

# Bank of America Stock Price Research

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## Abstract

The stock price is always an interesting topic. On the one hand, from intuition, the stock price of bank is relatively stable since bank usually does not take risk behavior. From 2007 to 2014, the price of stock of Bank of American is relatively stable by checking the RRV (relative realized volatility). There is only one day has relatively high RRVs during 2007 to 2014. The date May 6<sup>th</sup> 2010, which called crash day, is a special day that needs to analyze separately. On the other hand, to find the pattern of frequency of trading, there are different sample sizes tested and compared with Poisson distribution. The result is that we can use Poisson distribution to predict probability of no arrival trade when second gap is relatively small. In addition, when plotting the daily 100 seconds accumulated RV (realized volatility) and daily average RV, there was found strong linear relationship between these two variables. In the end, using the Heston model to verify if there exist linear relationship between daily average and mean reversion rate. Then comparing trend of alpha with weekly VIX from Yahoo Finance. When using 5 days as a period to calculate the daily average RV and mean reversion rate, the significance of linear relationship is stronger. It proved the statistic intuition that larger sample size tends to decrease the volatility. The overall trend of VIX from Yahoo Finance is similar to the shape of five-day period alpha.

## Keywords

Stability, Heston Model, Linear Regression

## 1. Introduction

The US stock market began since March 8<sup>th</sup>, 1817. It was the time that New York Stock Exchange opened. People analyzed the stock price with different variables everyday and wanted to find the clue to predict the price of equities. Time went by, people started to have more and more experience with stocks and learned from several times of crash. By looking at the crash history of US stock market,

the first crash from September 1929 to June 1932 caused SP500 loss 86.1 percent. Then there were 10 other historical crashes before 2020. Excluding the year 2020, the most recent crash was from October 2007 to March 2009 which caused SP500 loss 56.4 percent (Hristova, n.d.). Therefore, analyzing the volatility and price index trend is one of the critical parts of predicting stock price. People can learn from the past and try to forecast the future to avoid the loss from crash.

Bank of America, which found in 1998, is one of the greatest banks in the United States. Researching on stock price of Bank of America is intuitive because bank stock price is considered as the most stable stock and Bank of America is an icon of conservatism (Johnston, 2000). While some people do prefer risk behavior in order to gain greater return, there are some people who like to stay safe and have stable return. Researching on stocks which have relative low volatility is significant and fitful for people who want to play safe.

Especially when people want to save money or keep gaining money for retired life, dividend is another attractive point for people who want to be safe. Stable and reliable company can pay dividend on time. Based on the history of dividend, Bank of America steadily grows from 0.01 dollar per share to 0.18 dollar per share (Bank of America Corporation Common Stock (BAC) Dividend History, n.d.). From this aspect, Bank of America is definitely a stable choice.

In addition, researching Bank of America, an international corporation, can give insight to other international banks. Bank of America has about 5700 branch offices in 29 states and the District of Columbia. It operates 16,500 ATMs and boasts about online banking customers. It also has significant international operations with offices in 31 countries in Europe, Asia and North and South America (Bank of America, 2005). The size of Bank of America attracts people to study and research on it.

Based on the reasons above, this research contains several steps to analyze the stability of stock price. The first step is to calculate the realized volatility and then calculate the relative realized volatility to check the stability. Secondly, comparing Poisson distribution to the real frequency distribution. Thirdly, the daily average RV and daily accumulated RV is another direction to research the stability of stock price. The result can check if there are outliers when we plot daily average RV and daily accumulated RV since they have strong correlation. In the end, building Heston model can help us to discover more about daily average realized volatility. The data and research are organized and lead by UCLA Economic Department.

## 2. Body of the Paper

### 2.1. Stability of Stock Price

To get RRV (Relative Realized Volatility), the first step to calculate log return and then calculate realized volatility by using the following formulas:

$$\log \text{ return} = \log(t) - \log(t-1) \quad (1)$$

$$RV_t = \sum_{i=1}^N r_i^2 \quad (2)$$

In this experiment, the 100 second period realized volatility is used to calculate RRV. By using the equation below, it is straight forward to get RRV:

$$RRV = \frac{RV}{\text{Daily Median RV}} \quad (3)$$

From **Table 1** and **Table 2**, there is only 1 day that has RRV greater than 1000. The day is May 6<sup>th</sup>, 2010. From the output we can see that the interval 0 to 2.5 has 95.1% days and it means that most of days do not have large realized volatility. The interval 0 to 2.5 and 2.5 to 5 contains more than 99% of days. It indicates the stock prices of Bank of American are relatively stable and will not change too much in a day.

## 2.2. Probability of No Trade Arrive and Poisson Distribution

Secondly, to test if Poisson distribution can predict the probability of no trade arrive, the first step is to divide the gaps by different interval such as 5 second, 10 seconds. Then using the average gap as  $\lambda$  in Poisson Model and calculate the Poisson model probability. For the empirical probability, it is just simply use number of average gaps divided by total gaps. The outputs from 2007 to 2014 (as shown in **Table 3**) indicates that if choose small seconds to count gaps, the result will be much closer to the Poisson distribution probability. However, when choose larger seconds to count gaps, the difference between empirical probability and Poisson model probability will be relatively large. This trend can be clearly seen in **Figure 1** in every year.

