Early Warning of Chinese Stock Market Crises Based on Volatility Model

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Abstract. The stock market has always been known for its instability, and it has been too risky for investors to invest without being warned of the coming crisis. To improve the situation, volatility model, ARMA-GARCH in this research, is used to predict value at risk (VaR) to provide a reference for investors. So, investors can be alarmed ahead. This article tries to structure a proper volatility model that suits the situation of the Chinese market, and further, to help create an efficient early warning system.

Keywords: component; GARCH; ARMA; VaR

1. INTRODUCTION

The stock market has been known for its instability, and volatility is the significant character of the stock market. Risk has always been next to opportunity. It will be impossible to avoid every loss, but it can be foreseen whether a crisis, which we assume, follows a conceivable sign. Since the stock market was introduced to China in 1990, there have been several major crashes. Unpredictable drops may cost the investor a fortune. The first decline took place in May 1992 as a resilience of the impulse caused by the import of the stock exchange. The stock index fell from 1429 to 386 in half a year. In February 1993, another slump in stock was triggered by the issue of a new share. This situation did not stop until August the same year at the point of 325. At the initial stage of the stock market, the stock value fluctuates rapidly, for rules are unset, and the market itself is immature. Following significant slump occurred in November 1994, which fell almost 50%, May 1995, May 1997, June 2001, October 2007, August 2009, June 2015, and of course, in 2018 and the end of 2019. Though the Chinese domestic stock market developed astonishingly fast over the past few decades, it is still immature. The market is filled with unstable factors and concerns its investors. As investors and supervisors, we would like to be alert of potential risk ahead of its actually taking place. It concerns us whether we can figure out a model that can anticipate the future opportunities and risks in the stock market. The aversion to coming across an unknown bear market drives us to study the market and try to draw a pattern that helps us find clues of crash out of prospering and prepare for coming crises. It would be a delight if investors could be alarmed before a crisis comes. Building an effective and reasonable monitor and early warning system is also essential for motivating the economy's development and protecting the market itself. Every time a financial crisis hits society, there will be a significant negative effect. It would be nice if there were a way for the supervisors to anticipate the crisis and cope with it early.

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In order to make the model valid, proper data ought to be chosen carefully. Not all data represent the market, and if we use those data to modeling, it can hardly achieve the purpose. In the last two crushes mentioned, an influence, or impact, from the outside should be taken into consideration. Things like a political and unexpected epidemic cannot be foreseen, so we shall try to exclude the variation caused and focus on the market itself. In order to do that data in a certain period, basically no big events that concern the market takes place. Besides, we are trying to obtain the newest data as our object to fit the current situation and be more precise while predicting without losing timeliness. As we tend to do the research validly and focus on the risk generated by the market itself instead of impact from other fields, an interval of data between the beginning of 2012 and the end of 2017, which is quite a peaceful time, is taken as the training set. As a result, we can avoid a major impact from outside the market, and the data is still convincing for the latest forecast. The article is trying to build a volatility model based on the daily rate of return. The data is from China Center for Economy Research.

In 1952, the public of Markowitz's Portfolio Selection had started a brand-new theory of portfolio. Although there were ways to evaluate risk, they all had their flaws and disadvantages. Because of that, people began to notice that the current estimate of risk was inadequate, and a new and more effective method was desperately wanted. As the economy develops, people are paying more attention to controlling the risk in every single investment. Measurements based on deviation and variation have an obvious practical flaw, such as the strictly restricted normal distribution condition, fixed variation and lack of an absolute value of risk. Later Engle came up with the idea of the ARCH model in a paper he published on Econometrica in 1982 [1], which solves the problem of the volatility in time series to some extent. And in 1986, GARCH was launched by Bollerslev [2,3]. It needs fewer parameters and matching the situation better than ARCH most of the time.

The autoregressive moving average model (ARMA) is a common method to study stationary random processes. It usually does better than AR or MA separately. This study combines with GARCH to compensate for the neglect of the mean function of GARCH to complete an entire model.

Shoudong Chen and Shidian Yu used the GARCH model to simulate the stock market and analyze the risk in 2002. And ZHOU Aimin and CHEN Yuan [4]'s work on simulate small and media-sized board markets on the basement of GARCH is rather accurate. As an extent or updating of their work, this article will refer to some of their results. This article is going to use later data and adjust it to fit the current stock market.

