National Research University Higher School of Economics

Valeriya Lakshina

SPATIAL SPECIFICATIONS OF FINANCIAL ASSETS' VOLATILITY MODELS

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Academic Supervisor:
Andrey M. Silaev,
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Motivation

In financial econometrics, models of conditional variance, which depends on time, or heteroskedasticity, are in demand, since these models characterize the volatility of financial assets. The fact that the volatility of some assets affects the volatility of others, and the associated assets may belong to different sectors of the economy, formed the basis of multivariate volatility models, which allow to obtain more accurate estimates of volatility than separate univariate models, which, in turn, allows make more effective decisions in the tasks of asset pricing, asset allocation, hedging and risk management (V. Lakshina, 2014).

In the literature there is a large amount of work on the description of volatility models. Among them are models of generalized autoregressive conditional heteroskedasticity (hereinafter GARCH), as well as stochastic volatility and realized volatility. Most models are formulated both in univariate and multivariate versions.

An interesting task for the researcher is to estimate the volatility of the portfolio, especially if the portfolio contains a large number of assets. At the same time, the existing multivariate volatility models contain such a number of unknown parameters that it is extremely difficult to estimate them in a reasonable time with sufficient accuracy (V. Lakshina, 2014). Growth can be so rapid that the number of parameters in a model can exceed the number of observations and make parameter estimation impossible (Caporin and Paruolo, 2009). This situation is sometimes called the "curse of dimensionality" of multivariate volatility models (Caporin and McAleer, 2012). An important area of work is the formulation of multivariate volatility models, in which the problem of dimensionality would be solved (V. Lakshina, 2014).

One of the possible ways of solving this problem is to use the so-called spatial matrices (Caporin and Paruolo, 2015). The name of the matrices is due to the fact that they were borrowed from spatial econometrics, namely the spatial lag model (Arbia, 2006). In this thesis, a out-of-sample comparison of spatial specifications of multivariate volatility models BEKK, GO-GARCH, CCC with their non-spatial specifications is carried out (V. Lakshina, 2014). In addition, an attempt has been made to solve the dimensionality problem for another class of multivariate volatility models, namely, stochastic volatility, for which new specifications with spatial matrices have been formulated.

It should be noted that spatial dependence in the context of the present study does not necessarily imply the geographical proximity of the objects of study. On the contrary, spatial dependencies are considered in a more general context of economic distance.

The number of parameters in the new specifications is growing linearly relative to the number of assets in the portfolio, which makes the study relevant. In addition, spatial specifications allow building dynamic hedging strategies, which take into account the relationships between assets, and evaluating the volatility spillover effects, which is important for solving practical problems in the field of investment management and risk management.

Brief literature review

Since the publication of the seminal paper on autoregressive volatility, — (Engle, 1982) — a significant number of different variations of this model have appeared, both for the univariate (Bollerslev, 1986; Nelson, 1991; Glosten, Jagannathan and Runkle, 1993; Heston, 1993; Zakoian, 1994), and for multivariate (Bollerslev, 1990; Harvey, Ruiz and Shephard, 1994; Engle and Kroner, 1995; Engle, 2002; Engle and Kelly, 2012) cases. One of the distinguishing features of these multivariate models is the presence of a large number of estimated parameters, which was described in the (Engle and Kroner, 1995). For example, the VEC model proposed there, implies that the number of parameters to be estimated does not grow faster than a certain constant multiplied by the cross-sectional dimension of the model (in this case, the number of assets in the portfolio) to the fourth power. A more detailed analysis of the dimensionality problem is presented in the (Caporin and Paruolo, 2009), where it is shown that the vast majority of multivariate GARCH models demonstrate a quadratic growth in the number of parameters relative to the number of assets in a portfolio. There are various ways to deal with the curse of dimensionality in multivariate volatility models. They include the use of restrictions on the parameters in order to reduce their number, targeting (Caporin and McAleer, 2012) and non-parametric methods (Abadir, Distaso and Žikeš, 2014). An example of the application of restrictions on parameters is (Caporin and Paruolo, 2015), where the authors, applying the ideas of spatial econometrics, proposed a new specification of the multivariate BEKK volatility model (named after the first letters of the names of its authors — Baba, Engle, Kraft and Kroner (Baba, Engle, Kraft and Kroner, 1989), the published version of the manuscript — (Engle and Kroner, 1995)), in which a linear increase in the number of parameters relative to the number of assets in the portfolio was achieved. (Anatolyev and Khrapov, 2016) conducted a thorough out-of-sample comparison of the spatial and original BEKK specifications, concluding that, in general, the use of spatial matrices improves the predictive power of the model according to the (Hansen, Lunde and Nason, 2011) test. At the same time, different spatial BEKK specifications have different predictive ability with respect to the original BEKK.