**Table 1.** Daily RRV from 2007 to 2014.

No. Observations	Min	Max	Median	X1stQ	X3rdQ
371499	0	1755.393	0.9999737	0.6474082	1.416034
Intervals			Percentage		
[0, 2.5)			95.1%		
[2.5, 5)			4.12%		
[5, 10)			0.552%		
[10, 100)			0.176%		
[100, 1000)			0.0151%		
≥1000			0.000808%		

**Table 2.** Number of RRV greater than 1000 and number of NNR less than 500.

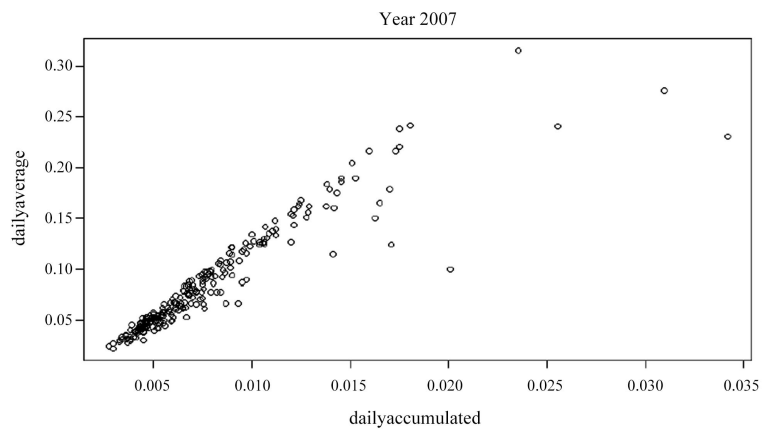
RRVS	Pool. Number
RRV < 500	1595
RV ≥ 1000	1

**Table 3.** Compare empirical probability and Poisson model probability.

(year 2007)				
Seconds	Average	Total gaps	Empirical probability	Poisson model probability
5	4405.9402	4680	0.9407992	0.9425175
10	2079.7291	2340	0.8887731	0.8947357
15	1313.6892	1560	0.8421085	0.8539424
20	934.7171	1170	0.7989035	0.8178335
25	710.4741	936	0.7590535	0.7858837
30	562.8442	780	0.7217234	0.7570874
35	459.0598	668.5714	0.6866278	0.7309778
40	383.2908	585	0.6551980	0.7083608
(year 2008)				
5	3458.2806	4680	0.7389489	0.7702415
10	1342.6680	2340	0.5737897	0.6529790
15	723.2846	1560	0.4636440	0.5848756
20	447.2213	1170	0.3822405	0.5391510
25	300.0198	936	0.3205339	0.5068876
30	212.8142	780	0.2728388	0.4832790
35	156.1937	668.5714	0.2336230	0.4646936
40	117.9763	585	0.2016689	0.4500795
(year 2009)				
5	3329.3373	4680	0.7113969	0.7493095
10	1231.0437	2340	0.5260870	0.6225614
15	636.2063	1560	0.4078246	0.5531227
20	380.1190	1170	0.3248881	0.5090994
25	248.6984	936	0.2657034	0.4798429
30	173.0238	780	0.2218254	0.4592435
35	124.5238	668.5714	0.1862536	0.4431946
40	92.2619	585	0.1577127	0.4307242
(year 2010)				
5	4027.9643	4680	0.8606761	0.8699462
10	1715.1151	2340	0.7329552	0.7656387
15	981.1905	1560	0.6289683	0.6900220
20	638.4444	1170	0.5456790	0.6348789
25	446.4206	936	0.4769451	0.5927071
30	326.3810	780	0.4184371	0.5590240
35	245.9008	668.5714	0.3678003	0.5314216
40	190.2500	585	0.3252137	0.5092652

Continued

(year 2011)				
5	4034.2421	4680	0.8620175	0.8711140
10	1723.4563	2340	0.7365198	0.7683728
15	992.9524	1560	0.6365079	0.6952442
20	650.7698	1170	0.5562135	0.6416024
25	457.5198	936	0.4888032	0.5997774
30	336.6786	780	0.4316392	0.5664532
35	255.8532	668.5714	0.3826864	0.5393915
40	200.7302	585	0.3431285	0.5184708
(year 2012)				
5	4163.2440	4680	0.8895821	0.8954598
10	1830.1340	2340	0.7821085	0.8042127
15	1079.0766	1560	0.6917157	0.7347064
20	717.4833	1170	0.6132336	0.6792497
25	512.3636	936	0.5473970	0.6359706
30	383.0144	780	0.4910440	0.6011228
35	294.1244	668.5714	0.4399297	0.5711689
40	231.3206	585	0.3854198	0.5463037
(year 2014)				
5	4109.6535	4680	0.8781311	0.8852644
10	1783.0472	2340	0.7619860	0.7881917
15	1037.8740	1560	0.6653039	0.7155555
20	687.4646	1170	0.5850125	0.6603485
25	482.0079	936	0.5149657	0.6156761
30	354.9921	780	0.4551181	0.5799103
35	269.3228	668.5714	0.4028333	0.5503688
40	209.8346	585	0.3586917	0.5266030



**Figure 1.** The daily accumulated realized volatility versus daily average realized volatility in 2007. The plot of 2007 is closed to linear relationship, but it does have several obvious outliers. Those outliers are on 20070227, 20070228, 20070301 and 20070816. Overall the shape is approximately linear.

