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Modeling spatial and temporal dependencies among global stock markets

Yingliang Weng*, Pu Gong

School of Management, Huazhong University of Science and Technology, Wuhan 430074, China

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ABSTRACT

An intensive analysis of the dependence structure among stock markets is invaluable to financial experts, policy makers, and academic researchers, providing them with important implications for portfolio management, policy-making, and risk assessment. This paper proposes a novel spatiotemporal model to both examine global stock market linkages and investigate what drives stock returns. The newly introduced model allows us to go beyond conventional correlation analyses confined to studying pairwise relationships and seems to be more suitable for detecting the dependence structure of high-dimensional financial time series. Moreover, a new copula-based approach to define the spatial weight matrix is presented that is based on the construction of a dissimilarity matrix using the Spearman's contagion index. To the best of our knowledge, this paper is the first to incorporate copulas into the definition of the spatial weight matrix. In addition, the maximum likelihood estimator of our model is derived, together with a Monte Carlo simulation study evaluating its performance compared to two other methods. Finally, the results demonstrate that our proposed measure of the spatial weight matrix, coupled with our model, performs very well in terms of capturing spatial and temporal dependencies among global stock markets, and that the relative values of conditional volatilities are also important factors in determining stock returns.

1. Introduction

The recent global financial crisis (GFC, hereafter), triggered by the collapse of the US mortgage market in August 2007, has shown that global financial markets, especially global stock markets, tend to be more dependent rather than independent on each other during the crisis. Indeed, with the increasing significance of international trades and investments, the spatial interrelationships among global stock markets are becoming increasingly strong. These phenomena indicate that understanding the nature of the dependence structure among global stock markets holds important implications for financial experts, policy makers, and academic researchers. On a practical level, the analysis of the dependence structure among global stock markets can help investors construct optimal asset allocation portfolios and can be beneficial for governments allocate countries' economic resources reasonably.

The dependence structure between market assets was initially studied using the Pearson correlation coefficient based on the covariance of two variables. Nonetheless, the correlation between different market assets might be non-linear and time-varying, which indicates that the hypothesis of linear correlation is not appropriate. Thus, towards a better understanding of these relationships, more recently many researchers proposed a number of approaches, which are based on different techniques like multivariate GARCH models (Jaworski & Pitera, 2014), copula-based clustering procedures (Durante & Jaworski, 2010; Durante, Foscolo, & Sabo, 2013; Durante, Foscolo, Jaworski, & Wang, 2014; Durante, Pappadà, & Torelli, 2014; Durante, Fernández-Sánchez, & Pappadà, 2015), and non-parametric clustering methods (Durante, Pappadà, & Torelli, 2015). Besides, there are many other methods to analyze the similarity of different stock markets such as three-phase clustering method (Aghabozorgi & Teh, 2014), clustering method based on topological features (Pereira & de Mello, 2015), multidimensional scaling and clustering analysis (Esmalifalak, Ajirlou, Behrouz, & Esmalifalak, 2015), etc.

From a methodological point of view, the dependence can be estimated and tested in all of these models. It is noticed that most of the previous studies focused on analyzing the dependence structure between one and other stock markets separately rather than simultaneously by using time series approaches such as GARCH models. In other words, the majority of these models are confined to studying pairwise relationships and there is still much negligence with respect to the estimation of the spatial dependencies among stock markets. Moreover, it is apparent that there might be several nearby stock markets affecting one stock market due to the geographical proximity or

* Corresponding author.
E-mail addresses: wyl_hust@163.com (Y. Weng), gongpu@hust.edu.cn (P. Gong).

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economic and financial similarities in the real world, that which includes the virtual world.

In this context, spatial econometric model has recently emerged as a useful tool to study the spatial interaction effects among geographical units. The spatial econometrics literature has exhibited a growing interest in the specification and estimation of spatial dependence models in the last decade. For instance, Baltagi, Bresson, and Pirotte (2012) discussed various forecasts using a panel data model in which the disturbance term follows an error component model with the spatial autoregressive (SAR) and the spatial moving average (SMA) residuals. More recently, Qu and Lee (2015) presented the specification and estimation of an SAR model with an endogenous spatial weight matrix. Wang and Yu (2015) investigated the quasi-maximum likelihood (QML) estimation of spatial panel data models with time varying spatial weights matrices.

In addition, the contemporary literature across many disciplines has stressed the importance of incorporating the idea of specification and estimation of serial and spatial dependence from spatial econometrics. As stressed by Elhorst (2014), both spatial and serial autocorrelations are likely to be present in the analysis of space-time dataset, so that dynamic rather than static modeling of the economic relationships is preferred. In general, the dynamic spatial panel data models often consist of two core components; one is serial correlation between the observations on each spatial unit over time, and the other is spatial dependence between the observations on the spatial units at each point in time. The literature on time-series econometrics is rich with dealing with serial correlation, and the case is true for spatial dependence in spatial econometrics. In the spatial literature, two commonly used spatial error processes are the SMA and the SAR error processes (Fingleton, 2008). It is well known that the SMA error process transmit the shocks locally while the SAR error process transmit the shocks globally via the power of the spatial weight matrix (Anselin, Gallo, & Jayet, 2008). In an earlier study, Baltagi, Heun Song, Cheol Jung, and Koh (2007) took into account the testing of the spatial and serial autocorrelations in a random effects panel data model, where the serial and spatial correlations in the disturbances are separated. Later, Elhorst (2008) specified a regression model in which the error terms are both serially and spatially correlated jointly. Recently, Lee and Yu (2015) considered a QML estimation of a linear panel data model with serially and spatially correlated disturbances. For a dynamic panel data model with a spatial error of the SAR type, Su and Yang (2015) derived its QML estimator under both fixed and random effects specifications.

