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Aggregating expert knowledge for the measurement of systemic risk ☆

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ABSTRACT

The policy objective of safeguarding financial stability has stimulated a wave of research on systemic risk analytics, yet it still faces challenges in measurability. This paper models systemic risk by tapping into expert knowledge of financial supervisors. We decompose systemic risk into a number of interconnected segments, for which the level of vulnerability is measured. The system is modeled in the form of a Fuzzy Cognitive Map (FCM), in which nodes represent vulnerability in segments and links their interconnectedness. A main problem tackled in this paper is the aggregation of values in different interrelated nodes of the map to obtain an estimate of systemic risk. To this end, Choquet integral-based aggregation is employed to expert evaluations of measures, as it allows for the integration of interrelations among factors in the aggregation process. The approach is illustrated through two applications in a European setting. First, we provide an estimation of systemic risk with a Pan-European set-up. Second, we estimate country-level risks, allowing for a more granular decomposition. This sets a starting point for the use of the rich, oftentimes tacit, knowledge in policy organizations.

1. Introduction

Measurement of systemic risk has become a pivotal topic among academics, policymakers and supervisors. The search for the one unrivaled systemic risk measure has mostly stimulated empirical research for a mechanistic analysis of system-wide risks. Exploiting the fact that macroprudential supervisory authorities possess a variety of specialized domain intelligence and experience, this paper takes a bottom-up approach to address the topic: *How do we tap into the expertise of individual supervisors to measure systemic risk?*

The current financial crisis has highlighted the importance of a macroprudential approach to ensuring financial stability [5]. In contrast to only being concerned with the stability of individual financial institutions (i.e., microprudential), the shift towards a system-wide perspective has imposed complexity in terms of analysis tasks and the underlying data (see Flood and Mendelowitz [18]). It accentuates the need for an understanding of not only individual financial components, be they economies, markets or institutions, but also interconnectedness among them and their system-wide risk contributions. Despite the rise of big data and analytics in previous years, macroprudential analysis as a support to policy remains highly dependent upon market intelligence and expert judgement and experience. An illustrative and intuitive example is the ever increasing shadow banking activities occurring behind the scenes, in which quantitative risk analysis and measurement are challenging tasks. Going beyond lack of data, one could in line with Lucas' critique and Goodhart's law also question the use of quantitative models in an ever changing environment, such as the impact of regulation on markets and the endogeneity of risk (e.g., Danielsson and Shin [11]).

Managing knowledge within an organization in an efficient way is an essential capability, not the least for knowledge-producing organizations like macroprudential supervisory bodies. Leveraging on groups of experts knowledgeable in specific topics, a key concern ought to be judging (*i*) which expert's knowledge is more relevant or reliable than the others, and (*ii*) how to combine the knowledge of different experts in a structured way to obtain a unique solution to a problem. One solution to these types of challenges comes from the family of aggregation operators. To this end, we need to answer the remaining question: *How do we aggregate expert opinions to measure systemic risk?*

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The quantification of expert knowledge in risk assessment is not uncommon [23]. In this paper, the objective is to provide a framework for measuring systemic risk by aggregating the knowledge of financial supervisors. In this paper, we present an approach that combines Fuzzy Cognitive Maps (FCMs) and aggregation based on Choquet integrals to handle the two abovementioned challenges. In this paper, the FCM [48], as a special type of a weighted graph, is utilized to capture and make use of expert evaluations regarding the interrelation between different sectors of a financial system. In this paper, we show how we can model the spread of risk in the system, represented as a FCM, by aggregating values in the nodes of the map. With our approach, we not only provide a measure of systemic risk but also identify the most central parts of a system, such as the most vulnerable components or countries. The main theoretical contribution of the article lies in combining FCMs and Choquet integral-based aggregation to represent and analyze complex systems of interrelated objects. Additionally, we propose approaches for assessing the system through quantitative network measures and visual network graphs.

We illustrate the proposed approach through various applications in a European setting, for which we also discuss practical implications and challenges. The main advantages of the proposed aggregation procedure over traditional aggregation operators are shown using different system structures. Additionally, we provide an estimation of systemic risk in a Pan-European set-up, where we model systemic risk at the European, country and sectoral levels. Finally, we also estimate country-level risk, allowing for a more granular decomposition, by modeling risk at the level of the country, its sectors and sub-dimensions of the sectors. The visualizations of the examples are available as a web-based application.[1]

The rest of the paper is structured as follows. Section 2 links systemic risk to expert knowledge of supervisors and policymakers, as well as introduces aggregation operators and FCMs. In Section 3, we describe the proposed methodology to aggregate values in a FCM, particularly for the measurement of systemic risk. Section 4 presents the applications, including the case of systemic risk in a group of European countries and in an individual country. Finally, we conclude and discuss future research in Section 5.