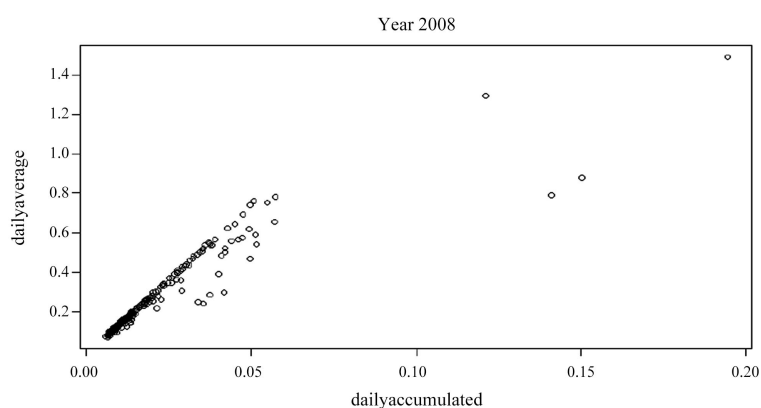
### 2.3. Linear Relationship between Daily Accumulated RV and Daily Average RV

Thirdly, the daily accumulated RV and daily average RV are really close to each other and they have approximately linear relationship. Except just a few outliers, many points are approximately in linear relationship (as shown in **Figures 1-7**). The followings are the graphs for each year.

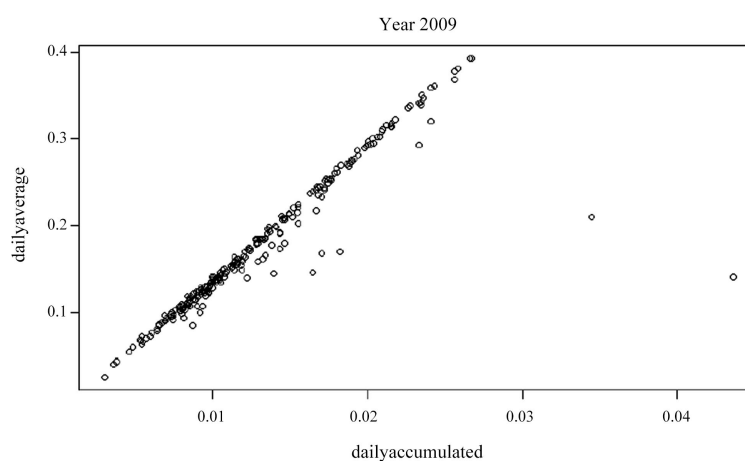
### 2.4. Heston Model

In the end, the final goal is to measure the alpha (the daily average realized volatility for 100 seconds) and Beta (the mean-reversion rate) by linear regression. To derive the linear format, the following equation is the initial equation for Heston model:

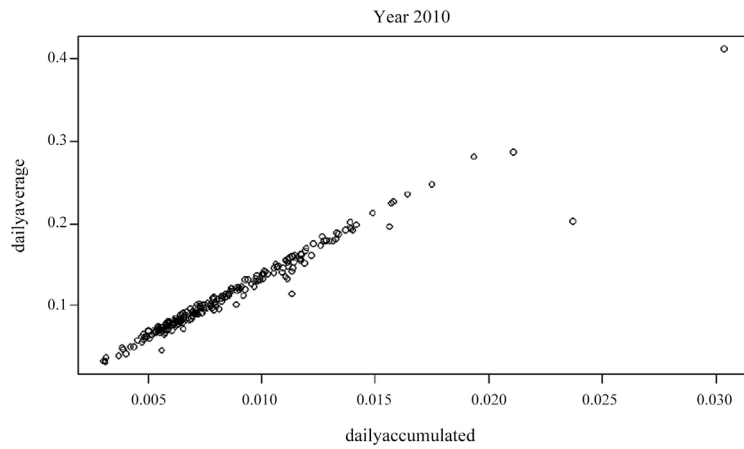
$$RV_t - RV_{t-1} = \beta(RV_{t-1} - R_{bar}) + \text{error} \quad (4)$$



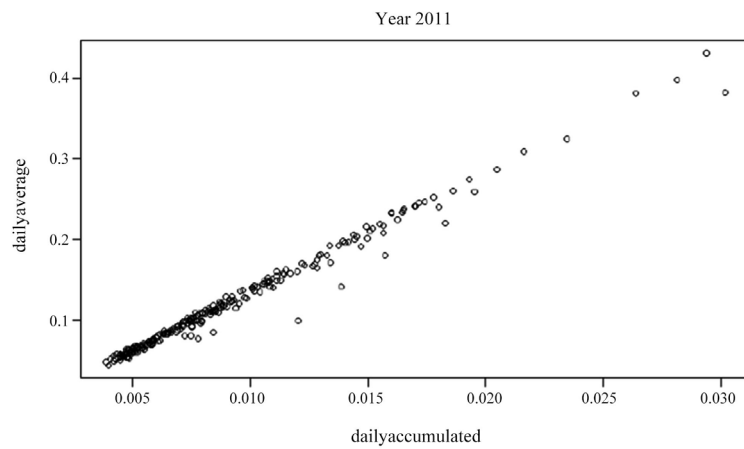
**Figure 2.** The daily accumulated realized volatility versus daily average realized volatility in 2008. The plot of 2008 looks like that it has two separate parts. The first part which looks closed to linear and the second part is 4 distinct outlier points. These outlier points are 20081010, 20081016, 20080919 and 20080122.



