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Abstract

Purpose – In the process of discussing the relationship between volume and price in the stock market, the purpose of this paper is to consider how to take the flow of foreign capital into consideration, to determine whether the inclusion of volume information really contributes to the prediction of the volatility of the stock price.
Design/methodology/approach – By comparing the relative advantages and disadvantages of the two main non-parametric methods mainstream, and taking the characteristics of the time series of the volume into consideration, the stochastic volatility with Volume (SV-VOL) model based on the APF-LW simulation method is used in the end, to explore and implement a more efficient estimation algorithm. And the volume is incorporated into the model for submersible quantization, by which the problem of insufficient use of volume information in previous research has been solved, which means that the development of the SV model is realized.
Findings – Through the Sequential Monte Carlo (SMC) algorithm, the effective estimation of the SV-VOL model is realized by programming. It is found that the stock market volume information is helpful to the prediction of the volatility of the stock price. The exchange market volume information affects the stock returns and the price-volume relationship, which is achieved indirectly through the net capital into stock market. The current exchange devaluation and fluctuation are not conducive to the restoration and recovery of the stock market.
Research limitations/implications – It is still in the exploratory stage that whether the inclusion of volume information really contributes to the prediction of the volatility of the stock price, and how to incorporate the exchange market volume information. This paper tries to determine the information weight of the exchange market volume according to the direct and indirect channels from the perspective of causality. The relevant practices and conclusions need to be tested and perfected.
Practical implications – Previous studies have neglected the influence of the information contained in the exchange market volume on the volatility of stock prices. To a certain extent, this research makes a useful supplement to the existing research, especially in the aspects of research problems, research paradigms, research methods and research conclusion.
Originality/value – SV model with volume information can not only effectively solve the inefficiency of information use problem contained in volume in traditional practice, but also further improve the estimation accuracy of the model by introducing the exchange market volume information into the model through weighted processing, which is a useful supplement to the existing literature. The SMC algorithm realized by programming is helpful to the further advancement and development of non-parametric algorithms. And this paper has made a useful attempt to determine the weight of the exchange market volume information, and some useful conclusions are drawn.

Keywords Exchange market volume, SMC algorithm, Stock price-volume relationship, SV-VOL model
Paper type Research paper

1. Introduction

The managed floating exchange rate system has been put into action in China since July 21, 2005. Facing the abnormal fluctuation (represented by abrupt appearance and disappearance of circuit-breaker mechanism) in the stock market at the beginning of

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2016 and under the background that RMB has showed the depreciation trend upon being added to SDR, it is essential to delve deeper into the issue whether the stock market fluctuation is buffered to some extent as a result of capital control for its restriction of capital flight, or aggravated for the gambling operation of the foregoing capital in the stock market. When exploring the stock price-volume relationship in the stock market, this dissertation makes tentative efforts to take the intention or strength of capital flight into consideration. In the foreign exchange market, capital flight will lead to the supply demand change of RMB and eventually demonstrate as an important factor of exchange rate fluctuation. Based on the analytical framework of stock price-volume relationship, the spot inquiry of financial institutions can represent more directly the intention and strength of capital flight in the foreign exchange market. With this, the spot inquiry volume of foreign exchange, as the direct representation, ranks to be a more targeted, direct and effective proxy variable compared with the exchange rate volatility. Therefore, this dissertation attempts to judge the forecast function of volume on stock price fluctuation by integrating foreign exchange volume information into the analytical framework of stock price-volume relationship, and to identify the external effect of capital control on stock market volatility, so as to provide experience reference for the existing policy adjustment in Chinese stock and foreign exchange market by virtue of research design and conclusions.

According to the stock price-volume theory, volume reflects whether the stock market is prosperous and active, and the stock price fluctuation and trend supported by volume backs the dynamic performance of the supplier and the demander in competition. Thus, volume can be treated as the leading indicator of stock price and the driving power of stock market operation. Compared with the sequence of closing price and average transaction price, the volume-based stock price sequence bears smaller mean square and equal error (Wu and Wu, 2001). In other words, volume and stock price are interdependent (Smirlock and Starks, 1988), and have time-varying characteristics, obvious individual difference (Chen *et al.*, 2015) and tail dependence (Wu and Li, 2017). However, relevant disputes over the positive (Liu and Zhang, 2004) and negative effects (Zheng *et al.*, 2007) exist. What relevance means is that volume is helpful to the stock price volatility forecast. Based on the research of Tang and Liu (2008), volume and volatility take on asymmetrical action mechanism, and have the current forecast capacity of return rate enhanced with intensifying market maturity and openness. Nevertheless, their relationship is also involved in the linear (Zhang and Li, 2003) and non-linear (Luo and Wang, 2005; Hiemstra and Jones, 1994) dispute.

Whether the inclusion of volume information is really conducive to the stock price volatility forecast? At present, this issue is in the midst of discussion. The research of Zhang *et al.* (2017) proves the strong lead-lag relationship between stock price volatility and volume. It is pointed out by Zhang and Wang (2005) that volume and yield volatility sequence share the same long memory parameter, which bears witness to the stock price-volume relationship and means that the stock price-volume relationship in the stock market can be deemed as a general attribute of the financial market (Chen and Liao, 2005). However, Tang (2011) holds that volume is significantly and positively correlated with volatility, yet irrelevant to stock price return rate, for which volume information cannot be used for stock price volatility forecast. The main dispute lies in that, whether the information contained in volume raises the forecast capacity of model by inducing stock price fluctuation, or lowers the forecast precision of model by decreasing the sustainability of stock price volatility (Wang, 2013). The root cause is the existence of other factors remarkably affecting the tendency and sustainability of stock price fluctuation (Liu and Zhang, 2004). It is detected by the research of Chen (2013), among ten samples, Asian countries shall witness at least one dualistic co-integration relationship of current account, exchange rate and stock price. With this, there is reason to believe that the fluctuation of foreign exchange market serves as a notable factor. With the unremittingly deepened

reform of exchange rate, the stock market and the exchange market have developed long-term stable equilibrium relationship (Deng and Yang, 2008). The specific demonstration is that the dynamic correlation between actual exchange rate and stock price (Moore and Wang, 2014) witnesses the long-term and short-term information overflow effect (Chen, 2013) and the price diffusion effect (Shu and Xie, 2008) from exchange market to stock market. In addition to the existence of the aforesaid effects in the first moment (mean value), the risk contagion in the secondary moment (volatility) is of more tremendous significance, and risk information contained in the volatility of exchange market is mostly embraced in foreign exchange volume. Therefore, this dissertation shall give great priority to that, whether volume-bearing stochastic volatility (SV) models in the stock market can be optimized upon integration of exchange market volume.

