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Spatio-temporal modeling of financial maps from a joint multidimensional scaling-geostatistical perspective

Gema Fernández-Avilés*, José-María Montero

Statistics Department, University of Castilla-La Mancha, Cobertizo de San Pedro Mártir, S/N 45071Toledo, Spain

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ABSTRACT

Modeling the propagation of extreme financial episodes and their consequences is currently a hot topic in international financial literature. This article focuses on the propagation of such episodes among the top stock exchange indexes in the world. Recent developments in spatio-temporal geostatistics are used to model this propagation process. However, as physical distance does not matter in the propagation of stock exchange returns, a multidimensional scaling of those returns is carried out to substitute the physical space with a financial one (a financial map). This process yields a set of financial-temporal coordinates which enable the use of the recent developments in spatio-temporal geostatistics. The way either extremely positive or extremely negative news propagates among the main stock exchanges in the world is a key factor for investors, financial experts and policy makers; it not only has important implications for portfolio management, policy-making, and risk assessment, but is also central to managing financial panic episodes.

This combined multidimensional scaling/spatio-temporal geostatistics methodology has been applied to a database containing financial information about a set of 7 extreme episodes in the 29 most important stock exchange markets in the world. Results indicate that this combined methodology captures the propagation of returns in crashes better than in booms. Another interesting feature of this methodology is that it can be easily implemented in an expert system where the inputs are daily observed returns and the outputs are short-term predictions about those returns in an extreme episode, when financial propagation becomes financial contagion.

1. Introduction

The present state of the world, in general, and the global economy in particular, makes countries more interdependent. This brings new advantages for countries, but also entails new dangers (Villar-Frexedas & Vayá, 2005). For these reasons, as Asgharian, Hess, and Liu (2013) point out, an examination of the underlying economic structures that affect the transmission of country (market)-specific shocks to other countries (markets) is essential. This analysis is especially important in the field of finance research, and more specifically for stock exchange markets (SExMkt) as they are a core factor in the development and strength of international global economies. According to Weng and Gong (2016), understanding the nature of the dependence structure among global SExMkt has major implications for financial experts, policy makers, and academic researchers. Therefore, it is no surprise that, currently, one of the most interesting questions in the international finance literature is how to model the linkages between different financial markets and, more specifically, the propagation of their returns in extreme episodes. However, this is a challenging task. The contribution this article makes to this pioneering literature lies in the combination of the multidimensional scaling (MDS) and spatio-temporal geostatistics approaches to study financial propagation (or contagion) during extreme financial episodes.

We should note that the term "contagion" is usually used in the context of financial crises to describe the way that negative externalities spread from one crashing market to another. More formally, Forbes & Rigobon (1999) defined contagion as a significant increase in cross-market correlations during periods of turmoil. However, in this article, we use the term in a more general sense to refer to a significant transmission or propagation of negative returns (in bust episodes) or positive returns (in boom episodes) among the financial markets of different countries.

It is also worth noting that we initially adopt a spatio-temporal approach because, according to Elhorst (2001), Holly, Pesaran, and Yamagata (2011), Tam (2014) and Weng and Gong (2016), among

* Corresponding author.
E-mail addresses: gema.faviles@uclm.es (G. Fernández-Avilés), jose.mlorenzo@uclm.es (J.-M. Montero).

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others, both spatial and temporal effects are likely to be present in the analysis of space–time data, so the simultaneous study of both in economic relationships is preferred. As an example, an understanding of such effects would be helpful in the design of sound portfolios (Nigmatullin, 2010; Plerou, Gopikrishnan, Rosenow, Amaral, & Eugene, 2000).

However, in this article we substitute the spatio-temporal geostatistical approach with the MDS/spatio-temporal geostatistics strategy, an original combination based on financial-temporal correlations among stock exchange indexes around the world rather than spatio-temporal dependencies. In theory, spatio-temporal geostatistics should be able to (i) explain the structure of the dependencies between daily returns of the main SExMkt through one of the permissible spatio-temporal covariance functions, or semivariograms, included in the literature on the topic; and (ii) make very short-term predictions using the kriging equations provided by geostatistics (see Montero, Fernández-Avilés, & Mateu, 2015, for details on both (i) and (ii)). These days, however, financial information is transmitted around the world almost instantaneously and, as a consequence, physical distance is not particularly informative for prediction in general, and especially in the case of an extreme financial episode. In fact, Fernández-Avilés, Montero, and Orlov (2012) prove that, at least from a geostatistical perspective, when it comes to dealing with the interdependencies between international SExMkt, the physical distance between them does not matter.