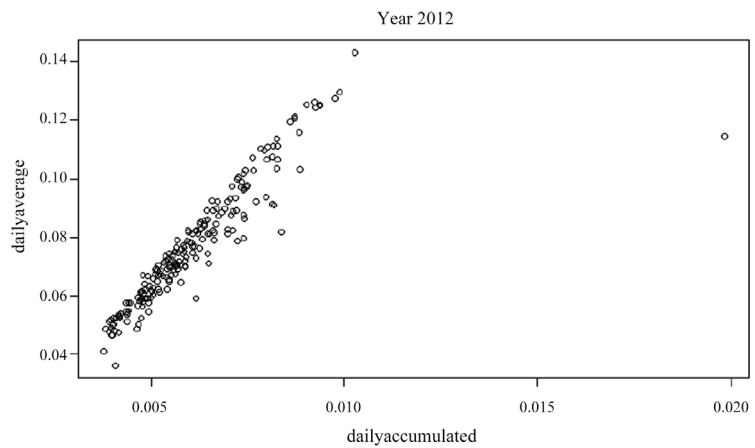
**Figure 3.** The daily accumulated realized volatility versus daily average realized volatility in 2009. The plot of 2009 has major points remaining on linear relationship and two outlier points on the right side. These outlier points' dates are 20091207 and 20090916.



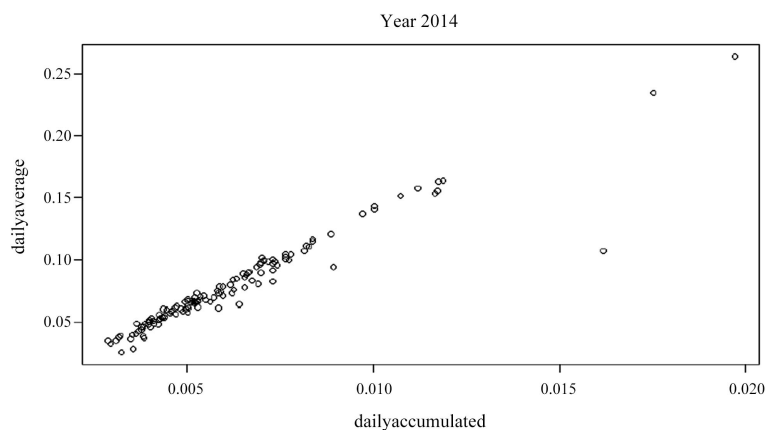
**Figure 4.** The daily accumulated realized volatility versus daily average realized volatility in 2010. The plot of 2010 does not have obvious outlier point and is closed to linear relationship.



**Figure 5.** The daily accumulated realized volatility versus daily average realized volatility in 2011. The plot of year 2011 is interesting since it is closed to linear relationship and it does not have obvious outliers.



**Figure 6.** The daily accumulated realized volatility versus daily average realized volatility in 2012. There is one obvious outlier point which is on the date 20120724.



**Figure 7.** The daily accumulated realized volatility versus daily average realized volatility in 2014. The plot of 2014 is almost on the one line except for one point on the date 20141027.

After switching terms and some calculations:

$$RV_t = \beta RV_{t-1} + \alpha + \text{error} \quad (5)$$

here the formula looks more like a simple linear regression. After calculating one-day period (as shown in **Figures 8-11**) and five-day period (as shown in **Figures 12-15**)  $RV_t$  and  $RV_{t-1}$ , then using the `lm` function in R studio to generate alphas and betas. It was found that the five-day period obviously has smaller variance. It makes sense because larger sample size tends to make variance smaller. The most obvious is the outlier point date May 6<sup>th</sup>, 2010 which is the Crash Day. On that day, the alpha of that day is more than 4 but in five-day period, the alpha is less than 4. After computing the alpha, we will use 5-day period to compare with the VIX from yahoo finance from 2007 to 2014. In addition, since the alpha for the crash day is not significant anyway, therefore it was excluded from the alpha plots.

The following is one day period alphas and betas plots.

The following is five-day period.

After calculating the alphas and betas from one-day period and five-day period, in order to compare with the movement of the market volatility, the resource that this paper chooses is VIX from yahoo finance. By plotting VIX with time from 2007 to 2014 (as shown in **Figure 16**), then the goal is compared VIX distribution and distribution of significant alphas. The following are the plot about VIX and plot about significant alpha.

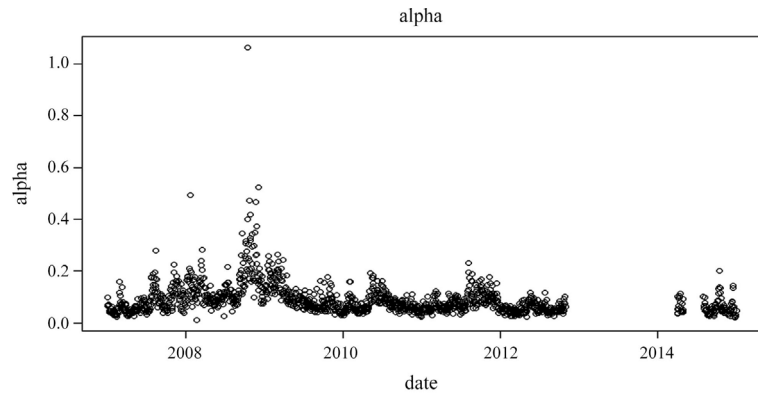
The VIX values are calculated from the implied volatility of stock options. However, our RVs are from actual stock prices. Comparing the four plots from VIX, their shapes are approximately the same, but surprisingly, our significant alphas with five-day period have close shape to the plots from VIX by ignoring the missing values in year 2013.