Upon concluding and teasing out the existing literature, we find that, most research on volume and stock market is limited to the information about stock market, and the research on foreign exchange and stock market focuses on the first moment effect supplemented by the second moment effect. Rare literature considers the volume information of the stock market and that of foreign exchange market simultaneously in models of stock price volatility forecast. Furthermore, there are disputes over whether volume information can forecast stock price fluctuation to some extent. The research methods are oriented at the traditional GARCH model, and often directly add volume into the volatility equation as an exogenous variable (Chen and Wu, 2017). This practice still awaits confirmation on the grounds that volume information is related to volatility and can prevent volatility sustainability whether there is casual relationship or not. With this, the SV model based on non-parametric simulation simultaneously covering volume information of foreign exchange market and that of stock market is applied by this dissertation to conduct empirical analysis, so as to verify whether stock market trading volume contributes to stock price volatility forecast and whether the introduction of exchange market volume information is available to improve the model forecast precision, and to offer new measures and thoughts for stock market trend forecast, risk prediction and prevention. Compared with the existing literature, the advances of this dissertation are mainly embodied in three major aspects. Regarding the topic selection, the observation of stock price fluctuation from volume and the simultaneous consideration of exchange market volume information launch new research thoughts for the stock price volatility forecast, and new research paths for the linked research of the stock market and foreign exchange market, thus forming a useful supplement to the existing literature. Regarding the empirical approach, the problem of insufficient use of volume information in traditional research measures (i.e. GARCH) is solved. Instead, volume information is introduced to the SV model in the form of endogenous variable, realizes more comprehensive grasp and more effective estimation of volume information via non-parametric simulation, as well as corresponding Sequential Monte Carlo (SMC) algorithm in an explorative manner, thus offering new research measures and improvement directions for the study of corresponding issues. Regarding the research design, it can be observed from the weight of exchange market volume information. Helpful attempts have been made in both direct channels and indirect channels, study approaches granted to subsequent research and some beneficiary conclusions obtained. Chapters are arranged as follows: Part I shall briefly introduce the background and meaning of the title, and systematically summarize and evaluate the existing literature for the purpose of highlighting the innovation of this dissertation; Part II shall verify whether stock market trading volume is helpful to the stock price volatility forecast and whether the introduction of exchange market volume information is available to improve the model forecast precision, and have research hypothesis proposed; Part III applies modeling and empirical analysis to verify whether the proposition of research hypothesis is true or false, dissects the deep mechanism and logical relationship beneath the surface, and expounds its practical significance for the Chinese stock market in terms of risk prevention and forecast on this ground; Part IV means conclusion.

2. Theoretical correlation between volume and stock price fluctuation and presentation of research hypothesis

The research on the volume information can date back to the stock price-volume theory as it reflects the popularity of stock (market) among investors, the great demand of market liquidity, and the information response degree of market price (Domowitz and Wang, 1994). However, the research with volume as an independent exogenous variable fails to integrate volume information into price behavior in a better manner, thus deemed as bearing internal defects. The information carrying capacity of volume is demonstrated by the first moment and the secondary moment of stock price return rate. Based on the theory of mixture distribution hypothesis, common potential unobservable information flow can drive the linked action between price and volume. Therefore, we may hold that the price level and the volume information have a common long-term memory and mutual cause-effect relationship (Tang and Liu, 2008). The asset allocation hypothesis holds that the change in relative gains will lead to the dynamic adjustment of stock investment shares; during the period of assets re-allocation, stock price rises with the increase of volume and initiates the mean reversion cycle upon assets allocation, which confirms the necessity of stock price decline in the subsequent trading days upon high volume, and takes on the negative correlation that volume precedes stock price. It is pointed out by asymmetric information hypothesis that, however, the activity of transaction is boosted with the enhancement of information asymmetry, and there is the inertia trend with specific demonstration as the positive correlation that volume precedes stock price. In addition, the uniformity hypothesis, upon integration of the asset allocation hypothesis and the asymmetric information hypothesis, analyzes the circumstance where stock asset and other assets, investors with information superiority and information inferiority co-exist, and holds that the dynamic game of the two driving factors, namely, assets allocation and information asymmetry, shall decide the positive or negative correlation showed by the precedence of volume over stock price. Eventually, the influence of volume change on stock price is presented in stock price fluctuation. With this, this dissertation presents:

H1. Stock market trading volume information is helpful to the stock price volatility forecast.

The development of stock market can lead to the fluctuation of effective exchange rate by affecting foreign trade (Fan *et al.*, 2015). Otherwise, there is the overflow effect from foreign exchange market to stock market. According to the flow-oriented model dominated by exchange rate, the international capital flow will change the exchange rate, cause the net value variation of enterprises' import and export business as well as the balance fluctuation between foreign currency's liabilities and assets by affecting international balance of payment, and eventually find expression in stock price. The Gorden Model offers a mathematical elaboration for the overflow effect from foreign exchange market to stock market proceeding from interest rate, and indicates that the profit pursuit of capital can decide the exchange rate fluctuation and further change the interest rate spread at home and abroad (domestic interest rate level), for which the pricing level of stock price under the net present value theory will experience instant changes. The international trade theory, proceeding from elastic analysis, puts forward with the internal mechanism that currency changes will trigger the adjustment of stock price at different directions. In other words, export decline and import increase can be realized on appreciation of domestic currency, provided that Marshall-Lerner Condition is satisfied, and the sum of demand elasticity proposed by import and export commodities for actual rate is beyond the unit circle. The aforesaid research indicates that the changes of exchange rate will cause the dynamic adjustment of stock price, while the action mechanism is indirect with volume as an important intervening variable. With this, this dissertation presents:

H2. The introduction of exchange market volume information is available to improve the model forecast precision.

3. Empirical test proving the superiorities of volume information for stock price volatility

The introduction of volume information into stock price fluctuation prediction model shall be intensively handled in the following two aspects. On the one hand, the influence of volume information on stock price fluctuation shall be studied in the way of exogenous variable or information flow, or having the causal relationship and dynamic correlation with stock price fluctuation directly studied; on the other hand, the price time series based on volume information shall be constructed based on such construction methods as piecewise function, which solves the insufficient use of volume information by traditional practices to some extent. However, the solution offered in this dissertation builds on model and deduction perspective.