2. LITERATURE REVIEW

Former scholars have done similar work, and the results can achieve relatively accurate results, such as CHEN Shoudong and YU Shidian's work and Takashi Kimoto and Kazuo Asakawa's [5] work on the Japanese stock market. But little researches on the aspect of risk prediction in the Chinese market have been done. To fill the gap, we decided to build a system to alert foreseeable risks in the Chinese stock market. In our research, to keep the conclusion in time, we try to use data as new as we can find. But as people tend to "overreact" to big events and cause unpredictable fluctuation [6] (WERNER F. M. De BONDT and RICHARD THALER 1985),

data in special periods are not valid to be a part of the data set. So, the Shanghai securities composite index from the beginning of 2012 to the end of 2017 is chosen for our research.

As "GARCH models have been applied to a wide range of time series analyses, but applications in finance have been particularly successful" [7] (Robert Engle 2001), we consider GARCH as an optimal to build the model we need to predicate the potential risks from the stock market. Former scholars have done a lot in Early-Warning System (EWS), such as the FR probity model by Frankel [8] (1996), the KLR model by Kamnisky [9] (1997) and STV by Sachs (1996) [10]. And, of course, value at risk by G30 (1993) [11]. In this article, VaR is adopted to evaluate the risk.

3. METHOD

In order to analyze the risk of the Chinese stock market, Shanghai security composite index from 2012 to 2017 was chosen. The reason is that the China-United States trade war took place in 2018 and had a major impact on the stock market, followed by the covid epidemic. As it is impossible to predict fluctuation outside the market, data influenced by unpredictable impacts cannot be considered. In the meantime, data as new as possible is ideal, for it can represent the latest status of the stock market. As a result, data during this period was trusted to be convincing and representative; it is safe to say the stock market was barely affected by anything besides the market itself.

This article used the ARMA-GARCH method to simulate and fit the current stock market to warn us of the potential crisis early effectively. For evaluating the risk validly, the variable of the rate of return was sufficient to build a model. Instead of using it directly, logarithm was a better choice. In the case of this, the data set is defined as

$$\ln(1 + \mathrm{rt}) \ (No. 1).$$

When Engle launched ARCH in 1982, the idea was to model both mean and variance simultaneously.

$$y_t = \alpha_0 + \alpha_1 y_{t-1} + \varepsilon_t \ (No. 2)$$

Which satisfies:

$$\mathrm{E}(y_{t+1}) = \alpha_0 + \alpha_1 y_{t-1} \ (No. 3)$$

And to evaluate the variance of error:

$$E_t[(y_{t+1} - \alpha_0 - \alpha_1 y_t)^2] = E_t(\varepsilon_{t+1})^2 = \sigma^2 \ (No. 4)$$

When $\{\hat{\varepsilon}\}$ stands for the evaluation of residuals, then the conditional variance presents as:

$$\mathrm{Var}\ (y_{t+1}/y_t) = E_t[(y_{t+1} - \alpha_0 - \alpha_1 y_t)^2] = E_t(\varepsilon_{t+1})^2 \ (No. 5).$$

Using the evaluation of $E_t(\varepsilon_{t+1})^2 = \sigma^2$ as an independent variable when the conditional variance is unknown. And modeling conditional variance AR(q) can obtain:

$$\widehat{\varepsilon_t^2} = a_0 + a_1 \widehat{\varepsilon_{t-1}^2} + a_2 \widehat{\varepsilon_{t-2}^2} + \cdots + a_p \widehat{\varepsilon_{t-p}^2} + v_t \ (No. 6)$$

Where v_t is white noise.

The main idea of ARCH is that the current residuals rely on former residuals.

In this study, to make the model simple, ARMA-GARCH was used for the experiment, where ARMA(p,q)=ARMA(1,1). Bollerslev extends Engle's model by considering conditional mean and conditional variance at the same time. GARCH (Generalized AutoRegressive Conditional Heteroskedasticity) model came up in the 1980s and is usually presented as

$$\sigma^2 = \alpha_0 + \alpha_1\varepsilon_{t-1}^2 + \cdots + \alpha_q\varepsilon_{t-q}^2 + \beta_1\sigma_{t-1}^2 + \cdots + \beta_p\sigma_{t-p}^2 \ (No.7).$$

$$\varepsilon_t = v_t\sqrt{\alpha_0 + \alpha_1\varepsilon_{t-1}^2 + \cdots + \alpha_q\varepsilon_{t-q}^2 + \beta_1\sigma_{t-1}^2 + \cdots + \beta_p\sigma_{t-p}^2} \ (No.8)$$

and GARCH(m,n)=ARMA(1,1). And GARCH (1,1) part presents as follows:

$$\sigma_t{}^2 = \alpha_0 + \alpha_1\varepsilon_{t-1}^2 + \beta_1\sigma_{t-1}^2 \ (No.9)$$

$$\varepsilon_t = v_t\sqrt{\alpha_0 + \alpha_1\varepsilon_{t-1}^2 + \beta_1\sigma_{t-1}^2} \ (No.10)$$