Notably, although there are extensive studies on the specification and estimation of dynamic spatial panel models, the applications of such models in economics and finance are not yet very popular, due to the difficulties in constructing the spatial weight matrices in the context of financial markets. Some important recent contributions include that of Fernandez (2011), who employed firm character variables like size and book-to-market to measure the spatial dependence between firms and derived a spatial capital asset pricing model. Eckel, Löffler, Maurer, and Schmidt (2011) measured the effects of geographical distance on stock market correlation via a regression approach. Fernández-Avilés, Montero, and Orlov (2012) and Hierro, Maza, and Villaverde (2013) used spatial techniques to investigate to what extent different linkages between countries affect the degree of stock market co-movements. Among others, for instance, Moscone, Tosetti, and Canepa (2014) examined the relationship between the real estate prices and bank exposures using a first-order dynamic panel data regression model with group-specific effects and SAR errors. Arnold, Stahlberg, and Wied (2013) proposed a simplified third-order spatial lag model, which has recently been extended by Schmitt, Schäfer, Wied, and Guhr (2015), to model spatial dependence in stock returns and to forecast risk measures. One common conclusion drawn from the above-mentioned two studies is that the combination of spatial modeling and finance allows for superior risk forecasts. The last two papers are closely connected to our approach. However, neither considers the intuitive serial dependence of stock returns in the analytic framework.

Therefore, in this paper we attempt to ease such restrictions by explicitly illustrating one-to-one spatial linkages among spatial units using spatial techniques. Particularly, this paper investigates spatial and temporal dependencies among 24 global major stock markets over the period from 2000 to 2014 using dynamic spatial panel data models. The current paper contributes to the economics and finance literature that studies the dependence structure among financial markets in several aspects.

One of the main contributions of this article is that it pays special attention to the use of dynamic spatial panel data models for filtering out the potential spatial and serial correlations among global stock markets. The current paper draws on the methodological contribution by Elhorst (2008), extends the idea to allow for a linear panel data regression model with SMA error disturbances and with first-order serial correlated remainder disturbances, and takes into account whether variously chosen spatial weight matrices have effects on the root mean square error (RMSE) performance of the model. Our main motivation for studying spatial dependence is that currently a country's stock market is prone to be affected by its nearby countries not only because of geographical proximity (see Eckel et al., 2011; Zhu, Füss, & Rottke, 2013), but also because of economic and financial similarities (see Abate, 2015; Asgharian, Hess, & Liu, 2013; Fernandez, 2011). The main reason for studying temporal correlation is that investors often make decisions in the current period that are influenced by the behavior of their decisions in the previous period and therefore, the current period's stock returns should be correlated to the previous period's stock returns (Tam, 2014).

Other contributions include a new copula-based approach for the definition of the spatial weight matrix extended from the work by Durante and Foscolo (2013), and an emphasis on the importance of the relative values of the stock return volatilities constructed by the quartile method in the determination of stock returns. To the best of our knowledge, this paper is the first to incorporate copulas into the construction of the spatial weight matrix. The motivation for choosing copulas lies in the fact that copulas offer much more flexibility compared to other correlation approach in terms of modeling the dependence structure between financial time series. Particularly, this approach is based on the use of suitable copulas associated with the stock markets and on the calculation of the related conditional Spearman's correlation coefficients between two stock markets. In addition, although many factors might affect stock returns, such as stock return volatility, industry, social media, investor behavior, and market characteristics (Aghabozorgi & Teh, 2014; Liu, Wu, Li, & Li, 2015), we believe that it is still necessary to propose a new model to reflect the influence of the investor behavior on stock returns from a reference group perspective. A reference group is a group to which an investor or another group is compared. We support the view that stock returns are affected not only by the absolute values of factors like trading volumes, volatilities and market caps, but also by the relative values of factors such as ranking of stocks' trading volumes, ranking of stocks' volatilities and ranking of stocks' market caps. In other words, it is reference group or these rankings which form investors' trading behaviors that will result in discrepancy between current and desired stock returns. Hence, differently from the previous literature, we use the relative values of the estimated conditional variance, based on the quartile method, to construct the exogenous explanatory variables. One merit of this approach is that we can examine the risk-return tradeoff in view of the fact that the first quartile of the volatilities imply high risk stocks while the fourth quartile of the volatilities imply low risk stocks.

The paper is divided into five sections. The following section formally presents the model specification and the maximum likelihood (ML) estimation of the models. In Section 3, we perform a series of