The introduction of volume information means that the time-varying characteristic of variance shall be handled. SV model is identified as one of the effective solutions, such as GARCH model. However, the majority of existing literature research on the correlation between volume and stock price fluctuation takes volume information as an exogenous variable and then adds to the volatility equation, which bears defects as it fails to handle the intersection and overlapping between volume information and volatility information. In other words, the direct exogenous handling neglects the distribution hypothesis that volume and volatility bear endogenous correlation. Therefore, the model in this dissertation, based on the original foundation, assumes that volume information and volatility conform to the Poisson Distribution of any way (Abanto-Valle *et al.*, 2010), and is known as the SV model with Volume (SV-VOL model). It has been expanded by Abanto-Valle *et al.* (2014) and Liu and Chen (2015) from different aspects as distribution hypothesis and estimation algorithm. At the realization level of non-parametric algorithm, there are two mainstream branches. The first refers to the Markov Chain Monte Carlo (MCMC) simulation method based on Bayesian inferences and supplemented with Gibbs sampling process. The application of Markov process leads to the sensitivity to short-term data, thus applicable for relatively stable time sequence data with fewer singular values and jump points, and highlighting the integrity and whole characteristic of time sequence. The second refers to the SMC simulation method based on auxiliary particle filter (APF, Pitt and Shephard, 1999) and supplemented with LW strategy (Liu and West, 2001), whose superiority lies in the stronger robustness and higher estimation efficiency, thus, available to realize the full recognition of model systems and effective estimation of parameter space under the data environment of singular values and jump points, particularly, the prominent performance in handling latent variable. As the volume time sequence features mutability and clustering (Liu and Zhang, 2004), priority shall be given to the SMC simulation method. However, both MCMC and SMC methods have their convergence rate and estimation efficiency relatively sensitive to different parameter setting. MCMC simulation method mainly takes the parameter estimation upon stable burn-in as initial value, and Forward Filtering Backing Sampling of Gibbs-based sampling applies residual data for the rolling estimation of parameters, for which appropriate design of data generation process and probability of acceptance is of greater significance. The difference of SMC simulation method lies in that, it gains initial samples based on the prior distribution and makes forward recursion, has sample particle number of every period remaining the same during the recursion process, utilizes the thought of maximum likelihood, and takes the actual data set as constraint condition, until particles of the new period cannot substitute sample particles of the last period. In other words, the recursion estimation of parameters is completed via self-reference by using LW strategy to absorb new information, for which reasonable prior parameters and significant characteristic functions are crucial. It can be observed that, the SMC simulation method is involved in such problems as whether parameters are convergent and whether the convergent speed is fast. Those problems can

serve as the alternative evaluation method of model validity as well as the criterion of comparative analysis, and remedy the limitation that the MCMC simulation method has no evaluation standard.

Compared with the realized volatility model available to be unbiased estimation of integrated volatility on the premise of simple estimation, convenient calculation and frequent sampling (Duan and Tu, 2005), the SV model fails to give consideration to regression error and prediction bias for the existence of many parameters to be estimated. However, it describes the asset price behavior as the mean reversion of price, the sustainability of volatility and the random diffusion process of absolutely horizontal three-loop drive, thus deemed as more comprehensive and reasonable cognitive framework. In the meantime, the evolution of non-parametric simulation method has improved the issue of regression error and prediction bias to some extent, and enabled the SV model to enjoy a more extensive application prospect in terms of assets pricing and forecast. Upon comprehensive comparison of the advantages and disadvantages of the two major non-parametric methods and in combination with the own characteristic of volume time sequence, eventually, the SV-VOL model based on APF-LW simulation method is applied to explore the algorithm estimation yielding higher efficiency. In addition, volume information is included into the SV-VOL model to conduct latent variable processing, which solves the insufficient use of volume information in the past research, and realizes the expansion of SV model. Besides, the research on the stock price volatility forecast no longer depends on the single stock market trading information. Instead, it, in an explorative manner, introduces the exchange market volume information into the model as well, which is quite innovative.

3.1 Mathematical basis of the mixture of distribution hypothesis (MDH)

3.1.1 Theoretical basis of the of SV model of return rate. The GM theoretical framework (Glosten and Milgrom, 1985) holds that price discovery and information absorption occur and only occur when the advent of new event is the information superiority brought about by informed traders. With this, this dissertation shall construct the MDH of volume behavior. To simplify analysis, it is assumed that: first, all traders in the stock market take on risk neutral, and can be divided into technical analysts, informed investors and non-informed investors, whose access into the market is continuous and random, and non-informed traders enter into the market via fixed Poisson process $P(m_0)$ on each trading day (Milgrom and Stokey, 1982); second, the advent of new information will instantly generate an information absorption process, followed by a new price equilibrium range, which means that the stock price fluctuation process is the movement process from a temporary equilibrium to another temporary equilibrium; third, as continuous transaction price is governed by the martingale process of public information, the sampling of transaction process in any form shall be a martingale sequence. According to *H2*, each trading day can be divided into random quantity of inter-cells with each inter-cell comprising the information absorption range and the price equilibrium range. Priority shall be given to verify whether the given stock price and the volume in every inter-cell are homogeneous. In the context of large-scale samples, the simultaneous distribution of combined extraction of stock price and volume from the equilibrium range submit to i.i.d. $P_{j,t}(j = 1, ..., J_{t-1})$ represents the transaction price of j price equilibrium range within t trading days. J_t is random and represents the total quantity of new information within t trading days. The total revenue within t trading days is shown as follows:

$$1+R_t = \prod_{j=1}^{J_t} \frac{P_{j,t}}{P_{j,t-1}} = \frac{P_{J,t}}{P_{0,t}}$$

$P_{0,t}$ and $P_{J,t}$ means opening price and closing price, respectively. The nature of price sequence martingale shall decide whether R_t has zero-mean. The logarithmic return rate is approximately concluded via Taylor expansion:

$$R'_t = \ln\frac{P_{J,t}}{P_{0,t}} = \sum_{j=1}^{J_t}\left(\ln\frac{P_{j,t}}{P_{j,t-1}}\right) = \sum_{j=1}^{J_t}\xi_{j,t},\ \xi_{j,t}\sim i.i.d\left(0,\sigma_\xi^2\right)$$

To better describe the nature of random large-scale samples of J_t, the standard trading day of new information with total quantity as J has been granted. In the equation $J_t = K_t J$, K_t means information (arrival) intensity and $K_t > 0$. Obviously, the yield rate on the standard trading day is random and has mean value as 0 and variance as $\sigma^2 = J\sigma_\xi^2$. With this, $\xi_{j,t} = \sigma\varepsilon_{j,t}/J^{1/2}$ and $\varepsilon_{j,t}$~i.i.d(0,1) can be concluded. The logarithm of any trading day can be expressed as follows:

$$R'_t = \sigma K_t^{1/2}\frac{1}{(JK_t)^{1/2}}\sum_{j=1}^{K_t J}\varepsilon_{j,t}$$

Under the regularity condition, R'_t shall comply with the normal distribution subject to information intensity when J is big enough (Ross, 1989):

$$R'_t|K_t \sim N\left(0,\sigma^2 K_t\right)$$

For the standardization processing with $\sigma\equiv 1$ as precondition, $R'_t|K_t \sim N(0,K_t)$, which means $R'_t = K_t^{1/2}Z_t$ and Z_t~$N(0,1)$. With this, yield volatility equals to information intensity, while unobserved latent variable K_t an authentic SV process. It also reflects that the stock price sequence (or stock price yield rate volatility) is decided by the time sequence that information flow enters into the market, and refers to a transaction time course, other than calendar time course (Wu and Wu, 2001).