### 3. Conclusion

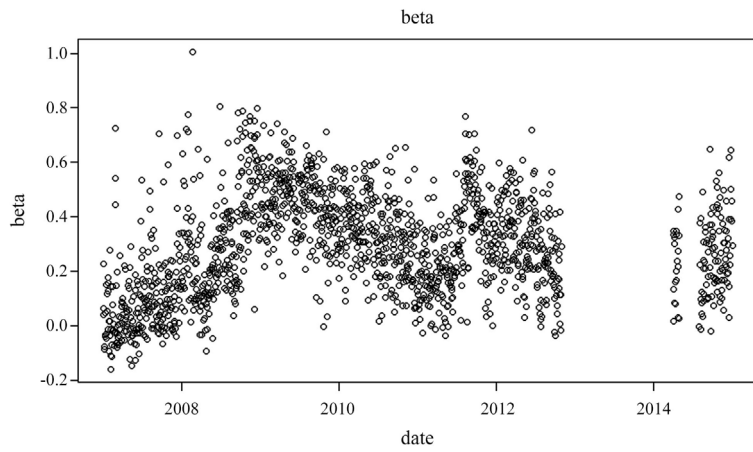
Through the research, each question in the beginning of the paper is answered. First, although the data used in this research missing the price of year 2013, the



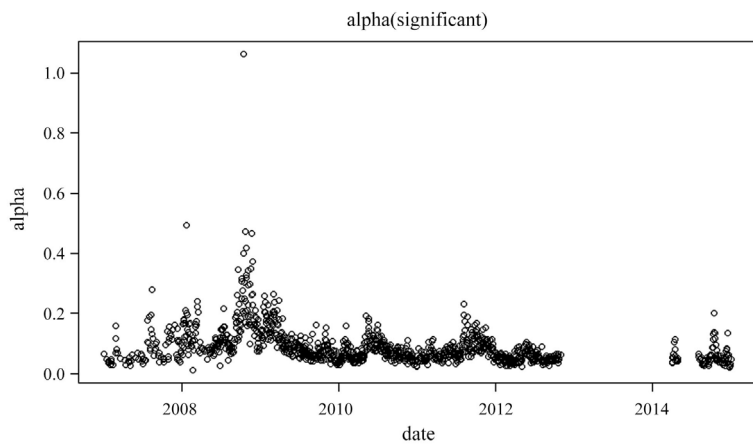
stock price of Bank of America is relatively stable and there is no abnormal variance expect for the crash day in May 6<sup>th</sup>, 2010.



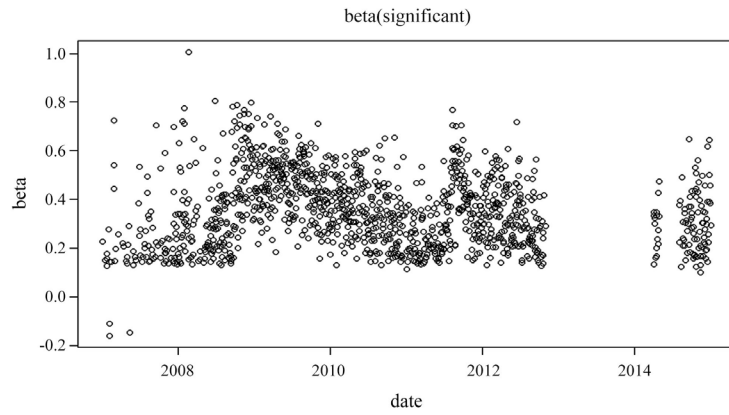
**Figure 8.** The one-day period alphas (Daily Average RV from 2007 to 2014). Alpha without outlier 20100506.



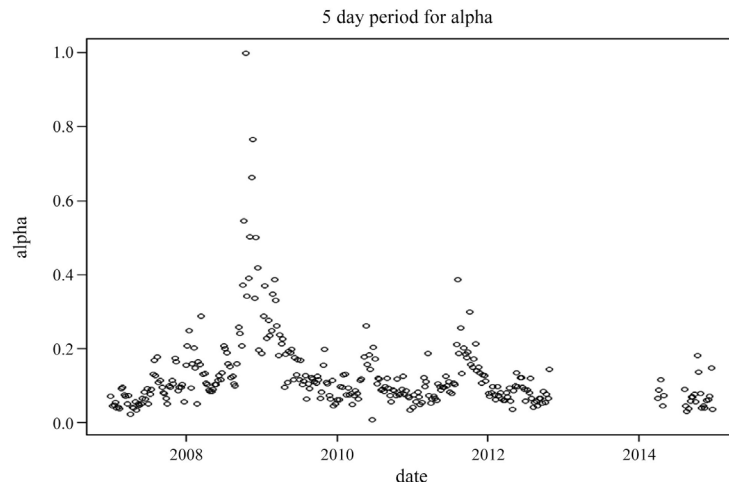
**Figure 9.** The one-day period beta (Mean-Reversion Rate from 2007 to 2014). The beta plot does not have obvious or significant outliers. The highest beta is a little bit larger than 1.