Along with the BEKK model, generalized orthogonal GARCH models (GO-GARCH, (Van der Weide, 2002)), constant conditional correlations (CCC, (Bollerslev, 1990)), as well as multivariate models of stochastic volatility (see, for example, (Asai and McAleer, 2009)), can also be applied to solve investment tasks. These models are also subject to the dimensionality problem, but have not yet been discussed in the literature in this context.

Methodology

We use methods of time series analysis, numerical modeling, as well as probability theory and mathematical statistics. The models were evaluated using the R (R Core Team, 2018) statistical programming language, including the rmgarch (Ghalanos, 2014) and rstan (Stan Development Team, 2018) packages, as well as the Stan (Stan Development Team, 2017) software module for work with econometric models within the framework of the Bayesian approach.

Object and subject of the research

The object of the study is the volatility of financial assets portfolio. The subject of the research is multivariate volatility models of two classes, GARCH and stochastic volatility, as well as their various specifications. In addition, the subject of research is also the efficiency of the above-mentioned models in applied problems of financial economics, such as hedging and modeling of volatility spillovers.

Research goal and objectives

The aim of the study is to build and estimate spatial specifications of multivariate volatility models, including models of the GARCH class and models of stochastic volatility. Objectives include:

- to formulate spatial specifications for multivariate volatility models of the GARCH class;
- to formulate spatial specifications for the multivariate model of stochastic volatility;
- to develop and implement a procedure for estiamting these models;
- to compare spatial specifications with non-spatial according to various criteria, including explanatory power, predictive power, efficiency in solving applied problems;
- provide examples of the practical application of the obtained models to the tasks of investment management, including the assessment of the optimal hedging ratio, modeling of the volatility spillover effects.

Originality of the thesis

The originality of the work is as follows:

- six specifications, including three spatial, for multivariate volatility models of the GARCH class, namely BEKK, GO-GARCH and CCC, are analyzed;

- a multivariate model of stochastic volatility has been developed, spatial specifications have been proposed for it;
- spatial specifications are compared with non-spatial;
- new specifications are applied to the task of hedging a portfolio of financial assets;
- the volatility spillover effects for the oil and gas market are evaluated by means of the spatial specifications.

Theoretical significance of the research results

The developed specifications allow to solve the problem of dimensionality of multivariate volatility models for both the GARCH class models and for stochastic volatility. The developed specifications allow to take into account the spatial dependence between assets and have some attractive properties in terms of their estimation. In addition, by means of the specifications, existing econometric models are developed and new ones are built.

Applied significance of the research results

The proposed specifications can be used to solve various problems of investment management, including the building of a hedging strategy, risk assessment, the optimization of an investment portfolio. The use of spatial matrices allows you to take into account the relationship between financial assets by a certain criterion and thereby increase the amount of information available when making an investment decision.

Main findings and contributions

1. The dimensionality problem in multivariate models of the GARCH class and stochastic volatility has been studied.

2. Six specifications, including three spatial, are formulated and analyzed for multivariate models of the GARCH class — BEKK, GO-GARCH and CCC.

3. For the above models, an empirical out-of-sample comparison of spatial specifications with original ones was carried out. The comparison was based on logarithmic stock returns of twenty American companies included in the S&P500 index and belonging to five different industries. The the predictive power of all specifications was compared using the Diebold and Mariano test. It is shown that on average in 63% of cases spatial specifications demonstrate a higher or equal predictive power compared to non-spatial specifications.

4. A new multivariate model of stochastic volatility based on the use of compound distributions has been proposed, several of its specifications have been formulated, including the spatial one. The latter is remarkable in that it does not have a dimensionality problem. In this model, innovations have Student's t distribution, and the volatility matrix is distributed according to Wishart distribution. An empirical example of estimating the parameters of the model on the data from the Russian stock market is given.

5. The spatial specifications under consideration were applied for solving the task of direct hedging of the investment portfolio, taking into account the investor risk aversion degree. To do this, hedging strategies were based on maximizing the investor expected utility. Comparing models of the GARCH class and stochastic volatility in the context of the hedging task showed that ADCC provides a high maximum achievable risk reduction for 59% of the assets under consideration. At the same time, a hedging strategy based on stochastic volatility allows achieving a better financial result among the assets under consideration in 70% of cases if the investor prefers risk.