3.1.2 Mechanism interpretation of volume's Poisson distribution processing. Volume v_t comprises Part NV_t based on noise trading (obtainable public information or given information) and Part IV_t based on unknown internal information or instant message, namely, $v_t = NV_t + IV_t$. According to *H1*, the noise trading complies with NV_t~$P(m_0)$, for which the systematic changes of volume is caused by IV_t. Although the informed traders in the market and samples of new information yield sufficient great quantity, the quantity of IV_t is limited, which is determined by the probability $p_{j,t}$ that informed traders conduct transaction on the advent of the j single information flow within t trading days. As a result of many factors, $p_{j,t}$ is relatively smaller, and the different of $p_{j,t}$ with various information flows included very limited. Therefore, the practice of approximate treatment by using any distribution is reasonable (Andersen, 1996). As transaction occurs within the information absorption range, the volume generated from the occurrence of any new event shall satisfy binomial distribution $Bin(I,p_{j,t})$ with expected value as $I\bullet p_{j,t}$, among which I refers to the maximum quantity of informed traders available to gain internal information concerning new events. With this, IV_t yields limited quantity. In the meantime, the said binomial distribution enjoys a favorable approximate distribution, namely, Poisson Distribution $P(I\bullet p_{j,t})$ (Feller, 1968). If assuming that any informed trader expects to conduct π times of transaction within t trading days, $E(p_{j,t}) = \pi/J_t$. If assuming that the transaction probability $p_{j,t}$ of different new information is a stable process and always experiences limited deviation

degree from its mean value, the approximate representation of Poisson distribution can be applied to conclude that:

$$IV_t|K_t \sim P(IK_t\pi)$$

$v_t|K_t \sim P(m_0+IK_t\pi)$ can be concluded. As I and π cannot be independently recognized, attention is paid to the global recognition of $m_1 = I\bullet\pi$ only. Then:

$$v_t|K_t \sim P(m_0+m_1K_t)$$

3.2 SV-VOL modeling and estimation

SV-VOL model is constructed as follows:

$$y_t = \sqrt{h_t}\mu_t \tag{1}$$

$$\log\ h_{t+1} = \alpha+\beta\log h_t+\eta_t \tag{2}$$

Therein, $\mu_t \sim N(0,1)$ and $\eta_t \sim N(0,\tau^2)$. It should be pointed out that logarithm process is essential on the realization of τ^2. y_t and h_t are the logarithmic return rate of stock price and the random volatility of stock market, respectively:

$$v_t \sim P\left(m_0+m_1e^{h_t}\right) \tag{3}$$

$$v_t = \omega_1v_1+\omega_2v_2 \tag{4}$$

Therein, $\omega_1+\omega_2 = 1$ and $\omega = 0, 10\%, \ldots, 90\%, 100\%$. v_1 and v_2 means stock market trading volume and exchange market volume, while P represents Poisson distribution. m_0 reflects the influence of noise component on fixed trading intensity and responds to the known information; m_1 reflects the influence of internal information on volume volatility, and responds to the instant message. Equations (1) to (4) constitute the kernel of SV model with Volume. On the hypothesis of $\lambda = \log h_t$, priority shall be given to verify $\phi \sim TN_{(-1,1)}(\phi_0,C_\phi)$, $\tau^2 \sim IG(a, b)$ and $\lambda_0 \sim N\left(\lambda_{00}, C_{h_0}\right)$. To make the selection of hyper-parameters represents information-free prior verification, we further assume $\phi_0 = \lambda_{00} = 0$ and $C_\phi = C_{h_0} = 100$ (Carvalho and Lopes, 2007). Regarding the construction of parameter vector θ to be estimated, APF is updated for the purpose of realizing the recursion update of posterior density function (p) in the following form:

$$p(\lambda_{t+1}, \theta\left|D_{t+1}\right.) \propto p(_{yt+1}\left|\lambda_{t+1},\theta\right.)p(\lambda_{t+1}|\theta,D_t)p(\theta|D_t)$$

其中$D_t = \{y_1, \ldots, y_t\}$, $p(\lambda_{t+1}|\theta,D_t) = \int p(\lambda_{t+1}, \theta|\lambda_t)p(\lambda_t|D_t)d\lambda_t$。

Therein, $D_t = \{y_1, \ldots, y_t\}$ and $p(\lambda_{t+1}|\theta,D_t) = \int p(\lambda_{t+1}, \theta|\lambda_t)p(\lambda_t|D_t)d\lambda_t$.

Approximate posterior density can be obtained by utilizing the multivariate mixture of normal distribution:

$$\hat{p}(\theta|D_t) = \sum_{j=1}^{M}\rho_t^{(j)}N\left(a\theta_t^{(j)}+(1-a)\tilde{\theta}_t; b^2V_t\right)$$

Therein, $\tilde{\theta}_t = \sum_{j=1}^{M}\rho_t^{(j)}\theta_t^{(j)} \approx E(\theta|D_t)$ and $V_t = \sum_{j=1}^{M}\rho_t^{(j)}(\theta_t^{(j)}-\tilde{\theta}_t)(\theta_t^{(j)}-\tilde{\theta}_t)' \approx V(\theta|D_t)$. a represents the convergence intensity of distribution and satisfies $a = \sqrt{1-b^2}$; b represents the over-dispersion degree of distribution and satisfies $b = 1-((3\delta-1)/2\delta)^2$

with discount factor $\delta \in (0,1]$ as the parameter of smoothing control. b shall gradually preserve the information of recursion update in function.

$\{\lambda_t^{(j)}, \mathrm{Pr}_t^{(j)}\}_{j=1}^{M} \sim p(\lambda_t|D_t)$ is the approximate representation of the posterior density function of λ_t, among which Pr represents corresponding discrete probability. One characteristic of APF lies in that experience filtered density functions are deemed as the mixture of multiple distributions, and the simplified analysis of potential indexes introduced. Then, we conclude:

$$p(\lambda_{t+1}|k) \propto p\left(y_{t+1}\middle|\lambda_{t+1}\right) p\left(\lambda_{t+1}\middle|\lambda_t^{(k)}\right) Pr_t^{(k)}$$

The recursion update process of SMC algorithm is as follows:

(1) Sample initialization: $\{\lambda_t^{(j)}, \theta_t^{(j)}, \mathrm{Pr}_t^{(j)}\}_{j=1}^{M} \sim p(\lambda_t, \theta|D_t)$;

(2) For $j = 1, \ldots, M$, $\xi_{t+1}^{(j)}$ is a predicted value and shall be valued $\xi_{t+1}^{(j)} = \alpha_t^{(j)} + \beta_t^{(j)} \lambda_t^{(j)}$;

(3) For $j = 1, \ldots, M$;
withdraw k^j from $p\left(y_{t+1}\middle|\xi_{t+1}^{(k^j)}\right)\mathrm{Pr}_t^{(k^j)}$;
withdraw $\theta_{t+1}^{(l)}$ from $N(\gamma_t^{(k^j)}; b^2 V_t)$, among which $\gamma_t^{(k^j)} = a\theta_t^{(k^j)} + (1-a)\tilde{\theta}_t$;
withdraw $\lambda_{t+1}^{(k^j)}$ from $p\left(\lambda_{t+1}\middle|\lambda_t^{(k^j)}, \theta_{t+1}^{(l)}\right)$.

