Systemic and Extreme Risks: Ways Forward for a Joint Framework

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ABSTRACT: Systemic risk is getting increasing attention in the science as well as popular press not to the least due to the growing complexity of the world as well as increasing data availability. The aim of this paper is to discuss selected topics in extreme and systemic risk modelling, measuring and management approaches. We find that from a purely quantitative modelling perspective, single and systemic risk assessment can be jointly performed via the concept of copulas and therefore can be embedded within an integrated framework without major difficulties. Consequently, we see single and systemic risks as not independent but indivisible which have to be assessed jointly. However, from a risk measure perspective we see some important differences as single risk measures focus on probability distributions while systemic risk measures focus on dependency measures. Hence, we call for ensembles of risk measures which should be a superior approach for studying single and systemic risks in complex networks as different events can cause systemic risk to realize (e.g. too big to fail, too interconnected to fail, keystone species etc.). From a risk management perspective, we conclude that the inclusion of human agents causes a fundamental difference in the management of systemic risks compared to other systems as their decisions are contingent and may cause unpredictable shifts due to mutual uncertainties that can evolve. Consequently, we argue for an iterative risk management approach similar to the call from climate change and adaptation science, for example discussed in the various IPCC reports. Last but not least, the idea of collective responsibility echoes the need to target risks that threaten whole societies. That such risks are reduced is foremost in the public interest and we therefore call for an institutional change that enables the effective handling of it in the future.

Keywords**:** Single risk, systemic risk, modelling, measurement, management, copulas

1. INTRODUCTION

We start our discussion via the simple observation that a system usually contains some elements which are interconnected. Furthermore, these elements can be "at risk". One standard definition of risk is effect of uncertainty on objectives, most often quantified as the probability of the event happening, times its impact. Contrary to single or individual risk definitions, "systemic risk" emphasis the connections between risks ("sometimes also called networked risks") (Helbing, 2013). While the realization of single risk may lead to a disaster in part of the system, the realization of systemic risk, by definition, leads to a breakdown or at least major dysfunction of the whole system. Research on systemic risk is not new but particularly the financial crisis of 2007/2008 increased the interest in and funding for systemic risk (focusing mostly on the financial sector) to unprecedented levels. In other disciplines such as ecology there was already some time ago a paradigm shift from single actor/risk to dynamic network analysis including the investigation of systemic risks (for a review see for example Scheffer and Carpenter 2003). Interestingly, the bulk of research especially from a systemic risk perspective does not include humans at all (Page, 2015). The attention in systemic risks and ways of reduction is increasing also in applied and social science related disciplines, for example within the Loss and Damage debate, the SDGs related discussion as well as the Sendai Framework for Risk Reduction. However, currently there are no conceptual overviews of similarities/differences of systemic risks within physical-, ecological-, financial-systems as well as society (and its sub-system) as a whole and how they differ. Consequently, there are open questions if there are fundamental differences between such systems and therefore also in the methodologies which should be applied to model, measure as well as predict and manage (including repairing to restore a the system as well as reducing the risk) their systemic risks. The main goal of this paper is to shed some light on these issues and provide new avenues for a joint framework for future research and collaboration. We structure the paper around two important aspects. One is quantitative in nature and asks how individual and systemic risk are modelled, measured as well as managed in respective fields. The second aspect relates to the human dimension and its importance in regards to social aspects, possible biases, as well as its contingency relevant for systemic risk. Based on these aspects we suggest potential synergies and relevant differences, using the concept of copulas, iterative risk management approaches and the suggestion to connect future research on this topic in a similar way as within the climate change community, e.g. IPCC process. The ideas here are taken from a upcoming paper by Hochrainer-Stigler et al., (2017).

