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Bayesian dynamic financial networks with time-varying predictors

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ABSTRACT

We propose a targeted and robust modeling of dependence in multivariate time series via dynamic networks, with time-varying predictors included to improve interpretation and prediction. The model is applied to financial markets, estimating effects of verbal and material cooperations.

1. Introduction

The global financial crisis is a hotly debated topic having complex roots and ongoing effects. The crisis was driven by the coexistence of a complex system of factors covering lack of proper regulation, easy credit conditions and the introduction of new financial instruments. The 2004–2007 United States housing bubble is a key factor behind the subsequent financial instability, tracing back its causes to the unusually low interest rates decision of the Federal Reserve to mitigate the effects of the 2000 dot-com bubble (Taylor, 2009), and the growing demand for financial assets by foreign countries which generated an additional influx of "saving glut" (Bernanke, 2007) stimulating the proliferation of risky loans, predatory lending, increasing financial complexity (Brunnermeier, 2009) and a wide network of dependences between financial operators worldwide. Optimistic forecasts on the expansion of the real estate market contributed to the inflation of the bubble, which burst between 2006 and 2007, when subprime borrowers proved unable to repay their mortgage, triggering a vicious cycle with owners holding negative equity motivated to default on their mortgages.

The increasing interconnection between world financial markets and institutions, generated a contagion effect that took shape through the rapid development and spread of the subprime mortgage crisis to the 2008–2012 global recession, which affected the entire world economy and finance. In most cases the recession was manifested through a sharp drop in international trade, low consumer confidence and sovereign-debt crises, which propagated in the subsequent 2010–2012 European sovereign-debt crisis affecting mainly Greece, Portugal, Ireland, Spain and Italy, and requiring important material bailout investments by Eurozone.

Spurred by interest in financial crises and by the need to provide more flexible and accurate statistical analysis of financial systems, a rich variety of statistical methods have been recently developed. Beside descriptive studies interpreting empirical

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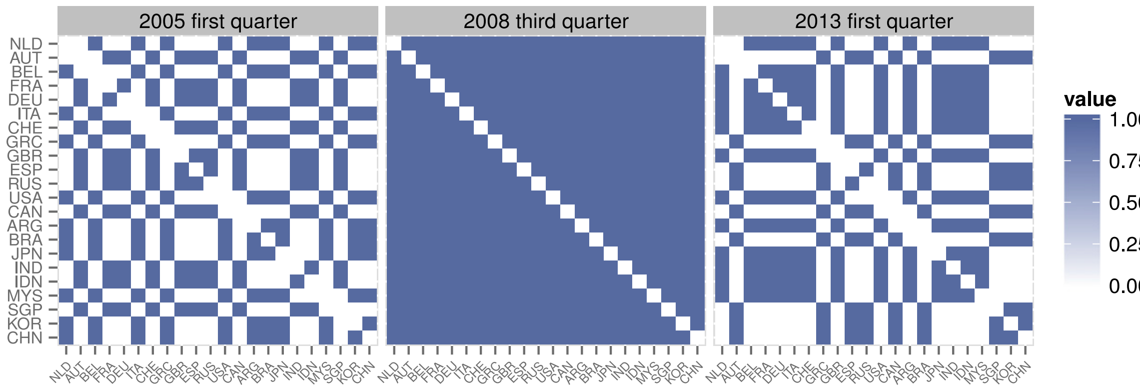

Fig. 1. Response network: dynamic co-movements in world financial markets.

evidences in the light of the key financial events, such as Taylor (2009), there is an abundant literature on model based statistics aimed at exploring co-variations and interconnection structures among financial markets during recent crises via vector autoregression (Longstaff, 2010), vector error correction (Gentile and Giordano, 2013), locally adaptive factor processes (Durante et al., 2014) and dynamic matrix factorization (Sandoval and Franca, 2012). Such applications provide useful overviews on the temporal and geo-economic changes in world financial markets, showing how high volatility phases are directly linked with increasing levels of interdependence. However, previous models do not account for covariates which may inform on the dependence structure, while relying on Gaussian assumptions for the log-returns distribution. It is well known that such assumptions can be violated in financial time series, leading to misleading inferences and predictions (Tsay, 2005).

Recent applications deal with the previous issue within a graph data modeling framework, motivated also by theory on financial markets (Acemoglu et al., 2013). Results are available in static (Mantegna, 1999) and dynamic settings (Onnela et al., 2003; Dal'Maso Peron and Rodrigues, 2011), via minimum spanning trees and synchronization statistics, with networks constructed exploiting correlation-based distance measures. Although key insights into the factors driving market behavior and risk are provided, the previous methods focus on specific network features instead of the overall generating process, and there is no inclusion of covariates informing on the relational structure. Beside these issues, correlation-based distance measures may fail in properly characterizing dependences outside the Gaussian assumption.

Durante and Dunson (2013) recently proposed a generative model for analyzing dynamic relational data via Bayesian nonparametric techniques. The focus is on methodology and theory, with a financial application serving as an illustrative example. In this paper we generalize the previous model to include time-varying predictors in dynamic networks and carefully deepen their financial application to stress the benefits of studying dependences in multivariate time series through a network lens. Avoiding correlation-based measures and Gaussian assumptions for analyzing co-variations in a time-varying vector $R_t = [r_{1,t}, \ldots, r_{V,t}]^T,\ t \in \mathcal{T} \subset \Re^+$, ensures more targeted modeling, greatly limiting concerns about lack of robustness to model misspecification. This is particularly true for financial time series, where the Gaussian assumption is rarely met. Additionally, the inclusion of time-varying predictors represents a key generalization for practical purposes, in providing new insights on the generating process and improving predictive performance.

When dynamic networks are constructed via correlation-based distance measures, there is no agreement on how to define such quantities for each time. Moreover, constructing dynamic correlation matrices by averaging the behavior in disjoint time sets (Onnela et al., 2003), or in overlapping windows (Dal'Maso Peron and Rodrigues, 2011), creates undesirable over-smoothing in the data, with extremal dependence behaviors, such as those occurring during financial crises, ruled out prior to estimation. A key in our construction is to avoid the previous issues by considering co-movements as dynamic relational data, with inference focused on the sequence of $V \times V$ symmetric matrices $\{Y_t,\ t \in \mathcal{T}\}$ having entries $y_{ij,t} = y_{ji,t} = 1$ if time series i and j co-move at time t, meaning that $r_{i,t} > 0$ and $r_{j,t} > 0$, or $r_{i,t} < 0$ and $r_{j,t} < 0$ (time series are similar); and $y_{ij,t} = y_{ji,t} = 0$ if opposite increments are recorded (time series are dissimilar); see Fig. 1, for an example related to our application on co-moments among national stock market indices during recent crises.

To provide new insights on financial crises and improve predictive performance, we additionally include time-varying predictors via two systemic indicators encoding the presence or absence of substantial increments in verbal and material cooperation efforts among pairs of countries as in Fig. 2.

2. Bayesian nonparametric dynamic networks with time-varying predictors

2.1. Relevant contributions

There is a growing literature on social networks mainly focusing on exponential random graphs (Frank and Strauss, 1986), stochastic block models (Nowicki and Snijders, 2001), mixed membership stochastic block models (Airoldi et al., 2008)