With this, the circular recursion update of parameters to be estimated is realized. Eventually, Shanghai and Shenzhen 300 Index (SS300) from August 21, 2015 to December 8, 2017, daily stock market trading volume (SMV)[1] and spot inquiry trading volume (conversion of USD to RMB) are selected to be sample data and to carry out research. All data come from wind database.

3.3 Logical analysis and mechanism interpretation of empirical results

This dissertation focuses on how to introduce the stock price volatility forecast information contained in the exchange market volume to the research on stock price-volume relationship, namely, how to properly confirm the information weight ω under the model framework. With this, this dissertation plans to confirm the information weight ω from indirect channels and direct channels, respectively, and compares with the empirical results of Benchmark model without exchange market volume information to analyze the influence of exchange market volume information on stock price-volume relationship.

3.3.1 Determination criterion of ω and estimation of v_t. As a time-varying causality testing method available to verify the partial causality existence among polytomized variables, the time-varying Dirichlet-VAR model with infinite state Markov regime switching process (Chen *et al.*, 2015) is obtained to conclude the time-varying coefficient at the level of causality, which is deemed as information weight ω_2 with v_t synthesized on this basis.

Regarding indirect channels, the essence of exchange market volume volatility means the flow-in and flow-out of cross-border capital, and the capital eventually flowing into the stock market will inevitably lead to the fluctuation of stock market trading volume and finally the fluctuation of stock price-volume relationship. Upon building the ternary Dirichlet-VAR model taking net capital inflow (SS300) as media, time-varying coefficients between SMV and EMV are concluded, which are deemed as information weight information weight with v_t (evol-T) synthesized on this basis, as shown in Figure 1 and 2.

Regarding direct channels, it is generally assumed that the fluctuation of exchange market volume will cause the direct fluctuation of stock market trading volume by virtue of expectation mechanism, and find its expression in stock price-volume relationship, which

