J. Int. Financ. Markets Inst. Money xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Journal of International Financial Markets, Institutions & Money

journal homepage: www.elsevier.com/locate/intfin

An entropy-based early warning indicator for systemic risk ☆

Monica Billio *, Roberto Casarin, Michele Costola, Andrea Pasqualini

University Ca' Foscari of Venice, Department of Economics, Cannaregio 873, Venice, Italy

ARTICLE INFO

Article history:
Received 19 October 2015
Accepted 25 May 2016
Available online xxxx

Keywords:
Systemic risk measurement
Entropy measures
Bayesian inference
Early warning indicator
Banking crisis

ABSTRACT

We analyze the time evolution of systemic risk in Europe by using different entropy measures and construct a new early warning indicator for banking crises. The analysis is based on the cross-sectional distribution of systemic risk measures such as Marginal Expected Shortfall, Delta CoVaR and network connectedness. These measures are conceived at a single institution level for the financial industry in the Euro area and capture different features of the financial market during periods of stress. The empirical analysis shows the forecasting ability of entropy measures in predicting banking crises.

1. Introduction

Much attention is reserved to modeling systemic events by academics and regulators, given the relevance and the high impact of latest financial and sovereign crises. Many authors have found the complex interconnectedness among financial institutions and markets as the potential channel that magnified the initial shocks to the system (see Billio et al., 2012; Diebold and Yilmaz, 2015). Also the Financial Stability Board (FSB) confirms the importance of systemic interconnectedness among financial institutions in its consultative document of 2014, since it may cause significant disruption to the global financial system and economic activity across jurisdictions. In providing a framework for strengthening financial and thus macroeconomic stability, policy makers are currently not only refining the regulatory and institutional set-up, but also looking for analytical tools to better identify, monitor and address risks in the system. See also the recent debate on the role of the capital requirement in the stability of the financial system (Admati et al., 2010) and on the difficulties of the microprudential regulation of the banking system in maintaining the financial stability (Allen and Carletti, 2012).

By definition, systemic risk involves the financial system, a complex and strongly interrelated system where the interconnectedness among financial institutions in period of financial distress may result in a rapid propagation of illiquidity, insolvency, and losses. Given the endogenous nature of systemic risk, its measurement represents a complex task, which involves different financial and macroeconomic aspects. In fact, the implications of systemic risk is relevant both in the macro and

☆ We thank the editor, the anonymous referees and conference and seminar participants at the: 9th CSDA International Conference on Computational and Financial Econometrics 2015, Italian Statistical Society meeting 2015, "Dealing with Complexity in Society" ISA-RC55 meeting 2015. We thank Fulvio Corsi, Lorenzo Frattarolo, Fabrizio Lillo and Loriana Pelizzon for their constructive comments. Authors' research is supported by funding from the European Union, Seventh Framework Programme FP7/2007-2013 under grant agreement SYRTO-SSH-2012-320270, by the Institut Europlace of Finance, "Systemic Risk grant", the Global Risk Institute in Financial Services, the Louis Bachelier Institute, "Systemic Risk Research Initiative", and by the Italian Ministry of Education, University and Research (MIUR) PRIN 2010-11 grant MISURA. This research used the SCSCF multiprocessor cluster system at University Ca' Foscari of Venice.

* Corresponding author.
E-mail addresses: billio@unive.it (M. Billio), r.casarin@unive.it (R. Casarin), michele.costola@unive.it (M. Costola), andrea.pasqualini@unive.it (A. Pasqualini).

http://dx.doi.org/10.1016/j.intfin.2016.05.008
1042-4431/

micro perspectives. At macro level, the aim of policy makers such as European Central Bank (ECB), European Systemic Risk Board (ESRB) and Federal Reserve System (FED) is to guarantee the stability of the banking system (Rochet and Tirole, 1996; Freixas et al., 2000) and more in general of the financial system, while at micro level, systemic risk reduces the gains of diversification in an investor perspective (Das and Uppal, 2004). There is no widely accepted definition of systemic risk, but as in Billio et al. (2012) we consider any set of circumstances that threatens the stability of or public confidence in the financial system. Accordingly, different measures have been proposed in the literature to exploit the variety of aspects expressed by relevant economic and financial variables. Bisias (2012) present an excellent survey on systemic risk measures.

In this paper we consider two classes of systemic risk measures. Within the first class of measures, we focus on the tails of the financial returns capturing the co-dependence between financial institutions and the market. Among these measures we consider: the ΔCoVaR (Adrian and Brunnermeier, 2011), defined as the difference between the VaR of the financial system conditional on the institution being under distress and the VaR of the financial system conditional on the "normal" state of that institution; the Marginal Expected Shortfall (MES) proposed by Acharya et al. (2010), defined as the average return of a financial institution during the 5% worst days for the overall market return.