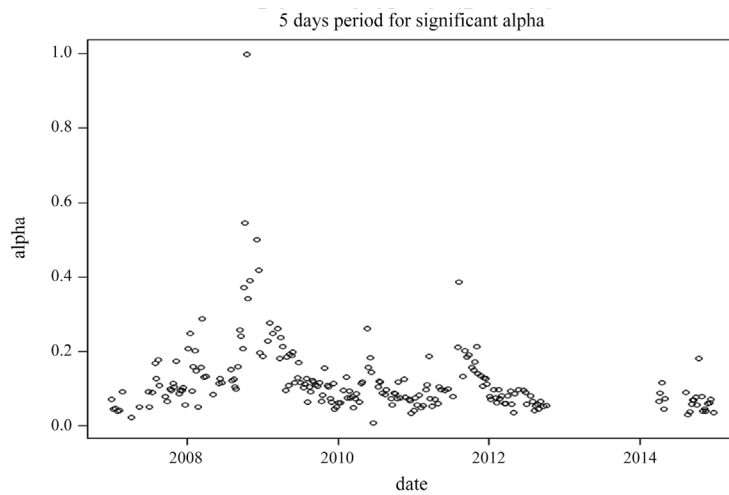
**Figure 10.** The one-day period significant alphas (Daily Average RV from 2007 to 2014). The plot without outlier 20100506 and only includes alphas which have significant linear relationship.



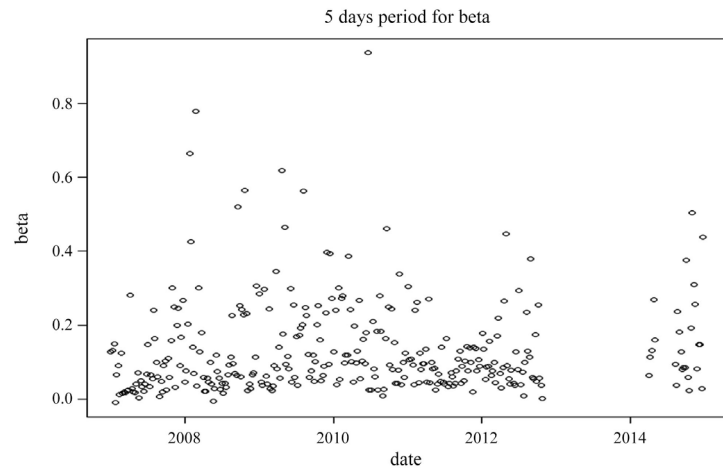
**Figure 11.** The one-day period significant alphas (Daily Average RV from 2007 to 2014). Beta graph with only significant days does not have significant or obvious outlier.



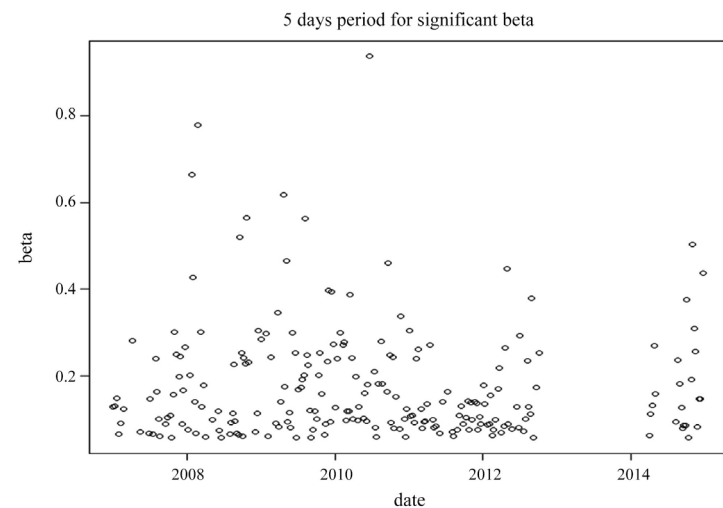
**Figure 12.** The five-day period significant alphas (Daily Average RV from 2007 to 2014). Five-day period without outlier.



**Figure 13.** The five-day period significant alphas (Daily Average RV from 2007 to 2014). The overall shape of five day period is similar to one day period but the variance is smaller due to larger sample size.



**Figure 14.** The five-day period significant betas (Daily Average RV from 2007 to 2014). There is no significant outlier in five-day period beta.

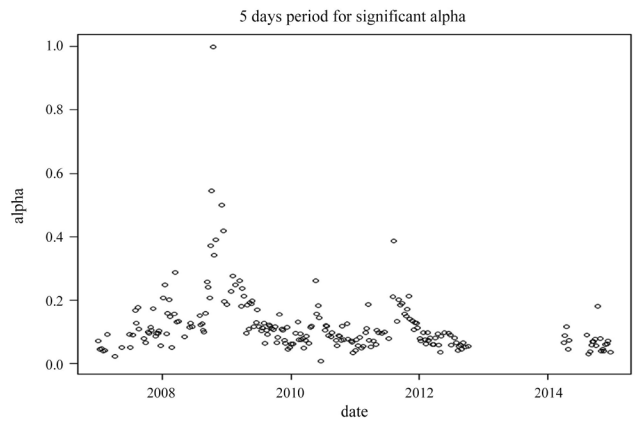


**Figure 15.** The five-day period significant betas (Daily Average RV from 2007 to 2014).

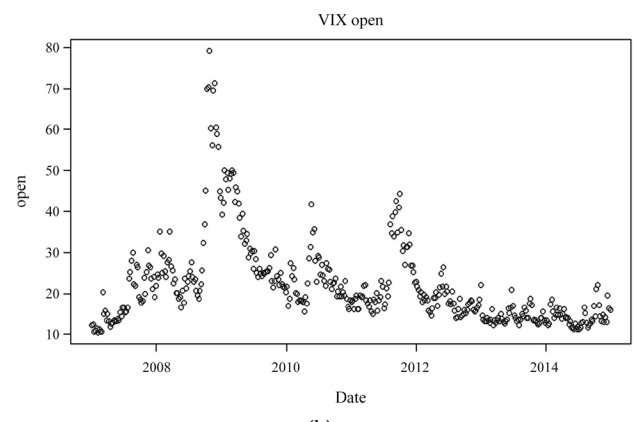
Secondly, if defining the gap as small number of seconds, for example, 5 seconds or 10 seconds as a gap, then Poisson distribution is a good prediction about probability of no trade arrival. However, when unit of gaps increases, Poisson distribution may not be a good choice.

