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Measuring systemic risk using contingent claims analysis model with higher-moment and machine learing technology

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ABSTRACT. *Accompanied by financial risk all time, financial market has made great progress. It is necessary to measure the change and character of financial risk and try to avoid the risk in terms of theory and practice. Based on the contingent claims analysis (CCA) framework, this paper tries to use higher-moment transformation to quantify the risk of financial distress better. The average distance to default under HCCA model of the Chinese banks fluctuated at low-level in recent years, the same goes for traditional average distance to default. And, more remarkable, the systematic distance to default under HCCA model and original normal distribution random model fluctuated at low-level too. These are signs that the systemic risks for the listed banks in China take on an increasing trend at the high level. HCCA model can improve the accuracy and effectiveness of financial policies, and strengthen the forward-looking prediction of policy measures.*

KEYWORDS: *systemic risk contingent claims analysis (CCA); higher-moment; machine learning*

1. Introduction

Financial risk refers to the risks related to finance, such as financial market risk, financial product risk and financial institution risk [1]. Risks in a financial institution often have consequences beyond their own. The risks of financial institutions in specific financial transaction activities may pose a threat to the survival of the financial institutions. The crisis of a specific financial institution caused by poor management may threaten the sound operation of the whole financial system [2]. Once the systemic risk occurs, the failure of the financial system will inevitably lead to the chaos of the whole social and economic order and even lead to a serious

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political crisis [3]. The economy development and financial reforms put forward the urgent request for the construction of the risk early-warning of the financing institution. Because the development of the financial industry makes it circulate the risk in the process and continuously enlargement, and accumulate little by little[4].

Accompanied by financial risk all time, financial market has made great progress. it is necessary to measure the change and character of financial risk and try to avoid the risk in terms of theory and practice[5]. The prevailing model, gauging financial systemic risk on the time dimension, was contingent claims analysis (CCA) model. For all its mainstream approach, the model discarded skewness and kurtosis that could be put into full play [6]. CCA model could not predict prospectively the systematic financial crisis well. To this end, the higher-moments (skewness and kurtosis) were incorporated into the banking systemic risk measures, which forged a looking-forward higher-moment contingent claims analysis (HCCA) model. It will be state-of-the-art and far-reaching to forecast financial systemic risk or prevent financial crisis beforehand [7]. Based on Corrado-Su's formula and correction, it extends the CCA model, and measures the risk indicators such as individual DD, systemic DD and expected loss among 8 banks with their stock price and balance sheet data. The model reflects the dynamic processes of the systemic financial crisis and China 's real economy well.

2. The theoretical basis and design

2.1 HCCA model

Contingent claims analysis (CCA) model is a modeling study that depond the uncertainty of future returns of some assets on the value of other assets. CCA model is based on the Black-Scholes theory and the Merton option pricing theory. Based on Corrado-Su's formula and correction, it extends the CCA model, and measures the risk indicators such as individual DD, systemic DD and expected loss among 8 banks with their stock price and balance sheet data. The model reflects the dynamic processes of the global financial crisis and Chinese real economy well. Based on asset market value and the relationship between the equity financing and the bond markets, CCA model is suit for the total study of the financial risk. Traditional CCA model is foundation on the Black-Scholes-Merton (BSM) model, which is the accepted standard for option valuation. The expression of CCA model is as follows:

$$dA_t = \mu_A A_t dt + \sigma_A A_t dz \quad (1)$$

In the formula above, A refers to the market value of an asset at the time of t; μ_A is the volatility ratio of the asset; based on the Winner Process model, dz is a function of t. In order to forecast the risk of the overall banking system of China better, this paper introduced Corrado-Su model and CCA model extension based on the Gray-Merton-Bobie model to the higher-moments contingent claims analysis (HCCA) model. The expression of HCCA model is as follows:

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$$C_{HCCA} = VN(d) - De^{-r(T-t)}N\left(d - \sigma_v\sqrt{T-t}\right) + S \times \left\{\frac{1}{3!}V\sigma_v\sqrt{T-t}\left[\left(2\sigma_v\sqrt{T-t} - d\right)n(d) + \sigma_v^2\sqrt{T-t}N(d)\right]\right\} + (K-3) \times \left\{\frac{1}{4!}V\sigma_v\sqrt{T-t}\left[d^2 - 1 - 3\sigma_v\sqrt{T-t} \times \left(d - \sigma_v\sqrt{T-t}\right)n(d) + \sigma_v^3(T-t)^{3/2}N(d)\right]\right\} \quad (2)$$

After differentiating, we can get the following:

$$\sigma_E = \frac{V\sigma_v}{C_{HCCA}}\left\{N(d) + \sigma_v n(d)\sqrt{T-t}\left[\frac{S}{3!} \times \left(2\sigma_v\sqrt{T-t} - d + \frac{K-3}{4!} \times \left(d^2 - 1 - 3\sigma_v\sqrt{T-t} \times \left(d - \sigma_v\sqrt{T-t}\right)\right)\right)\right]\right\} \quad (3)$$

In the formula above, C_{HCCA} refers to the market value under the high order moment; V is the asset value under the high order moment; D is about the book value of the debts under the high order moment; r expresses the risk-free interest rate; T is the date of the debt maturity; t is the current date of the liability; n(d) refers to the standard normal probability density function; N(d) is the cumulative standard normal distribution function; σ_v shows the volatility of the asset values; S expresses the skewness and K shows the kurtosis.