The question then becomes one of how to use the rudiments of a discipline as useful as spatio-temporal geostatistics to explain the structure of the dependencies between returns of different countries' stock markets and to make predictions accordingly. According to Fernández-Avilés et al. (2012), the First Law of Geography which states that "*Everything is related to everything else, but near things are more related than distant things*" (Tobler, 1970) could apply to financial markets, but only in a financial sense. That is, with respect to financial markets, the word "near" must be understood as having a financial meaning. Therefore, if we are able to substitute physical distances between SExMkt with the financial distances between them (a more realistic approach), there is no reason why we cannot apply the techniques provided by spatio-temporal geostatistics to achieve the two above-mentioned objectives.

The financial distances between markets are provided by MDS. There are other multivariate techniques capable of providing economic or financial distances (clustering or neural networks, for example), but the great advantage of MDS is that it provides a representation of the SExMkt under study in a *k*-dimensional map, according to the researcher's criteria. Therefore, MDS provides not only "financial distances" between SExMkt but also their "financial coordinates". This is vital information not only at a practical level, in order to implement this combined methodology in the corresponding software, but also in theoretical terms, since in non-stationary situations, such coordinates are necessary in order to solve the kriging equations provided by geostatistics to make predictions.

In this article, the combination of MDS and spatio-temporal geostatistics (which could be referred to as financial/temporal geostatistics because the financial and time dimensions are used in a non-separable way) has been applied to a dataset including the following extreme events: (i) the Al-Qaeda attacks in the US in 2001; (ii) the Al-Qaeda attacks in Spain in 2004; (iii) the Lehman Brothers bankruptcy in 2008; (iv) the tsunami and earthquake in Japan in 2011; (v) the Obama administration's stimulus package in 2009, (vi) the European rescue packages in 2010 and (vii) the Christmas rally in 2013. We work with the daily (log) returns of the 29 most important SExMkt from around the world.

Although Tenreiro, Duarte, and Monteiro (2011a) anticipated that the maps created by applying MDS techniques could be used to guide the construction of multivariate econometric models, to the best of our knowledge, this is the first paper to analyze financial propagation (or even contagion) from a joint MDS/geostatistical perspective. What is more, as far as we are aware, no research to date has used this combination of techniques in the study of financial relations in general.

The remainder of the paper is organized as follows. Section 2 is devoted to a literature review on the topic. Section 3 addresses methodological questions related to MDS and spatio-temporal geostatistics. Specifically, Section 3.1 describes our approach to creating financial maps using the MDS method, and Section 3.2 deals briefly with the main geostatistical tools. Section 4 details the empirical study carried out as well as the main results obtained. Finally, Section 5 concludes and provides managerial insights and promising avenues for future research.

2. Literature review

The study of the relationships between international SExMkt is not new. However, as pointed out in Asgharian et al. (2013), earlier studies have focused solely on assessing the degree of dependence among markets while the channels through which SExMkt are connected to each other have received insufficient attention. These earlier studies include, for example, the research by Bekaert and Harvey (1995), Karolyi and Stulz (1996), Longin and Solnik (1995), and Asgharian and Bengtsson (2006), and basically use conventional correlation analysis and volatility-spillover models, which are confined to the study of pairwise relationships. Of all the model-based analyses, the most popular strategy was ARCH modeling (Engle, 1982), and especially its generalization, the multivariate GARCH models (Bollerslev, 1986). As stated in Fernández-Avilés et al. (2012), vector autoregressions, vector error correction models and Granger causality tests are also popular approaches when it comes to studying the issue of interdependencies in financial markets (e.g., Cheung, Fung, & Tsai, 2010). These methodologies clearly have their merits, but none of them consider the issue of how close (financially speaking) the markets are, or explicitly acknowledges the complex structure of SExMkt interdependence. In addition, as stated in Cheung et al. (2010), they require a better understanding of factors that may affect the dynamics of global interdependence, such as market imperfection, investors' sentiment, and information efficiency.

Time-series-based clustering is one of the most popular multivariate tools in financial studies, but it is typically used to group stocks in a specific stock exchange that display similar patterns (Basalto, Belloti, De Carlo, Facchi, & Pascazio, 2005; Ohta, 2006; and Yu & Wang, 2009, are some examples). It is only recently that clustering has been used to examine contagion in financial markets. Jaworski and Pitera (2014) study this topic via conditional copulas and also combine the spatial contagion approach with time-series models (multivariate GARCH models). However, they only focus on pairwise relations (they use data from the FTSE100 and DAX indexes) and do not focus on extreme episodes but rather on an extended period of time. In addition, although this procedure can be useful for describing the contagion effect it is not suitable for predicting boom and crash situations. The same can be said of the copula-based clustering procedures used by Durante and Foscolo (2013), Durante and Jaworski (2010) and Durante, Foscolo, Jaworski, and Wang (2014) to define and detect spatial contagion between two markets. In the best of cases, these procedures can only be used to suggest indexes to measure the contagion effects between financial markets, detect changes in the dependence structure among them and identify subgroups of assets displaying similar behavior in periods of market distress.

Durante, Pappadà, and Torelli (2015) used non-parametric clustering methods for clustering financial time series according to the