6. In addition, the considered models have been applied to estimating the effects of the financial volatility spillovers. Using the spatial specifications of the multivariate BEKK, the effects of volatility spillovers for the oil and gas market for a sample of 67 firms from 13 countries have been evaluated. It is

shown that the largest positive volatility spillover effect is observed between companies belonging to the sectors “Exploration and production of natural gas on land” and “Oil and gas processing”. The largest negativevolatility spillover effect is observed between companies from the sectors “Oil and Gas Processing” and “Non-traditional oil and gas production”.

Reliability and validation of results

The main findings of the dissertation are based on the state-of-the-art economic and mathematical models. Methods of theoretical and econometric analysis used in the thesis meet modern academic standards.

The main results of the dissertation were tested by the means of discussions at a number of international academic conferences and research seminars:

1. Modern Econometric Tools and Applications — META 2016, Nizhny Novgorod, September 22-24, 2016, the report “Stochastic volatility with Student t errors”.

2. Third Russian Economic Congress, Moscow, 12.21.2016, report “Bayesian estimation of a multidimensional model of stochastic volatility for the case of distribution with heavy tails”.

3. XVIII April International Scientific Conference on the Development of the Economy and Society, Moscow, April 13, 2017, report “Hedging Russian Shares with the Model of Multidimensional Stochastic Volatility”.

4. Conference dedicated to the centenary of Academician N.P. Fedorenko, Moscow, 11.05.2017, report “Is it possible to break the “curse of dimensionality”? Spatial specifications of multivariate volatility models”.

5. Modern Econometric Tools and Applications — META 2017, Nizhny Novgorod, 22-24.06.2017, “Comparing hedging strategies based on MGARCH and MSV” report.

6. International Scientific School-Workshop "System Modeling of Socio-Economic Processes" named after Academician S.S. Shatalin, Nizhny Novgorod, October 31-4.10.18, report "Spatial aspects of the volatility spillover effects on the energy market" (N.Ya. Krasner Diploma for the best report and high level of research results using mathematical modeling methods).

Author's original articles

The main results of this thesis are published in the following articles:

Articles in Scopus journals:

1. Lakshina, V. (2014). Is it possible to break the «curse of dimensionality»? Spatial specifications of multivariate volatility models. *Applied Econometrics*, *36*(4), 61–78. Retrieved from http://ideas.repec.org/a/ris/apltrx/0249.html

2. Lakshina, V. (2016). Dynamic Hedging Considering the Degree of Risk Aversion. *HSE Economic Journal*, *20*(1), 156–174. Retrieved from https://ej.hse.ru/2016-20-1/179161613.html

3. Lakshina, V. and Silaev, A. (2016). Fluke of stochastic volatility versus garch inevitability or which model creates better forecasts?" *Economics Bulletin*, *36*(4), 2368–2380. Retrieved from http://www.accessecon.com/Pubs/EB/2016/Volume36/EB-16-V36-I4-P229.pdf

Articles in HSE list of recommended journals:

1. Karatetskaya, E. Y. and Lakshina, V. V. (2019). Multiple hedging on energy market. *Izvestiya of Saratov University. New Series. Series: Mathematics. Mechanics. Informatics*, *19*(1), 105–113

Reviewed Scopus conference proceedings:

1. Lakshina, V. (2017). Hedging and risk aversion on russian stock market: Strategies based on mgarch and msv models. In A. Althonayan, T. A. Belkina, V. S. Mkhitaryan, D. Pavluk and S. P. Sidorov (Eds.), *Proceedings of*

the the second workshop on computer modelling in decision making (cmdm), November 9–10, 2017 (2018, 83–92). CEUR Workshop Proceedings. Saratov, Russia. Aachen. Retrieved from http://ceur-ws.org/Vol-2018/#paper-10

Other papers:

1. Lakshina, V. and Karatetskaya, E. (2018). *Volatility spillovers with spatial effects on the oil and gas market*. Retrieved from https://ssrn.com/abstract=3185802

Structure of the thesis

The thesis consists of an introduction, three chapters, conclusion, bibliography and appendices. The text of the thesis is presented on 131 pages, contains 5 figures, 26 tables. The bibliography includes 228 sources.