2. MEASURING, MODELLING AND MANAGEMENT OF SYSTEMIC AND EXTREME RISKS

Due to space limitations we only present the joint modelling framework idea and the main messages and refer for more details to upcoming publications of the author. We see analogies between the importance of the probability distribution for single risk and the importance of connectedness for systemic risk. In more detail, for single risk the different risk measures can be related to the different risk layers of the probability distribution, e.g. mean and median are used to represent frequent risks, tail measures like VaR or CVaR are used for describing extreme outcomes. In the case of systemic risk the different risk measures are related to the network interdependencies and consequences due to internal events, e.g. SES for measuring the contribution of a node to a systemic crisis or DebtRank for measuring the centrality of a node within a network. As in the case for single risk some of them have the potential to act as warning indicators too. For single risks the Conditional Value at Risk stands out exceptional also due to its nice properties including being a coherent risk measure (Pflug and Roemisch, 2007) for systemic risk DebtRank may be a promising warning measure (Poledna and Thurner, 2015).

Recognizing that the failure of single nodes may cause systemic risk to realize it seems worthwhile to think about ways how to combine single risk measures with measures of systemic risks as both are intrinsically connected. Given that the probability distribution is the focal point for single risk measures and interconnectedness the focal point for systemic risk measures a possible connection between the two could be established via the use of copulas. Figure 1 is conceptually showing this idea using 2 single nodes, their single risks in terms of loss distribution and the copula model for the two nodes.

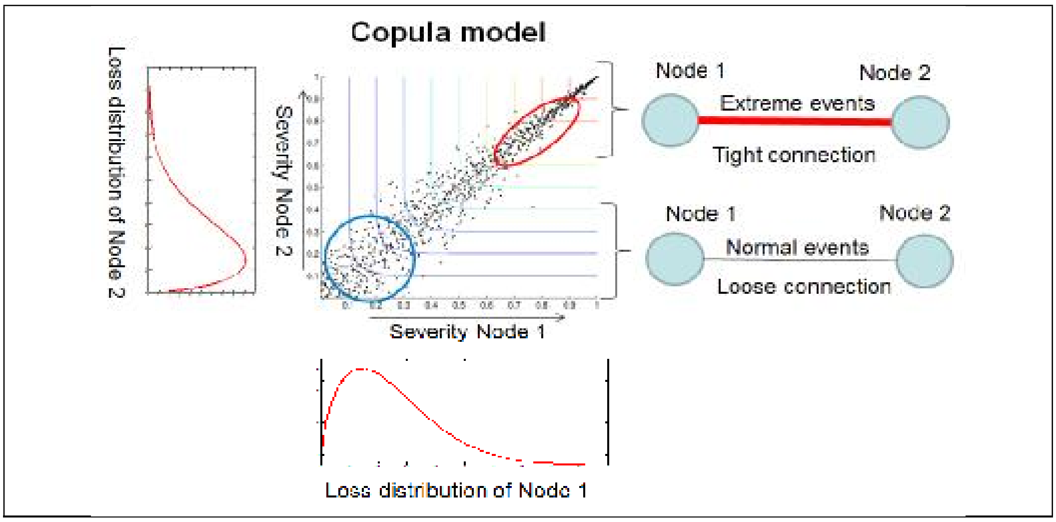

Fig. 1: Conceptual example how to link single risk with systemic risks incorporating increase in the tightness of connection between nodes using a copula model

As indicated, during normal times (blue area, this corresponds to the frequent events for node 1 and 2) the copula indicates a loose connection between them (lower figure on the right hand side) while for increasing severe or extreme events (red area, this corresponds to the tails of the 2 nodes and corresponds to extreme events) the copula model enforces a tighter connection between the two nodes. Consequently, systemic risk may be quite different during these distinct situations, e.g. DebtRank may show different centrality values for the two distinct situations due to the changes in the network structure.

In more detail, copulas are useful for modelling dependencies between continuous random variables. Using a copula model allows to separate the selection of the marginal distributions (e.g. the risk in form of a loss distributions) from the selection of the copula (e.g. the dependency between risks). In other words, while the marginal distributions contain the information of the separate risks, the copula contains the information about the structure of the dependency. For example, the two-dimensional distribution (e.g. a network of two nodes) could be represented with the marginal distributions (e.g. single risks) via the copula C as:

$$F(x,y)=C(F(x),F(y))$$

Hence, a copula approach as a measure of systemic risk seems promising too. However, while acknowledging some possible linkages it should be also stressed that for systemic risk analysis the dependency measures within the network are of foremost importance and sometimes require different modelling approaches (also due to data limitations) making it impossible to perform an additional investigation on the individual level.