The second class of measures focuses on linkages among financial institutions. Billio et al. (2012) use pairwise Granger causality tests to extract the financial network, to detect significant linkages among financial institutions and to describe which ones are systemically important. Battiston et al. (2012) propose a measure of systemic impact inspired by feedback-centrality, which takes recursively into account the impact of the distress of an initial node across the network. Loepfe et al. (2013) suggest that the analysis of the system should be included as a whole and investigate the networks topology on resistance to shocks, showing that the transition from safe to risky regime depends on diversification and shocks magnitude. We propose a new approach based on measuring the system-wide (or cross-sectional) entropy of systemic risk. Intuitively, in the proximity of a systemic event, the financial institutions, that are the systemic relevant or frail, are probably be the first to react and thus to provoke a structural change in the distribution of the risk across the financial institutions. In this regard, we exploit the ability of the entropy indicator to detect the heterogeneity and time variations in a system. Since we want to consider a mildly general framework, we do not impose any assumption on the cross sectional conditional distribution of the risk measures given the information set available at a certain point in time. Accordingly, we follow a non parametric approach to entropy estimation. To our knowledge we are the first to apply entropy to cross sectional analysis of systemic risk measures.

We explore two channels through which our entropy measure is related with systemic risk. First, we focus on tail interaction (MES and ΔCoVaR). As suggested by Acemoglu et al. (2012), higher-order intersectoral connections capture the possibility of cascade effects so that shocks in productivity into a sector spread not just to the closer downstream customers, but also to the overall economy. Also, our framework exploits the relationship between uncertainty shocks and real outcomes predicted by Bloom (2009) and Gourio (2012). These papers present theoretical models showing that shocks to volatility or to tail risk provoke common fluctuations across firms. Second, we measure interaction through causal dependence among financial institutions (linkages). Acemoglu et al. (2013) show that negative shocks beyond a certain level make interconnections acting as a propagation mechanism, which leads to a more fragile financial system. When representing the financial system as a network, the distribution of the number of linkages across institutions (i.e. degree distribution) plays a crucial role in the description of the network connectivity. The increased system fragility reflects in a network degree distribution which is symmetric and with thicker tails than the degree distribution in a "normal" situation. Following Barabási and Albert (1999) and Acemoglu et al. (2012), skewness and fat tails suggest that there is heterogeneity in the linkages among institutions since a large majority of financial institutions have low degree, but a small number, known as hubs (systemically important financial institutions), have a high number of linkages. In this case, the system is robust to random failures, but vulnerable to targeted attacks. We thus exploit this heterogeneity by considering entropy (Solé and Valverde, 2004; Wang et al., 2006). Entropy measures have been already used in finance; Zhou et al. (2013) provide an up-to-date review of the concepts and principles of entropy applied in finance. Jiang et al. (2014) propose an entropy measure for asymmetrical dependency in asset returns. Chabi-Yo and Colacito (2013) propose an entropy-based correlation measure to assess the performance of international asset pricing models. Bera and Park (2008) propose to use cross-entropy measure as shrinkage rule to overcome extreme portfolio weights in the mean-variance estimation framework. Gao and Hu (2013) study the income structures of different sectors of an economy and provide an early warning indicator based on entropy by measuring losses in term of quarterly negative income where exposure networks are modelled by the Omori-law-like distribution. Alvarez-Ramirez et al. (2012) apply approximated entropy measures at univariate level to study the dynamics of the market efficiency from an informational perspective.

The main contribution of our study is to apply entropy to systemic risk measures and to do it sequentially over time on a panel of measures, which capture different features of systemic risk in the financial market. See also Allen and Carletti (2012) for a detailed discussion on the sources of systemic risk and their importance for financial stability and macroprudential policies.

Another relevant contribution is the analysis of the relationship between systemic risk and stability of the banking sector. We find that our entropy measures have some predictive ability for bank crisis events and thus can be used as an early warning system and complementary tool to the stress testing procedures. See also the recent discussion on the effectiveness of some stress testing tools (Borio et al., 2014; Kahlert and Wagner, 2015; Schuermann, 2014). Following Davis and Karim (2008), we use our entropy indicator in a logit model to build an early warning system for banking crisis. We contribute to the early warning literature for systemic risk (e.g., see Alessi and Detken, 2011; Squartini et al., 2013; Puliga et al.,

Please cite this article in press as: Billio, M., et al. An entropy-based early warning indicator for systemic risk. J. Int. Financ. Markets Inst. Money (2016), http://dx.doi.org/10.1016/j.intfin.2016.05.008