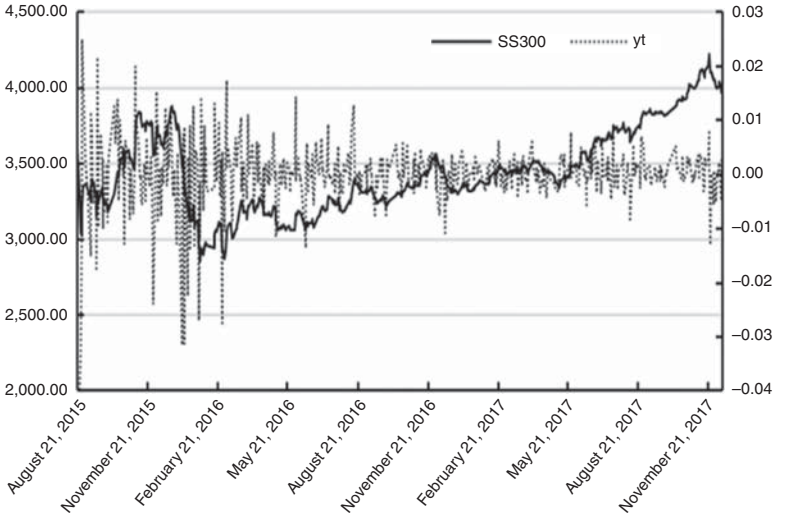


Figure 1.
SS300 and logarithm return rate

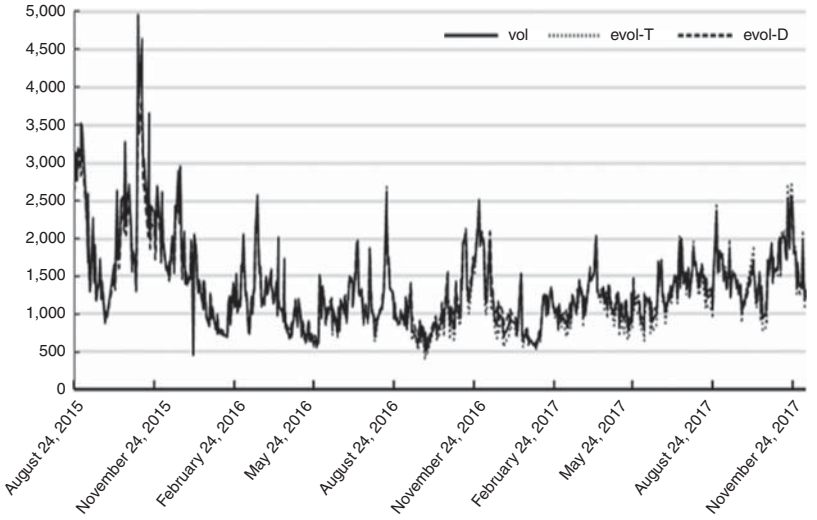


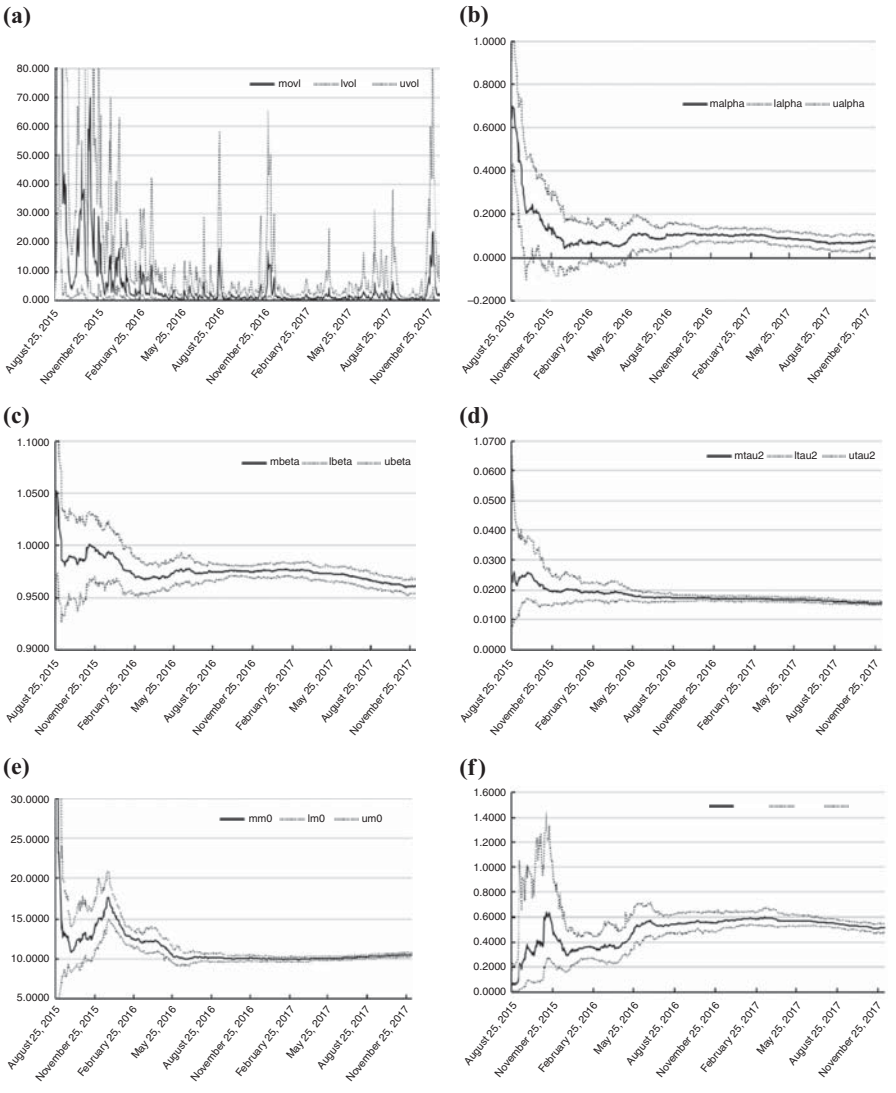
Figure 2.
v_t under different information weight

Note: Vol means the v_t with information weight of exchange market volume as 0

demonstrates the direct causality between SMV and EMV. Thanks to the direct analysis of the binary Dirichlet-VAR model, the time-varying coefficients between SMV and EMV are concluded to be information weight ω_2 with v_t (evol-D) synthesized on this basis, as shown in Figure 2.

According to the results shown in Figure 2, v_t bears very similar motion trails under different information weight, and has difference mainly reflected in degree. In this regard, $vol{-}D > vol > vol{-}T$ exists in the majority of sample range. Therefore, it can be concluded that the information shock of exchange market volume only changes the fluctuation degree, instead of causing the deviation or jump of motion trails.

3.3.2 Analysis of estimation results of benchmark model. Figure 3 offers the parameter estimation of SV-VOL model based on the stock market trading volume information. The realized volatility (mvol) bears rapider zero-toward mean convergence speed, and demonstrates the sufficiency of "stock price-volume relationship" described by SV-VOL model. Although the intercept α and the regression coefficient β in the vitality equation show the convergence trend yet the convergence speed is slower, it fails to realize the complete convergence within the sample period. However, the residual square τ^2 and m_0 fundamentally realize the complete convergence at a rapid convergence speed.



Note: From (a) to (f), it means the posteriori estimate of random volatility, α, β, τ^2, m_0 and m_1 under the quantile of 75%(l), 50%(m) and 25%(u)

Figure 3.
Posteriori estimate of SV-VOL parameter without exchange market volume information

m_0 represents the fixed trading intensity facing the influence of known information, and m_1 the random fluctuation strength facing the influence of instant message. Despite better convergence degree and convergence speed, m_0 yields higher instability under the initial state if compared with m_1. Regarding the posterior mean of convergence, m_0 is about 20 times of m_1. On the one hand, it is proved that known information can remarkably influence the fixed trading intensity, and due to the driving effect to some extent, the stock price return rate bears the momentum effect, which is connected to the higher information asymmetry degree and serious speculation act in the Chinese stock market, and means that the effectiveness of the present Chinese capital market is lower and thus needs to gradually perfect the price discovery function in the capital market by continuously deepening the financial supply side structural reform. On the other hand, it means that the response intensity of Chinese stock market to instant message of random fluctuation is significantly lower than that to the known information. As the Chinese stock market is still beset with relatively serious information friction and passivation, stock price and volume fail to make timely response to external instant shock, which goes against the recognition of potential risk points and weak links of systematic risks in the capital market as well as the risk control. As the SMC simulation method confronts the issue that whether parameters can realize convergence and that whether the convergence speed is fast, the convergence of parameters or not is deemed as the alternative evaluation method of model validation, and it is considered that the introduction of stock marketing trading volume information realizes the effective estimation of model parameters. On the whole, each parameter is characterized by definite economic meaning, as well as favorable convergence speed and stability. With this, there is reason to believe that the introduction of stock marketing trading volume information offers a more novel, in-depth and holistic interpretation for the action logic in the Chinese stock market.

In short, the stock market trading volume information is helpful to the stock price volatility forecast, and *H1* is proved as reasonable (Figures 4-7).

3.3.3 Analysis of posteriori estimate results of m_0 and m_1 under different information weight ω. The SV-VOL parameter estimation with stock market trading volume information