3. HUMAN AGENCY

There seems to be a discrepancy between the increasing understanding of systemic risk from a natural science perspective and the actual implementation challenges to model, warn, repair or manage systemic risks in the real world. In fact, most of the systemic risk research done today does not include humans at all (Page 2015). This is alarming as failure of social (e.g. financial, infrastructure, trade, ecological) systems can have dramatic, possible long lasting impacts and consequently the management of systemic risk should be foremost also in the public interest (Centeno et al., 2015). This section therefore focuses on the human agency dimension related to systemic risk. Again, due to page limitation we focus only on social processes causing increases of old and creation of new systemic risk which leads to the notion of contingency as an important cornerstone about the question how to manage systemic risk in the real world.

Generally speaking, modernity reflexively relies on increasing complexity to manage the very risks it creates which in turn causes disasters that are often embedded in the very construction of social organizations and institutions. In other words, the benefits and efficiencies which resulted from specialization of labor, economies of scale, collective knowledge, and information sharing exposes us now to disastrous outcomes which are derived from the characteristics of the relationships themselves. Theoretically, Beck with his idea of a reflexive risk society, Parsons with his idea of negative feedback loops to maintain order and building on him Luhmann with his focus on systems theory and complexity reduction, as well as Giddens with his positive emphasis on modernization and future, provided major contributions from a social science perspective. In his review of the emergence of global systemic risk Centeno et al. (2015) arrange theories of risk within the social sciences along a continuum from realist to constructivist. For the former a fundamental assumption is the possibility to probabilistically assess the likelihood and impact of any specified risk given its inherent characteristics. For the later the existence and nature of risk derives from its political, historical and social context, i.e. it is constructed. Therefore, risks do not exist independently from society, but are created socially in response to the need to regulate populations, interactions and processes. While the methodological approaches between the two are very different both viewpoints call for a continuous monitoring and management of current and identification of emerging systemic risks. The concept of iterative systemic risk management may provide a practical approach to deal with current and emerging systemic risks in such a dynamic setting. This can be achieved using the notion of contingency as discussed next.

Surprisingly little can be found about the distinct feature of social processes and human decisions in regards to systemic risk. One exception is Ermakoff (2015) which presents a new perspective on the structure of contingency which he illustrates via the political and social rupture in August 4, 1789, in Versailles. Ermakoff, (2015) claims that the moments of collective indecision which is generated by mutual uncertainty are the moment in which rules, procedures, scripts, and norms get suspended. Consequently these are the moments of contingency and high systemic risk. The focus on contingency moments therefore pins down the sudden susceptibility of collective behaviour to individual agency factors. In fact, many questions related to transition and systemic risks of social processes could be related to contingency in this sense (Cohen 2015). Contingency based on references to agency emphasizes a type of variability especially relevant in our context, namely the role of free will as a fundamental postulate (in the sense of being always possible) and therefore the essential indetermination of human agency. It should be noted that there could be also a negative reading of the agency factor which focus on the frailty of human judgments (e.g. hindsight bias). Such subjective contingencies that bulk large in every rapidly changing situation 'are' contingencies due to ignorance and error. These effects are mostly underrepresented in current systemic risk analysis and formal network dynamics are less able to capture such effects. Contrary to network systems focusing on rational agents or formal models, for decision making processes and on the policy level contingencies as discussed above (and mainly in the case of systemic risk) come from mutual uncertainties of social groups and are unpredictable, e.g. comes with a surprise.