Thirdly, the linear relationship between the Daily Accumulated Realized Volatility and Daily Average Realized Volatility is strong. Through all the plots from 2007 to 2014, there is obvious linear relationship in plots.

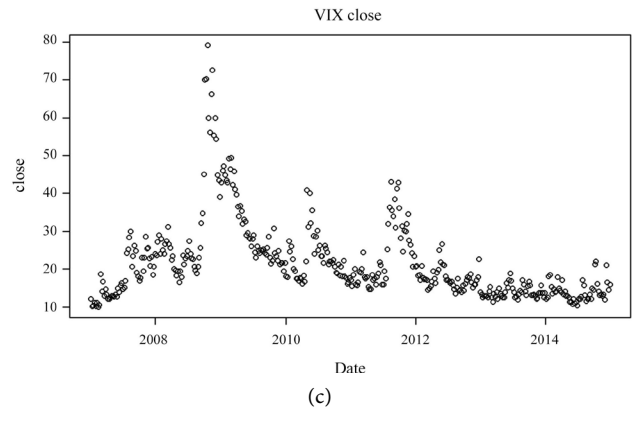
In the end, by transformation of Heston model and linear regression function of R studio, the daily average realized volatility and mean reversion rate were calculated. Then selecting the significant daily average realized volatility and mean reversion rate and plot them versus time. The result is that their distribution is closed to the distribution of VIX from Yahoo Finance. The Heston model can be used for stock price of Bank of America.



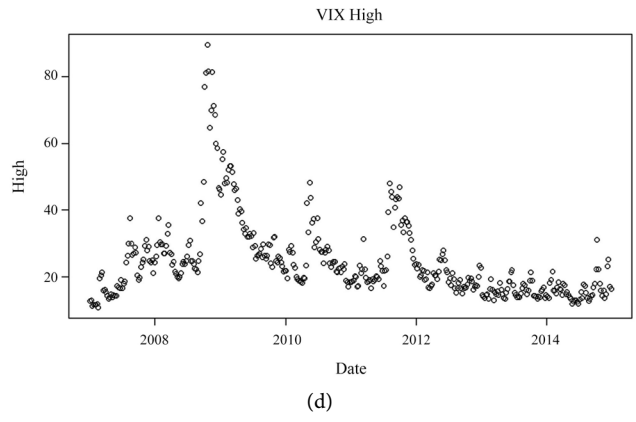
(a)



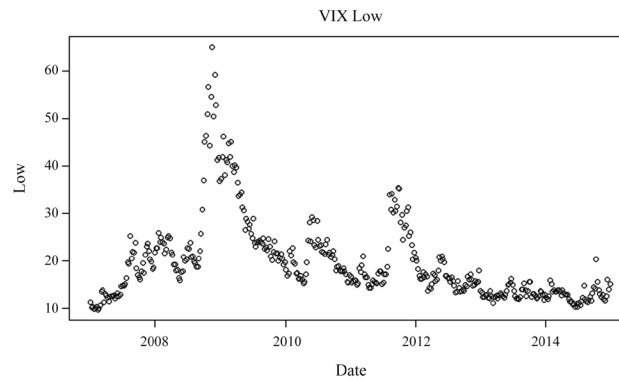
(b)



(c)



(d)



(e)

**Figure 16.** Comparing distribution of VIX with distribution of significant alphas. (a) Note: the data is missing year 2013; (b) Plot with open price; (c) Plot with closed price; (d) Plot with high price; (e) Plot with low price.

There are definitely some limitations of the method. First of all, although the RRV is relatively stable since there is only one RRV which is greater than 1000. However, there are still some RRVs which are approximately 100. It means that there is no guaranteed winning in stock exchange. Secondly, the stock price is dependent on many different variables and circumstances. Sometimes a breaking news can dramatically change the stock price and no one can always predict the future.

#### 4. Discussion

From the previous conclusion, there are some points which can be easily summarized. First of all, the Bank of America stock price is relative stable during long period. This is reasonable since it is a huge international bank and has thousands of clients. People cannot live without bank and bank is a significant pivot point of transactions.

Secondly, when we use small number of seconds, the Poisson distribution may be a good choice to predict no trade arrival. It is reasonable that the stock of Bank of America has lots of trading volume every day. Therefore, it is preferred to use small number of seconds to determine the number of gaps between two trades.