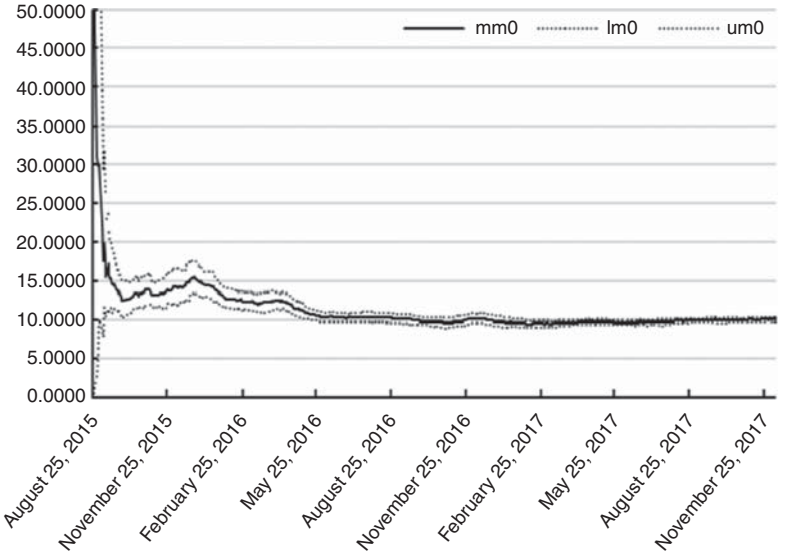


Figure 4.
Posteriori estimate of m_0 under indirect channels

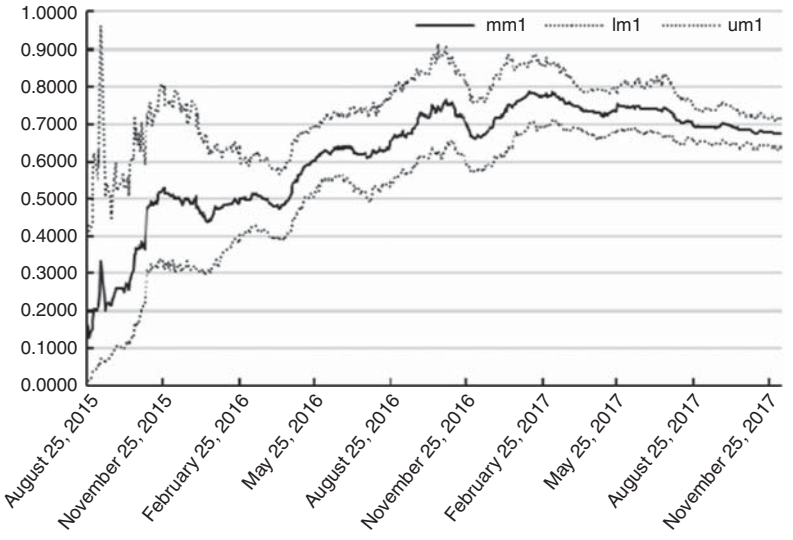


Figure 5.
Posteriori estimate of m_1 under indirect channels

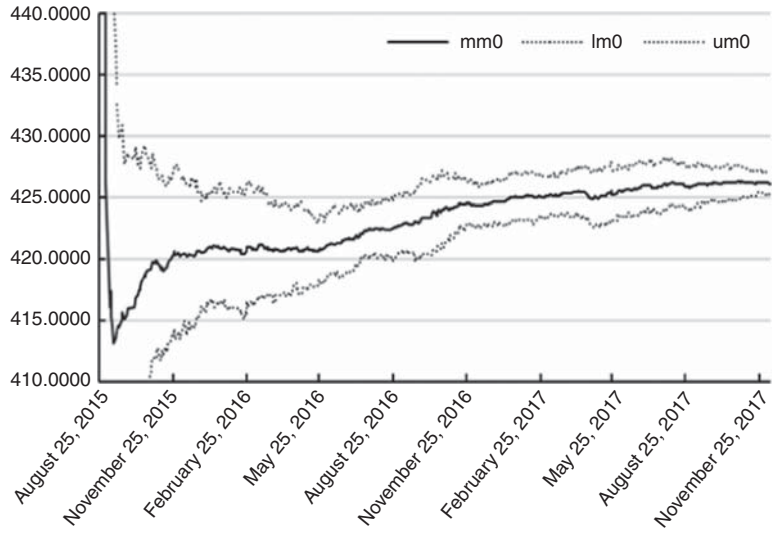


Figure 6.
Posteriori estimate of m_0 under direct channels

only features relatively better convergence tendency, yet still has the improvement space. We can reasonably believe that there are other factors markedly affecting the estimation efficiency and precision of the model and essential to be included into the model. Proceeding from the perspective of linking stock market with foreign exchange market, the layout adjustment of foreign capital in the Chinese stock market is treated as one of the paramount reasons for stock price fluctuation, and the change in exchange rate for foreign capital flows reflects the dynamic adjustment of foreign capital layout in advance with relevant information concealed in the data of exchange market volume. Upon considering the exchange market volume information in the SV-VOL model, the kernel parameter estimation

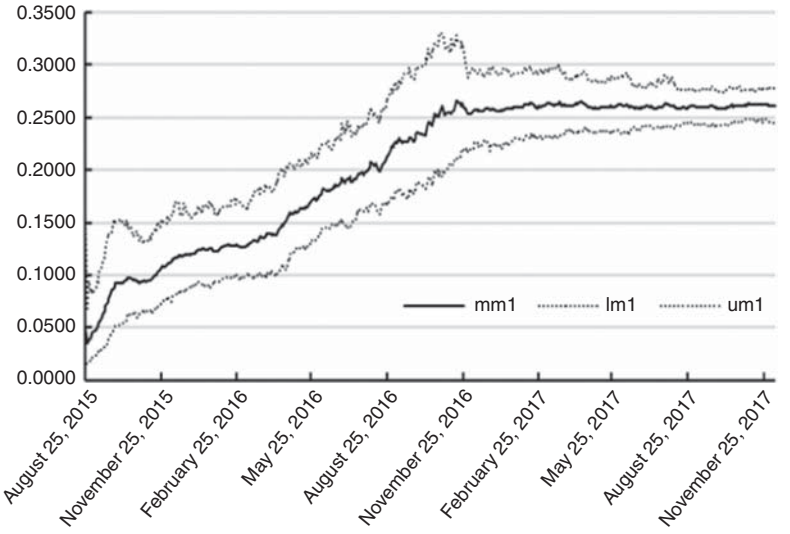


Figure 7.
Posteriori estimate of m_1 under direct channels

is shown in Figure 4, and priority given to concern whether the introduction of exchange market volume information is conducive to improving the model estimation efficiency and accuracy. The results show that the estimation of SV-VOL Model via v_t confirmed through indirect and that through direct channels both have the convergence of m_0 markedly superior to the convergence of m_1, which is identical with the estimation results of Benchmark model. In addition, the convergence of m_0 under indirect channels is markedly superior to that of Benchmark model, harboring relatively identical convergence mean value. In contrast, the convergence of m_1 suffers slight decline, and has the convergence mean value remarkably improved, which means that the influence of known information on fixed trading intensity experiences slight decline compared with the reaction strength of stock market to instant messages. In other words, the known information of the stock market and the exchange market volume information are overlapped, and play a role of information noise reduction via information reconstruction model of resolution, empowerment and recombination. Furthermore, the exchange market volume information conceals the instant impact generated from foreign capital during the operation process of stock market. It means that, upon amendment of exchange market volume information, the capital flow-in and flight information contained in the spot enquiry exchange market volume can strengthen the influence of instant messages on stock market fluctuation in addition to lowering the influence degree of known information on stock market fluctuation. Therefore, the present capital control is beneficial to lower the impact effect of historical events and emergencies on the Chinese stock market, available to alleviate the stock market fluctuation to some extent. The greater influence of known information shows that the exchange market volume information contains more instant messages in connection with stock market fluctuation. With this, the stock market fluctuation without capital control is more likely to suffer the impact effect of emergencies, and goes against the stable development of the stock market. As such emergencies are connected to the intention or strength of capital flight to a great extent, it is demonstrated in the way of negative impact effect. At present, the Chinese economic growth has declined accompanied with intensifying uncertainty degree, and RMB, upon admission into SDR, encounters strong depreciation appeal and finally opens the depreciation shock range, which not only aggravates the

potential pressure of deleverage of USD debts, but also leads to the pressure-bearing of exchange rate and increasing selling pressure of domestic financial assets. Eventually, the capital market suffers influence from two dimensions, namely, fundamental plane and funds face, and the fluctuation of assets price occurring therefore. Due to the fluctuation of exchange rate or plenty of stock market volatility information contained in the exchange volume, the unstable exchange rate is to the disadvantage of the discovery process of assets price and value, and delays the restoration and rehabilitation of the stock market. Direct channels witness poor convergence of both m_0 and m_1. In general, the introduction of exchange market volume information will affect the trading intensity of stock market to information response, and the grant of different information weight will cause remarkable difference in overflow effect.