2.2 The distance to default

- Due to random fluctuation of the value of banks' assets A_t, banks default (B_t) occurs when assets do not cover liabilities. The traditional formula for the distance to default is as follows.

$$DD = \frac{\log\left(\frac{A_t}{B_t}\right) + \left(r_f - \frac{\sigma^2}{2}\right)(T-t)}{\sigma_v\sqrt{T-t}} \quad (4)$$

The formula for the HCCA distance-to-default model is shown below:

$$DD_{it} = \frac{E(A_{it}) - B_{it}}{E(A_{it}) \times \sigma_v} \quad (5)$$

- DD_{it} represents the distance to default of an individual bank at the time of t; $E(A_{it})$ is the future value of underlying assets.

Then, we can get the formula for the average distance to default of all sample banks

$$ADD_t = \frac{1}{N}\sum DD_{it} \quad (6)$$

N is the number of the sample banks.

2.3 The expected loss

Once the banks defaulted, the government will do everything possible to pay debts for these banks in full, that is

$$EL = E[\max(B_t - A_T, 0)] \quad (7)$$

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The Implicit guarantees from the government for banks default are equivalent to the put option of the value of the banks assets. Therefore, the formula for expected loss using HCCA model is below:

$$\mathbf{EL} = \boldsymbol{B_t e^{-r_f(T-t)} N\left(\sigma_v\sqrt{T-t} - d\right) - A_t N(-d) - (S_F - S_A)\left[\frac{A_t^3 e^{2r_f(T-t)}}{3!}\left(e^{\sigma^2(T-t)} - 1\right)^{\frac{3}{2}}\right]\frac{d^3 a(A_t)}{dA_t^3} + (K_F - K_A)\left[\frac{A_t^4 e^{3r_f(T-t)} e^{-r_f(T-t)}}{4!}\left(e^{\sigma^2(T-t)} - 1\right)^2\right]\frac{d^4 a(A_t)}{dA_t^4}} \quad (8)$$

As can be seen from the formula (8), the expected loss using HCCA model is lager than the traditional expected loss under the condition of the normal distribution, which means the expected loss using HCCA model can evaluate the risk of banks default better.

3. Data sample

Based on 8 listed banks (the Bank of China, China Construction Bank, Industrial & Commercial Bank of China, the Bank of Communications, Beijing bank, Ping An Bank, Pudong Development Bank amd Minsheng Bank) during 2007~2016, this paper studied the possible systemic banking risks through analyzing the systemic distance to default and the average distance to default of the banks above.

4. The empirical analysis

4.1 The volatility rate of the intrinsic value of banks' asset

We got the volatility ratio of the intrinsic value of bank's asset through analyzing banks' asset data of the 8 banks using MATLAB R2016a. We found that the default risk of single bank under HCCA model is higher than that calculated by CCA model, which means HCCA model can describe real risk better than CCA model.

We also found that the σ_v of the 8 banks shares the same trend: the σ_v is in the 0 ~ 0.005 range. Besides, the σ_v of the big state-owned banks is lower than that of joint-stock banks. Some overload production in some industries, the high debt ratios, the high everage ratios, market-oriented reforms of interest rates and the increasing bad debts rates are the main reasons for the high systemic risks. Although the Chinses government had given efforts to make some economic structural adjustments, which was helpful to deleverage and reduce the capacity [15], however, Chinese major state-owned companies still had too much bank loan. As a result, the too much bank loan can increase the risks of the financial system.

4.2 The distance to default and the systemic risk

The systematic distance to default under HCCA model is smaller than under

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original normal distribution random model after calculated. That means that systemic risk under HCCA model is greater than the traditional CCA model. The average distance to default under HCCA model of the Chinese banks fluctuated at low-level in recent years, the same goes for traditional average distance to default. And, more remarkable, the systematic distance to default under HCCA model and original normal distribution random model fluctuated at low-level too. These are signs that the systemic risks for the listed banks in China take on an increasing trend at the high level.

4.3 The expected loss

We found that the expected loss under HCCA model is higher than that of original normal distribution random model. Meanwhile, the expected loss has an increased trend during 2007~2016, although China has set up a deposit insurance system since 2014. We think, the authority should enacte a reasonable level of expected loss so that they can make effective policies for the government recessive guarantee system.

5. Results

This paper studied the possible systemic banking risks through analyzing the systemic distance to default and the average distance to default of 8 listed banks data. We finds that: 1) HCCA model can predict global financial crisis and European sovereign-debt crisis ahead of three to six months or longer, and thus help the financial sector catch the valuable time to prevent and manage the financial crisis; 2) HCCA model shows that China's banking systemic risks are steadily accumulated,and puts forward the early warning of bank's systemic risks for the financial authorities and commercial banks. It is necessary to measure the effect of hidden capital value with higher moments on the risk indicators such as DD and expected loss. It can improve the accuracy and effectiveness of financial policies,and strengthen the forward-looking prediction of policy measures.

The empirical conclusions and policy advice of this paper are as follows:

(1) According to the time-varying characteristics of the financial systemic risk, the supervising department needs to make sure adequate regulatory mechanisms with foresight and scientificity. The evaluation on the financial risks at regular intervals is help to prevent and convert these risks.

(2) HCCA model is a positive tool for measuring systemic financial risks. HCCA model can use the indexe of distance to default to reflect risk status. Therefore, HCCA model, which is developed from higher moments transformation of CCA model, can feature higher sensitivity, accuracy, and specificity than CCA model.

(3) The international financial crisis is more and more contagious and destructive

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for the China's banks, the local government should take more measures to enforce the system of credit risk management and reduce the amount of bad assets. The banking sector should take flexible and prudent macro-prudential policies.

(4) The systemic risks for the listed banks in China take on an increasing trend at the high level, which means the financial risk management system that we have is imperfect, we aren't there yet. The Chinses government should make more economic structural adjustments to deleverage and reduce the capacity.

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