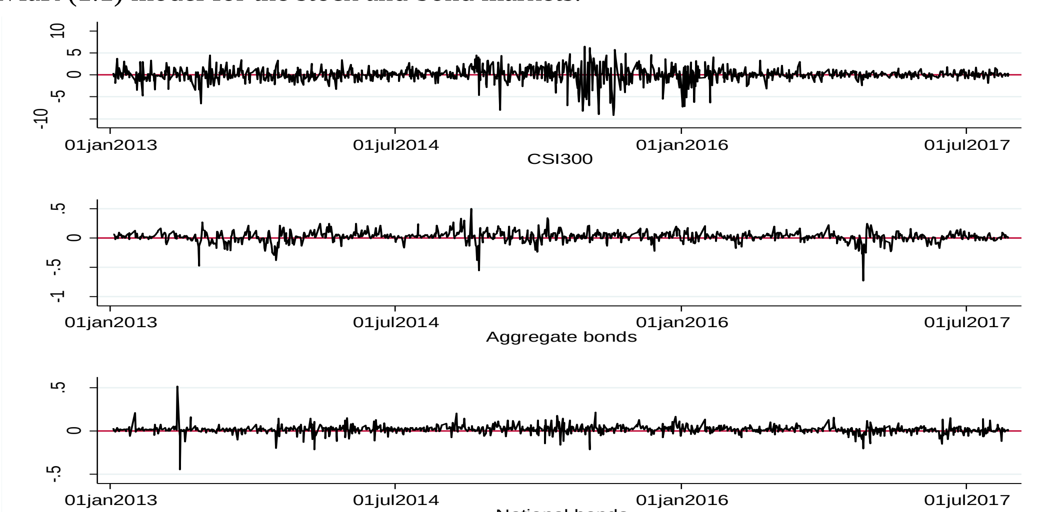
Therefore, compared with corporate bonds, enterprise bonds have certain features of government bonds with higher hedging characteristics. This paper selects the CSI 300 Index as the stock price index and selects China Aggregate Bond Index, China National Bond Index, China Enterprise Bond Index and China Corporate Bond Index as a representative bond prices index during the sampling period of January 4, 2013 to September 20, 2017. The above data comes from Wind database.

Table 1 Descriptive statistics of the total sample yield

	Mean	Min	Max	St. d.	Skewness	Kurtosis	KS-test
CSI 300	0.0366	-9.1544	6.4989	1.5926	-1.0044	9.1870	Reject
Aggregate bonds	0.0173	-0.7303	0.4998	0.0893	-0.9434	11.2218	Reject
National bonds	0.0146	-0.4495	0.5147	0.0469	0.0206	25.2907	Reject
Enterprise bonds	0.0246	-0.2930	0.1612	0.0333	-0.5881	11.5349	Reject
Corporate bonds	0.0210	-0.2810	0.2217	0.0447	-0.2833	6.6490	Reject

Table 1 gives the basic statistical characteristics of the daily returns of the CSI 300, aggregate bonds, national bonds, enterprise bonds and corporate bonds over the sample period, the daily rate of return is calculated as follows: $R_t = 100 \times \ln(p_t / p_{t-1})$, in the formula, p stands for market price index, there exists a negative relationship between bond market returns and bond yield to maturity. As can be seen from table 1, the mean and standard deviation of the return on the stock market are greater than the return on the bond markets, indicating that the stock market has the characteristics of high-yield and high-risk. The stock market return distribution has the characteristics of negative skewness and leptokurtic, the probability of yielding on the left side of the mean is greater than that on the right side. The KS test shows that the stock market returns follow a non-normal distribution. As for the bond markets, the mean value of national bond returns is less than enterprise bonds and corporate bonds, and the national bond returns have a positive skewness, enterprise bonds and corporate bonds are negative skewness, indicating that national bonds have low yield low risk characteristics. All bond market kurtosis are greater than 1 with leptokurtic feature. KS test results reject the null hypothesis, indicating that the bond yield sequence is non-normal, so it is suitable for us to use the quantile regression method to study the stock market and bond market risk contagion effect.

Figure 2 shows the daily rate of return of CSI300, aggregate bond index, national bond index, enterprise bond index and corporate bond index. It can be seen from figure 2 that the stock market experienced large market fluctuations during 2015-2016 with a volatility clustering feature. In the bond market, the corporate bond fluctuated the most significantly, followed by the enterprise bond with the smallest volatility in the national bond. For enterprise bonds and corporate bonds, the volatility between 2013 and 2015 was more obvious with volatility clustering characteristics which was in line with bull market of bonds from 2013 to 2015. Next, we estimate the MVMQ-CAViaR (1.1) model for the stock and bond markets.