In short, the introduction of exchange market volume information is conducive to improving the precision of stock price volatility forecast, and *H2* is proved as reasonable.

3.3.4 Contrastive analysis of influence of exchange market volume information on stock price-volume relationship. m_0 and m_1, as core information parameters of the SV-VOL model, offers a holistic reflection to the influence degree of known information and instant messages on the trading intensity. Upon comparing the results of core information parameters under different information weights, it is detected that the posterior mean evaluation of m_0 under indirect channels is highly identical with Benchmark model in terms of motion trails and degree, and the motion trails of m_1 also bear higher consistency. The difference lies in that the introduction of exchange market volume information remarkably improves the response intensity of the stock market to instant messages. In other words, the introduction of exchange market volume information will change the response intensity only, instead of altering the motion trails of the stock market upon suffering the shock of known information and that of instant messages. On the contrary, m_0 and m_1 under direct channels are distinctively different from the Benchmark model in terms of motion trials and response intensity. Upon consideration of the poor convergence of model parameters under direct channels, there is reason to believe that it is more reasonable and effective to take the net inflow of stock market capital as indirect index to confirm the information weight of exchange market volume (Figures 8 and 9).

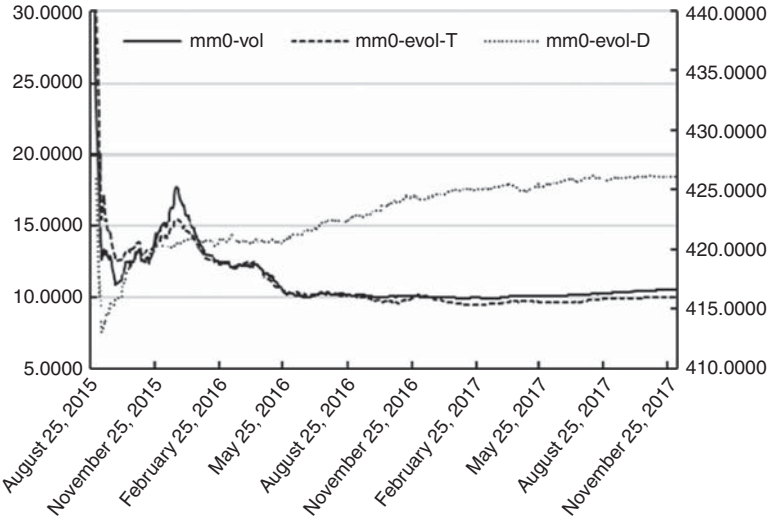


Figure 8.
Comparison of m_0 posteriori estimate under different information weights

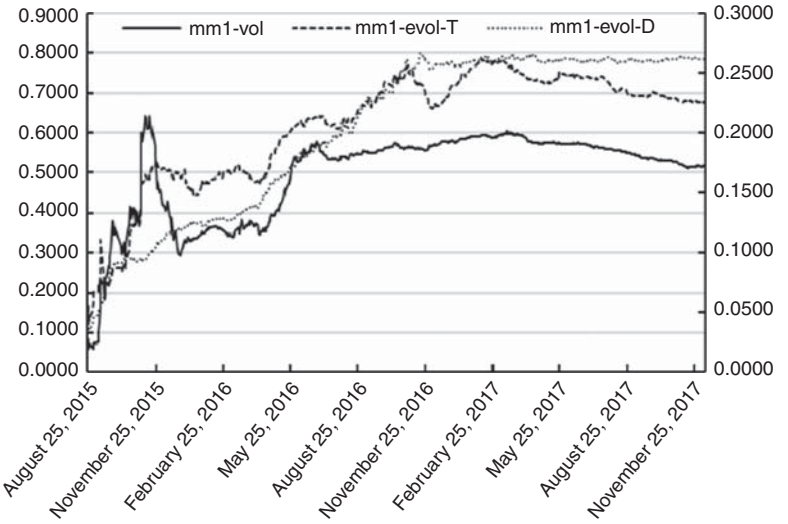


Figure 9.
Comparison of m_1 posteriori estimate under different information weights

Note: The posteriori estimate result of m_0 and m_1 obtained via v_t confirmed under direct channels shall be deemed as the secondary axis

4. Conclusions

Previous studies have neglected the influence of the information contained in the volume of foreign exchange market on the stock price volatility, which leads to the biased estimation of the model parameters. The SV-VOL model with volume information not only can effectively solve the traditional problem of insufficient use of volume information, but also further improve the estimation precision of the model and form a useful supplement to the existing literature by introducing the volume information into the model through weighted processing. The explorative SMC algorithm further advances and develops the non-parametric algorithm in the domestic, conducts beneficial attempts to confirm the information weight of exchange market volume, and gains some helpful conclusion. It is detected that:

(1) The stock market trading volume information is helpful for the stock price volatility forecast. The SV-VOL model estimate with the stock market trading volume information only features obvious parameter convergence trend yet has slower convergence speed, and the negligence of exchange market volume information is deemed as one of the reasons. The research results show that both known information and instant messages can exert influence on the trading intensity at different levels.

(2) The introduction of exchange rate volume information is conducive to improving the precision of stock price volatility forecast. The grant of different weights to the exchange market volume will markedly affect the precision and efficiency of the parameter estimate of SV-VOL model. It is widely believed that, the exchange market volume information indirectly affects the stock return rate and stock price-volume relationship via net capital flowing into the stock market. The confirmation of information weight based on the direct association between stock market and exchange market volume yields poor estimation effect and results.

(3) The spot enquiry volume in the foreign exchange market is deemed as the proxy variable of capital inflow intensity and flight intention, and the information contained

therein amends the impact effect of known information (historical events) and instant messages (emergencies) on the stock market. Upon amendment of exchange market volume information, the introduction of exchange market volume information can lower the impact effect of historical events and emergencies on the stock market, and play the role of buffer to some extent. However, as plenty of instant messages concerning stock market volatility are contained therein, at present, the release of capital control will make the stock market more likely to be exposed to the impact effect of emergencies, and undermine the stable development of the stock market. Therefore, the aggravated degree of exchange rate fluctuation and the intensifying depreciation expectation go against the renovation and recovery of the Chinese stock market.

Note

1. It is noted that the "INDEXV" commonly mentioned refers to the transaction amount, and thus selected to be the stock market trading volume data under this dissertation.

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