As indicated, the possibility of moments of collective indecision which may be generated by mutual uncertainty (e.g. such as financial crises) are the moments of contingency and high systemic risks. During such times the usual rules, procedures, scripts, and norms can get suspended and new ones can suddenly appear causing causal breaks not being able to be incorporated within formal modelling frameworks. This calls for a management approach quite different to usual risk management strategies. The situation maybe compared to the discussion about possible climate change effects now and in the future and its consequences as well as possibilities to cope with them (Linnerooth-Bayer et al., 2015). Due to these deep uncertainties, the IPCC suggests an iterative risk management approach for tackling such kind of risks as

> […] an iterative process of monitoring, research, evaluation, learning, and innovation can reduce disaster risk and promote adaptive management in the context of climate extremes (high agreement, robust evidence) […] Adaptation efforts benefit from iterative risk management strategies because of the complexity, uncertainties, and long time frame associated with climate change (high confidence) […] Addressing knowledge gaps through enhanced observation and research can reduce uncertainty and help in designing effective adaptation and risk management strategies (IPCC 2012, p. 17)

Hence in an ideal case, systemic risk assessment and management is performed in an iterative fashion that allows for continuous learning and course correction as new information becomes available. This should not only include the (important) possibility of (re-) framing the problem and approaches, or creating increased awareness of risk drivers, or enable a continuous learning of analysts and stakeholders but also the chance to introduce new innovative concepts, and finally the possibility for transformation. The introduction of possible ways to change the network topology of financial markets via taxes is a concrete example of how this could be actually achieved (Poledna and Thurner, 2015). However, other systemic risks not being able to be captured in formal models should be not forgotten. From an iterative risk assessment perspective both the systems perspective as well as the single risk dimension needs to be monitored and assessed. A necessary condition also indicated by Helbing (2013) is the introduction of collective responsibility and corresponding decision makers which focus on systemic risk modeling, measuring and managing from the systems perspective. There, depending on the risk bearer within the system, different time horizons may be appropriate for conducting (systemic) risk assessments. Summarizing, to tackle the implementation challenge and the various issues addressed above a global commitment must be made which we suggest could be framed around the processes developed for combating climate change effects which finally ended in the establishment of the intergovernmental panel for climate change. Furthermore, an iterative systemic risk management approach may be the best way forward to address the complex issues of dealing with current and avoiding the creation of new systemic risks around the globe.

4. CONCLUSION

Systemic risk is getting increasing attention in the scientific world as well as popular press not to the least due to the growing complexity of the world as well as increasing data availability (Page, 2015). While its origins are in mathematics (such as catastrophe theory) the concept found relatively early entry into the ecological realm and after the Asia crisis in the late 90s and especially after the financial crisis in 2007/2008 into the financial and risk disciplines. The human dimension aspect was up to now and with a few exceptions largely neglected. Furthermore, single risk assessment and particularly the possible disastrous outcomes which may be linked to systemic risks were also not looked at in detail.

The aim of this paper was to shed more light on selected topics of systemic risk modelling, measuring and management. We were especially interested in possible differences and reasons for it and how much they matter. We made various observations including that from a purely quantitative modelling perspective single and systemic risk assessment can be jointly performed via the concept of copulas and therefore can be embedded within an integrated framework without major difficulties. Consequently, one can treat single and systemic risks jointly. However, from a risk measure perspective we see important differences as single risk measures focus on probability distributions while systemic risk measures focus on dependency measures. Hence, we call for ensembles of risk measures which should be a superior approach for studying single and systemic risks in complex networks as different events can cause systemic risk to realize.

From a risk management perspective, we conclude that the inclusion of human agents causes a significant difference in the management of systemic risks compared to other systems as their decisions are contingent and may cause unpredictable shifts due to mutual uncertainties that can evolve. Consequently, we argue for an iterative risk management approach similar to the call from climate change and adaptation science, for example discussed in the various IPCC reports (Mochizuki et al., 2015, Schinko et al., 2016). Last but not least, the idea of collective responsibility echoes the need to target risks that threaten whole societies. That such risks are reduced is foremost in the public interest and we therefore call for an institutional change that enables the effective handling of it for the future similar to the process which leads finally to the intergovernmental panel for climate change.

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