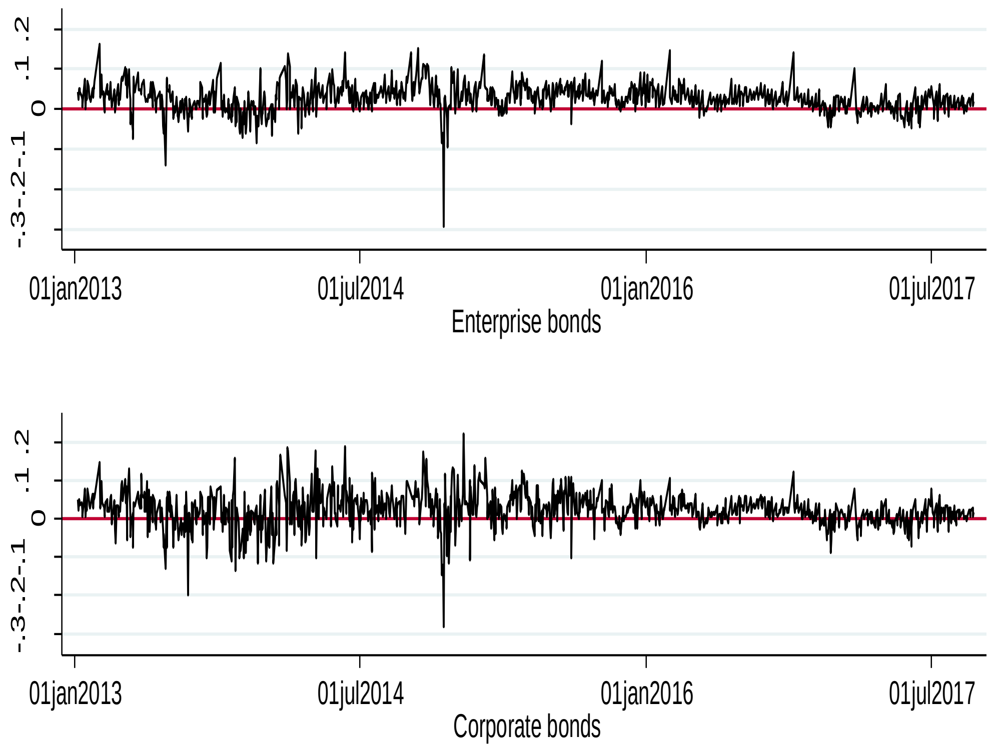


Fig 2 Daily returns of price index of the stock market and bond markets

4.2 MVMQ-CAViaR model estimation

In this paper, the quantile = 1%, the specific steps of the estimates of MVMQ-CAViaR model are as follows: First, q_{i1} is initialized by taking the first 100 observations from market i (i=1, 2), and the initial parameter values of the optimization program are estimated by the univariate CAViaR model proposed by Engle and Manganelli (2004). Second, the parameters of model (5) are optimized by using Simplex Algorithm and Quasi-Newton Method to minimize the objective function of quasi-maximum likelihood estimation, then the estimation of parameter matrix is obtained. Table 2 shows the estimation results of the MVMQ-CAViaR model. We see that the diagonal elements a_{11} and a_{22} of the coefficient matrix A are significantly negative, indicating that the negative shock on the stock market and the bond market will increase the market risk. The diagonal elements b_{11} and b_{22} of the coefficient matrix B are significantly positive, indicating that the increase of the previous term of the risk level leads to the increase of the current period risk level, i.e. the market has the characteristics of risk auto-correlation and volatility clustering. According to the regression results of the stock market and the aggregate bond market, we find that the coefficient b_{21} is significantly negative, indicating that the stock market has a negative risk spillover effect on the bond market, the stock market risk negatively correlated with the bond market risk. The probable cause is due to the investor’s risk hedging strategy, the fall in stock yields leads investors to invest more secure bonds, raising the price of bonds, which is in line with the "flight-to-quality" effect.

The coefficient a_{21} and b_{21} between the stock market and the national bonds market are significantly different from zero at a significance level of 10% and the coefficient values are very small, so the spillover effect of the stock market to the national bonds is very small. At the same time, the coefficient b_{12} is positive and significant in 10% significance level, indicating that the rising risk in the national bond market caused the rise in the stock market risk. The non-diagonal elements of the coefficient matrix between stock market and enterprise bonds market are insignificant, indicating that there is no significant risk spillover effect in both markets. The regression coefficient a_{21} between the market of stocks and corporate bonds is significantly negative, indicating that the negative shock on the stock market will increase the corporate bonds risk. The negative impact of the stock market such as rising interest rates and other fundamental impacts influence corporate bonds, resulting in investors to sell corporate bonds, and rising of the level of corporate bonds risk. The coefficient b_{21} is significantly negative, indicating that the increase of the risk of the corporate bond market decreases the risk level of stock market. The possible reason is that the decline of the corporate bond returns makes people instead invest in the stock market, raise the stock price and reduce the risk level of stock market.