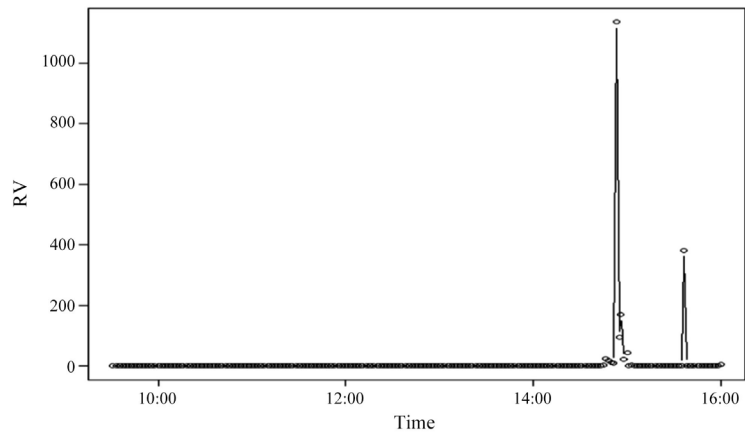
Thirdly, Heston model is one of significant model to predict stock price. Comparing to Black Scholes Model, it does not have constant volatility. Therefore, the outcomes of Heston mode are better performed. Overall, the stock price of Bank of America is reliable and worth to invest.

#### 5. Theory

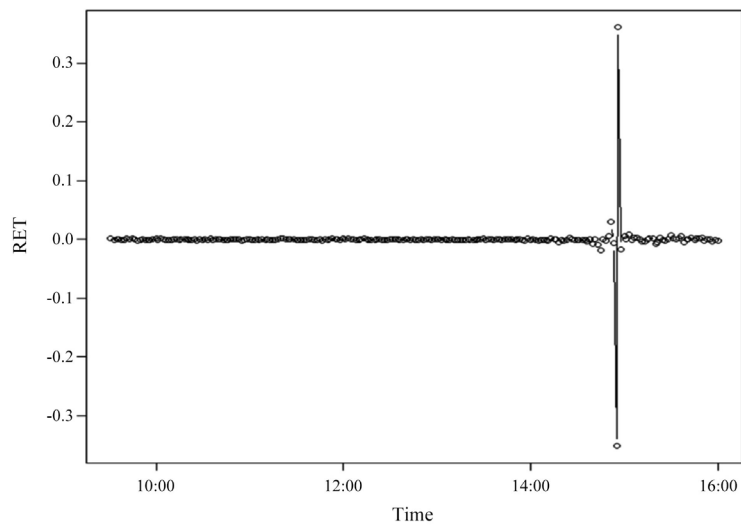
Log return: the formula of log return is following:

$$\log \text{ return} = \log(t) - \log(t-1)$$

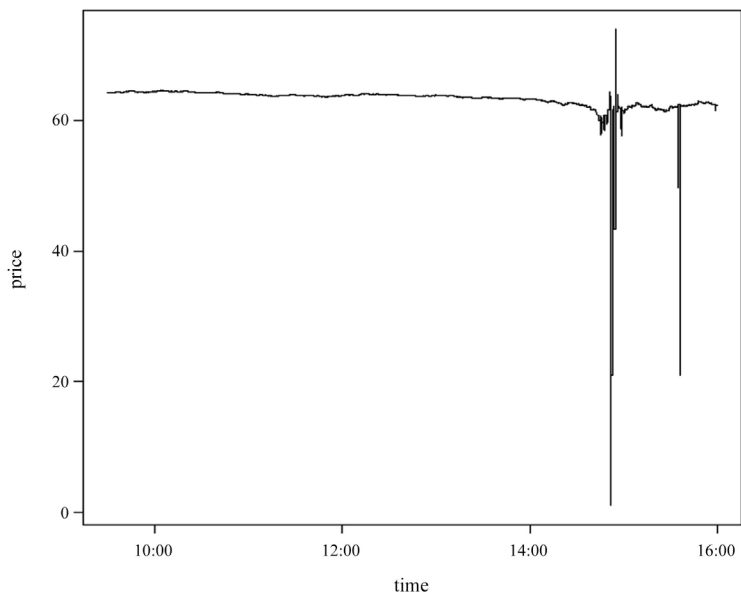
Realized Volatility (Shreve, 2010): the realized volatility is calculated by taking the sum over the past squared return



**Figure 17.** Realized volatility versus time on the Crash day.



**Figure 18.** Log return versus time on the Crash day.



**Figure 19.** Stock price versus time on the Crash day.

$$RV_t = \sum_{t=1}^N r_t^2$$

The definition and use of RRV: in order to observe pronounced volatility jumps in high-frequency data instead of in frequent data. To better analyze the jump effects in RV100s, it is helpful to calculate the relative realized volatility to normalize RV100s. RRV has the formula as follows:

$$RRV = \frac{RV}{\text{Daily Median RV}}$$

From the mean-reversion feature of Heston model, we have the following:

$$RV_t - RV_{t-1} = \beta(RV_{t-1} - R_{bar}) + \text{error}$$

By removing terms, we got the following equation:

$$RV_t = \beta RV_{t-1} + \alpha + \text{error}$$

We have the alpha which is daily average and beta as mean-reversion rate. Since the equation is similar to linear equation formula, we decide to test if there is strong linear relationship between mean reversion rate and daily average.

## 6. Additional Section

From the analysis of data of stock price, the most interesting values are RV in 2010/05/06. There was a significant flash crash happened on that day. It started at 14:32 pm and lasted about 36 minutes. Some research indicated that the most obvious reason is the debt crisis from Greece. The equity market began to fall rapidly and followed one 300-point drop and two 600-point drop (Treanor, 2015). It was the most significant crash on year 2010. The following are the RV versus time, log return versus time and price versus time (Treanor, 2015) (as shown in Figures 17-19).

## Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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