ARMA (Autoregressive moving average model) is written as:

$$x_t = \mu_0 + \sum_{i=1}^{p}\mu_i x_{t-i} + \varepsilon_t + \sum_{j=1}^{q}\theta_i\varepsilon_{t-i} \ (No.11)$$

Since the model wanted is build, all the parameters could be extracted from the model. And then put the value got from the calculation into the equation to get the mean function and variance function:

$$\sigma_t{}^2 = 0.053727\varepsilon_{t-1}^2 + 0.944326\sigma_{t-1}^2$$

$$x_t = 0.000292 - 0.303532x_{t-1} + 0.327051\varepsilon_{t-1}$$

Hence, according to the parameter method, the value at risk (VaR) could be obtained from the formula:

$$\mathrm{VaR}_t = \mu + \sigma_t F^{-1}(\alpha) \ (No.12)$$

Put actual value to replace the symbol:

$$\mathrm{VaR}_t = 0.000292 + \sigma_t F^{-1}(\alpha)$$

And this will be discussed later.

In the time series of the rate of return, the second-moment changes while time does, and the volatility tends to gather in a certain time. As for heteroscedasticity and the character of economical time series, applying the GARCH model would be conceivable, which proved valid later in practice. And to illustrate the model, ARMA was used to create the mean function. In this case, a complete model with both variance function and mean function was built.

After collecting the Shanghai Stock index data of the period, the logarithm of the rate of return was wanted. Before building the model, several tests need to be run. First of all, verifying the normality. And making sure the data is not white noise is also necessary, or the model would be meaningless. With the model built, to assure the weak stationary, the stationary of the time series need to be examined. Next, the article should verify the autocorrelation of the sequence of residuals. And the preparation was not finished until the ARCH effect was verified. So far, the data set has proved to be suitable to be evaluated by the ARMA-GARCH model.

With the ARMA-GARCH model, the variance and residuals could be calculated from the time series, value at risk could be calculated from the equation above and providing the most severe loss that could happen. VaR is the minimum loss in either currency units or as a percentage of

portfolio value that would be expected to be incurred a certain percentage of the time over a certain period given assumed market conditions [12]. Conventional measurements of risk, like sensitive measures and ALM, are too simple or depending on the analysis of former statistics so much that it loses its timeliness. So, in 1993, the Group of Thirty (G30) came up with the VaR method to estimate the level of risk in a report. And it has now become the mainstream way to evaluate risk. VaR has the advantage of being simple and intuitionistic, offering early warning instead of warning afterward and can calculate not only one but also the risk of multiple financial instruments. VaR has been used in situations like risk control, performance evaluation and the evaluation of risk-based capital. And to observe VaR, there are methods like the Monte Carlo method, historical method and parameter method. In this article, the parameter method is adopted.

4. RESULTS AND DISCUSSION

In order to construct an ARMA-GARCH model, the ARCH test ought to be run. Only when the data has an ARCH character can it be used to build a GARCH model.

Table 1 is the ARCH test of 5 moments, and the p-values are small enough that it is safe to say the data can be used. Otherwise, other methods have to be applied to complete the research. It also illustrates that the data is not white noise.

TABLE 1. ARCH LM-TEST

Chi-squared	df	p-value
82.533	1	< 2.2e-16
159.94	2	< 2.2e-16
200.9	3	< 2.2e-16
219.03	4	< 2.2e-16
225.22	5	< 2.2e-16

After that, the normality is as well proofed to establish. Shown as table 2.

TABLE 2. JARQUE BERA TEST

X-squared	df	p-value
3614.6	2	< 2.2e-16

Then it is time to build the model. According to the table below, the appropriate ARMA-GARCH is revealed. As showed in Table 3

TABLE 3. OPTIMAL PARAMETERS

parameter	estimate	Std.error	t value	Pr(>|t|)
μ	0.000292	0.000243	1.20145	0.229577
ar1	-0.303532	0.524048	-0.57920	0.562451
ma1	0.327051	0.518726	0.63049	0.528374
ω	0	0.000003	0.18887	0.850195
α_1	0.053727	0.029748	1.80609	0.070904
β_1	0.944326	0.027790	33.98064	0

Basing on the ARMA-GARCH model, the value at risk (VaR) can be calculated. And from the figures and Table 4-6, it will be okay to say this ARMA-GARCH model simulated well.