Table 2 MVMQ- CAViaR (1,1) model coefficients estimates

Parameters	c_1	a_{11}	a_{12}	b_{11}	b_{12}
	c_2	a_{21}	a_{22}	b_{21}	b_{22}
Stocks-aggregate bonds	0.0262	-0.1547***	0.0032	0.9679***	-0.0085
	(0.0636)	(0.0342)	(1.7454)	(0.0112)	0.6281
	-0.0575***	-0.0004	-1.3758***	-0.0071***	0.4720***
	(0.0093)	(0.0046)	(0.1109)	(0.0019)	(0.0302)
Stocks-national bonds	0.1283*	-0.1682**	-0.9970	0.9297***	1.2031*
	(0.0872)	(0.0725)	(3.3784)	(0.0308)	(0.9205)
	-0.0020	0.0096*	-0.3173	0.0047*	0.8761***
	(0.0080)	(0.0061)	(0.2557)	(0.0028)	(0.0699)
Stocks-enterprise bonds	-28.3174	-0.3509**	2.5979	-0.8765	-220.678
	(56.3267)	(0.1780)	(4.7281)	(3.4055)	(444.077)
	-0.0057	0.0010	0.0049	-0.0001	0.9573
	(0.4370)	(0.0034)	(0.0519)	(0.0285)	(3.4010)
Stocks-corporate bonds	0.0277	-0.1541	0.0347	0.9683***	0.0012
	(0.2051)	(0.1842)	(3.4763)	(0.0381)	(3.6926)
	-0.0162***	-0.0177***	-0.2955**	-0.0038***	0.6959***
	(0.0049)	(0.0045)	(0.1462)	(0.0014)	(0.0532)

Note: The data in parentheses is the standard deviation of the corresponding coefficients. *, **, *** represent the rejection of the null hypothesis at the significant level of 10%, 5% and 1% respectively.

4.3 Tail risk spillover test

In section 4.2, we discussed the significance of individual coefficient, but do not test jointly the multiple coefficients or draw a general conclusion about the extreme risk contagion effect between two markets. The Wald statistic test results, which test whether there is a significant tail risk infection in the two markets under the MVMQ-CAViaR (1,1) model, are given in table 3, the null hypothesis is $H_0 : a_{12} = a_{21} = b_{12} = b_{21} = 0$, assuming that there is no extreme risk spillover between the two markets. As can be seen from table 3, under the significance level of 5%, there is a significant extreme risk spillover effect between the stock market and aggregate bonds market, the stock market and the corporate bonds market, while there is no extreme risk spillover effect between the stock market and national bonds market, the stock market and enterprise bonds market.

Table3 Financial contagion test between stock market and bond market

	Stocks-Aggregate bonds	Stocks-National bonds	Stocks-Enterprise bonds	Stocks-Corporate bonds
$H_0 : a_{12} = a_{21} = b_{12} = b_{21} = 0$	Reject	Accept	Accept	Reject

Figure 3 shows 1% dynamic VaR sequence of the bond market. As can be seen from figure 3, VaR value reflects the market risk, and the most volatile value is the VaR of corporate bonds. We can also see that the bond market is sensitive to external information. On December 15, 2016, the collapse of aggregate bonds VaR was related to the plunge of the government bond futures in the inter-bank bond market due to rumors of default and the rise of the interest rate of US dollars. The returns of enterprise bonds and corporate bonds dropped sharply on December 9, 2014, which was related to the market overreaction to the "notice" issued by the CSRC.