2. Systemic risk and aggregation operators

This section discusses the concept of systemic risk, and the use of aggregation operators for the task of its measurement. After providing an overview of systemic risk, we provide a brief overview of aggregation operators, as well as a mapping back into the task of systemic risk measurement. Finally, a literature review on Fuzzy Cognitive Maps (FCMs), with a special focus on applications in finance is provided.

2.1. Macroprudential supervision and systemic risk

The term systemic risk belongs to the group of concepts that are broad and vague, yet implicitly understood. Still, we need a working definition as a basis for measurement and analysis. To start with, financial instability is defined as an event that has adverse effects on a number of important financial institutions or markets [16]. Systemic risk, as also defined by the ECB, is the risk of widespread financial instability that impairs the functioning of the financial system to the extent that it has severe implications on economic growth and welfare.

The definition used herein is untangled with the help of the systemic risk cube. The notion of a risk cube was introduced by the ECB [17], and represents their conceptual framework, but has its origin in a number of works.[2] The three dimensions of the risk cube are the triggers, origins and impacts. The nature of *triggers* unleashing the crisis could take the form of an exogenous shock, which stems from the outside of the financial system (e.g., macro-economic shocks) or could emerge endogenously from within the financial system (e.g., banks). The *origins* of the events may be distinguished to limited idiosyncratic shocks and widespread systematic shocks. While the former initially affect only the health of a single financial market, financial intermediary or asset, the latter may in the extreme affect the entire financial system. Further, the *impact* of the events may cause problems for a range of financial intermediaries and markets in a sequential and simultaneous fashion.

Beyond three dimensions, we herein concretize the notion of systemic risk through the three forms presented by de Bandt et al. [13]. The first form of systemic risk focuses on the unraveling of *widespread imbalances*. Hence, the subsequent abrupt unraveling of the imbalances may be endogenously or exogenously caused by idiosyncratic or systematic shocks, and may have adverse effects on a wide range of financial intermediaries and markets in a simultaneous fashion. The second type of systemic risk refers to a widespread *exogenous aggregate shock* with negative systematic effects on one or many financial intermediaries and markets at the same time. These types of aggregate shocks have empirically been shown to co-occur with financial instabilities [14]. The third form of systemic risk is *contagion and spillover*, which usually refers to an idiosyncratic problem, be it endogenous or exogenous, that spreads in a sequential fashion in the cross-section. There is wide evidence of cross-sectional transmission of financial instability, such as the failure of one financial intermediary causing the failure of another, which initially seemed solvent, was not vulnerable to the same risks and was not subject to the same original shock as the former.

Macroprudential oversight requires a broad toolbox of models for systemic risk measurement. The categorization by ECB [17] elegantly maps the three forms of systemic risk to analytical tools: (*i*) early-warning models, (*ii*) macro stress-testing models, and (*iii*) contagion and spillover models. First, to identify vulnerabilities and imbalances in an economy, *early-warning models* derive probabilities of the future occurrence of systemic financial crises [35]. Second, *macro stress-testing models* provide means to assess the resilience of the financial system to a variety of aggregate shocks [26]. These exercises assess the consequences of assumed extreme, but plausible, shocks for different entities, for which a key question is to find the balance between plausibility and severity of the stress scenarios [43]. Third, *contagion and spillover models* can be employed to assess how resilient the financial system is to cross-sectional transmission of financial instability (e.g., IMF [28]). Hence, they attempt to answer the question: With what likelihood, and to what extent, could the failure of one or multiple financial intermediaries cause the failure of other intermediaries?

The three types of systemic risk provide a starting point for an all-encompassing framework of systemic risk. For each market segment and economy, and at each point in time, the following characteristics should be measured: (*i*) specific imbalances building-up in the cross-section and their current state, the likelihood of these imbalances to unravel, and their potential severity; (*ii*) transmission channels of aggregate shocks, an overview of plausible shocks, impacts on other market segments, and potential severity of and resilience to shocks in case of materialization; and (*iii*) sources of contagion or spillover at the individual and system-level, as well as potential severity of and resilience to cross-sectional transmission. Accordingly, these two

[1] The complimentary web-based applications are available here: http://vis.risklab.fi/#/fuzzyAgg.

[2] For further information, see de Bandt and Hartmann [12], de Bandt et al. [13], and ECB [17].