TABLE 4. INFORMATION CRITERIA

Criteria	value
Akaike	-6.1354
Bayes	-6.1137
Shibata	-6.1355
Hannan-Quinn	-6.1273

TABLE 5. WEIGHTED LJUNG-BOX TEST ON STANDARDIZED RESIDUALS

	Statistic	p-value
Lag[1]	0.3525	0.5527
Lag[2*(p+q)+(p+q)-1][5]	1.6537	0.9937
Lag[4*(p+q)+(p+q)-1][9]	4.3073	0.6178
d.o.f=2		
H0 : No serial correlation		

TABLE 6. WEIGHTED ARCH LM TESTS

	Statistic	Shape	Scale	p-value
ARCH Lag[3]	0.5364	0.500	2.000	0.4639
ARCH Lag[5]				
ARCH Lag[7]	0.9732	1.440	1.667	0.7412
	3.3159	2.315	0.543	0.4560

With all the text passed, it will be safe to draw VaR out of the model. The Value at Risk series with a 1% limit is shown in figure 1. Intuitively, investors can roughly judge the level at which the market fluctuates by the Value of Risk obtained. It will be riskier to invest when Value at Risk is large and safer when it is small. But the model only evaluates the trend fluctuation and cannot help people foreknow the stock market.

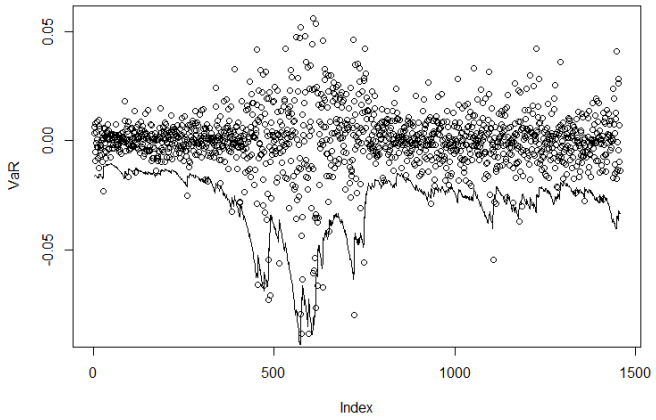

Figure 1. Series with 1% VaR Limits

In consequence, Value at Risk reflects the fluctuation nicely and is reasonable to be considered accurate. So the Value at Risk generated by the ARMA-GARCH model could be a reference of the future trend of the stock market, and coming crises can be detected in this way, which achieves the goal of early warning. In this case, supervisors, enterprises, and individuals can use this article to evaluate future trends and help make investment decisions.

From the figure, it can be told that the model fits the situation quite well, and as a consequence, this model can be applied to predict the future trend of the stock market. And figure 2 is a prediction of the unconditional sigma of the next 20 days. In figure 2, data after Dec 31st is evaluated by the model.

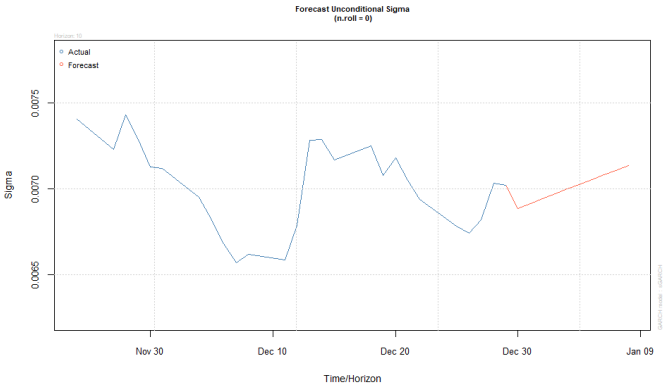

Figure 2. forecast unconditional sigma

But as the model has a constant unconditional expectation, the prediction of future series is invalid. It only shows the rate of return as its mean and has no value to refer to.

5. CONCLUSION

As shown from the figures above and the LM test, the Chinese domestic stock market possesses combined effect and time-variant characteristics. As a result, GARCH is suitable for analyzing the Chinese stock market.

As is shown in figure 2, VaR fits quite well and makes the model valid. According to the result, it would be effective to evaluate future risk by the ARMA-GARCH model. Hence, we can achieve a valid early warning through the ARMA-GARCH model. In other words, this method can effectively describe the Chinese stock market and could be used to evaluate future fluctuations in the stock market. Relative departments, enterprises and individuals can use this ARMA-GARCH model and VaR to evaluate whether it is a good investment opportunity.

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