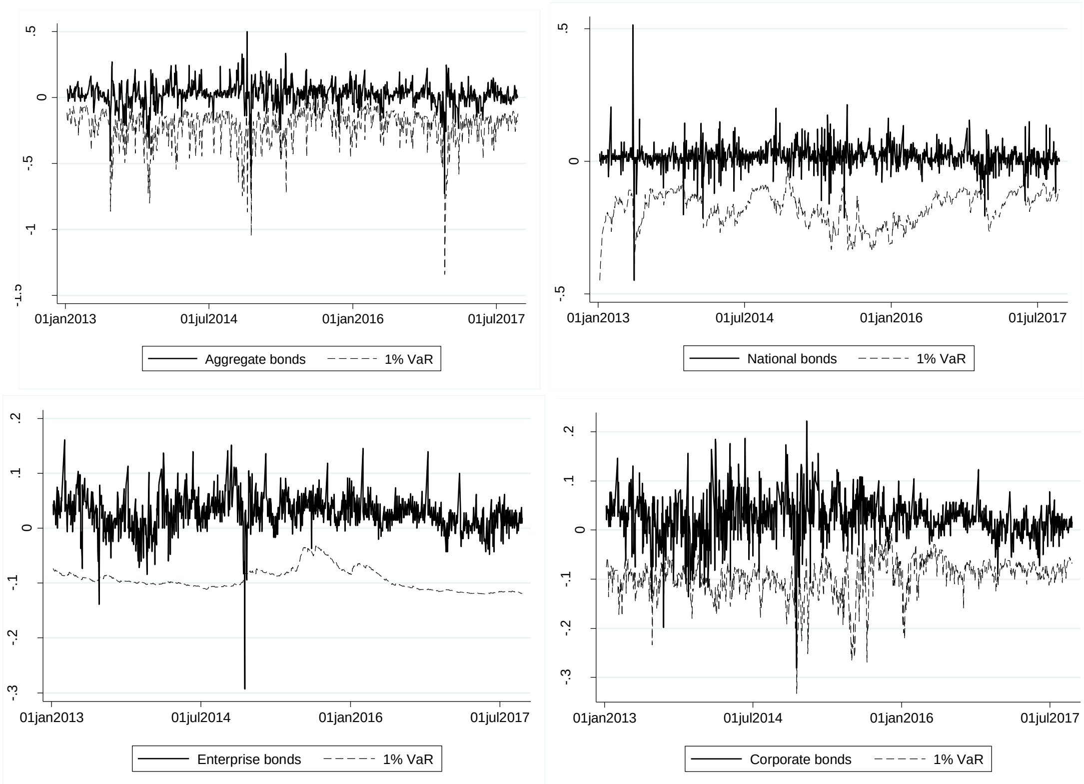


Figure 3 1% dynamic VaR sequence of the bond market

4.4 Quantile impulse response analysis

In Section 4.3, we obtained the general conclusion of the extreme risk spillover between the bond market and the stock market, and the dynamic VaR at the 1% level. Based on these, we use the quantile impulse response analysis to examine the dynamic impact of the negative shock on the market extreme risk. This paper uses quantile impulse response function proposed by White et al. (2015), the calculation steps are as follows: First, suppose the data generation process of two market returns Y_{1t} and Y_{2t} satisfies $\begin{bmatrix} Y_{1t} \\ Y_{2t} \end{bmatrix} = \begin{bmatrix} \alpha_t & 0 \\ \beta_t & \gamma_t \end{bmatrix} \begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \end{bmatrix}$, and the strength of shock depends on the Cholesky decomposition matrix $\begin{bmatrix} \alpha_t & 0 \\ \beta_t & \gamma_t \end{bmatrix}$. Second, Y_{1t} is received one-unit negative shock δ at time t, i.e. $\hat{Y}_{1t} := Y_{1t} + \delta$. Finally, analyze the dynamic impact of δ on the tail risk of market 2. Figure 4 shows the impulse response of the 300 periods of one market when the correlated market is impacted by 2 units of new standard deviation. The vertical axis represents the percentage change of market risk under the negative shock. It can be seen from figure 4 that all the new effects gradually weakened and disappeared in different speeds.

First of all, from the perspective of the stock market and the aggregate bond market, the negative shock of the stock market has a positive impulse response to the bond market, with a relatively short duration. The decline in the yield of the stock market makes investors tend to reduce the investment in the stock market, allocate more assets on the bond market, resulting the rise of prices and the decline of risk in the bond market, in line with the "flight-to-quality" effect. From the perspective of the bond market classification, the negative shock of the stock market has a positive impulse response on the national bonds and enterprise bonds, which is in line with the risk hedging strategy, while the impact on the corporate bond price is the first drop and then rise, probably due to corporate bonds are issued by the listed company, the negative impact of the stock market as a fundamental shock allows investors to sell both stocks and corporate bonds at the same time, and the price of both markets decline. With the decline in stock prices, due to lower default risk of bonds, investors instead increase the allocation of corporate bonds, resulted in corporate bonds prices arise. Second, from the impact of bond market shock on the stock market, the national bond market shock has a significant and negative impulse response on the stock market, which means that the negative shock of national bonds, increasing the stock market risk.

The rise of interest rate as a negative shock on national bonds, the rise of interest rate weaken the market liquidity, led to lower stock prices and higher stock market risk. The negative shock of enterprise bonds, making the stock market continued to shock, but quickly returned to the original level of market risk.

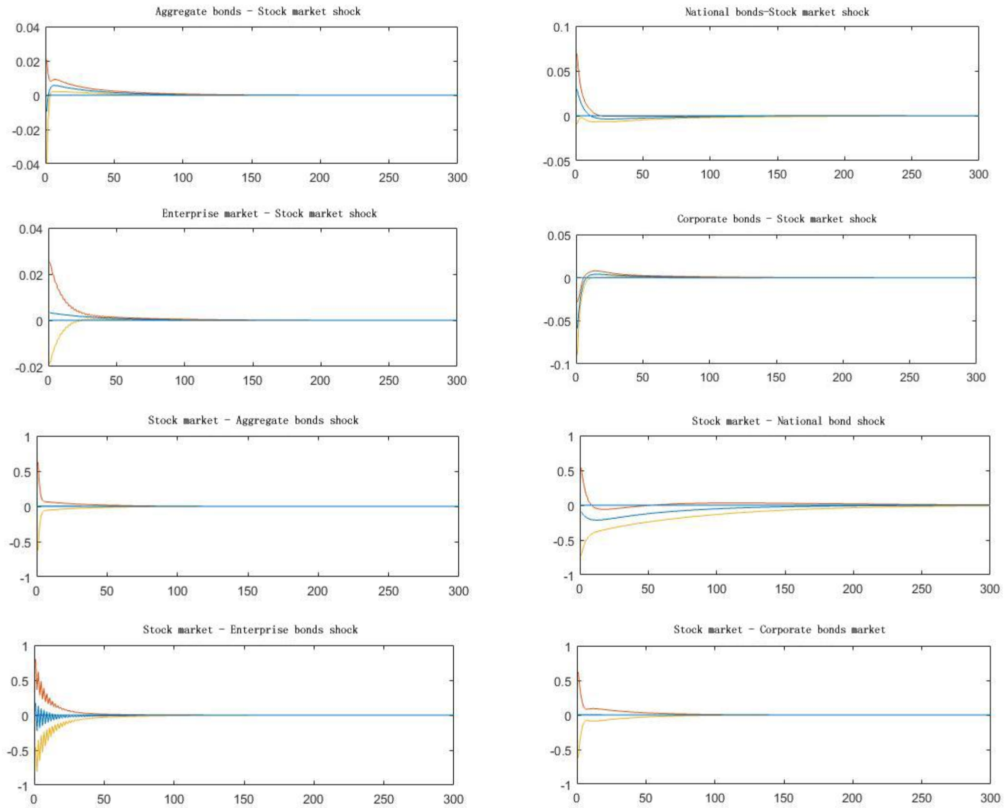


Figure 4 Bond market and stock market quantile impulse response analysis

5 Conclusion and suggestion

In the early stage, China's stock market and bond market were in a relatively divided state, making it difficult for them to have the risk contagion. However, with the further deepening of financial market reform in recent years, the correlation between the two markets has been strengthened. This paper studies the extreme risk spillover effect between the stock and bond markets by using the MVMQ-CAViaR (1,1) model combined with the plunge in the Chinese stock market in 2015 and finds that there is a significant risk contagion effect between the two markets under the worst market conditions. The conclusion of the study is as follows: First, from the influence of the stock market on the bond market, when the return rate of the stock market is reduced, the investors will increase the bond allocation through the risk hedging strategy, hence the bond prices rise, which is in line with the "flight-to-quality" effects. Second, from the stock market's impact on corporate bonds, the decline in stock prices increases corporate bond risk in the short term, and push up the price of corporate bonds in the long term. Third, as for the national bond's impact on the stock market, when the national bond returns fell, the rate of stock market return tends to reduce, the two prices will move in same direction. Fourth, there is no significant risk spillover effect between enterprise bonds and the stock market. Combined with the above conclusions, this paper draws the following policy implications: First, speed up the development of the bond market, especially the enterprise bonds and corporate bonds, continuously increase the size of the bond market and lower the threshold of investment, will avail investors to allocate their assets and diversify investment risks. The second is to further relieve the restriction on the investors' qualification, and strengthen the interconnection between the stock market and the bond market, which will help increase the market's price discovery function and risk adjustment capability. Third, the government should improve the financial system laws and regulations, increase the proportion of institutional investors in the stock market, avoid abnormal fluctuations in the rate of return caused by the flow of large amounts of funds across the market, maintain the stability of financial markets and prevent systemic risks.

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