On the resilience and the risk spillovers in innovation clusters

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Abstract: In this paper, we provide the determination of systemic risk in a networked structure that appears together with synergistic effect as a result of collaboration in innovation clusters. The interpretation of proposed conceptual model of evaluation of systemic risk can be at least twofold: core-periphery, business entities-R&D institutions, etc. The systemic risk is treated as a generalised risk impacting directly or non-directly the performance of an innovation cluster. The conceptual model of evaluation of systemic risk should be useful for understanding and further treatment of measuring risk in a case of innovation management. Also, the structure and further properties of systemic risk and contagion within innovation cluster are discussed in this paper.

Keywords: contagion; structure of innovation cluster; systemic risk; uncertainty; asymmetry; business; model of evaluation; commercialisation.

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1 Introduction

Researchers treating business cluster generating innovations as a networked structure consisting of various entities, however, appoint relatively little significance to their nature. Usually, they dedicate a greater significance to the management structure and the type of hierarchy in the value chain. Some researchers state that a company’s linkage has an impact to its rate of innovativeness due to the advantages of networking since networks as communication allow and promote knowledge sharing and flows between interconnected business entities (see, e.g., Ahuja, 2000; D'Alise et al., 2014). In addition, communication and collaboration between innovation entities ensure the faster innovation process due to their greater social capital (D'Alise et al., 2014). However, networking means not only mutual cooperation in innovation, but also the value creation process and the sequence of the value chain in this case. Despite the fact, that the transfer of technologies and knowledge from research to business is quite complicated (see Lal et al., 2013; Zuniga and Corea, 2013), the capitalisation and transfer of knowledge and technology are defined by various relations between education and science, government and business entities. In any knowledge transfer, an author selling these technologies has more information about the value of asset offered than the potential investors, i.e., partners in innovation cluster. On the other hand, the transferring information (by the supplier) and processing information (by the investor) demands a lot of resources and are, as a result, one of the sources of risk together with information asymmetry.

On the other hand, networking of innovation cluster means strong dependence on external partners providing knowledge transferring the technology and, as a result, is a relevant channel of contagion through which problems from one business entity belonging to a cluster can spread to other related entities. The channels of contagion within networked structure create and maintain systemic risk, meaning the danger that an initial shock can be amplified and spread when innovation cluster entities react and further transfer it to other entities within the cluster, so that the total effect proliferates largely from the initial default or another unfavourable shock. These contagion phenomena rely on complex network effects since collaborating entities of innovation cluster are interlinked by their diverse claims with business partners within the cluster and with external entities. As a result, various distresses can propagate to neighbouring entities in a way depending on the local features of the network and respective network nodes (Minca and Amini, 2012).

As a network-based structure that seeks to commercialise innovation, the cluster faces additional uncertainty in comparison to traditional businesses. A key element of the resilience of the innovation cluster is its ability to absorb internal and external shocks without creating disruption to external investors. Unlike as in traditional business, the case of innovation commercialisation is much more complicated in terms of uncertainty and risks. Therefore, the necessity to quantify the innovative business risks and elaborate the modelling approaches of the overall impact of various type risks generalised by systemic risk arises. In addition, business risk management (especially in order to avoid technological risks and intense competition) requires optimal co-operation under increased uncertainty between entities of different nature. Also, it is important to create and maintain such structure of innovation clusters that can ensure the efficient resource sharing and resilience to various external and internal shocks considering information asymmetry and heterogeneity of business entities in the cluster.

The scientific literature about innovation clusters as networking-based structures does not provide a lot of insight into their structure's optimisation of performance and systemic risk, and in the context of successful commercialisation, basically limited to just a variety of arguments about the nature of collaboration and the geographic becoming increasingly important cognitive distance. There is also no evidence of the impact of the organisational framework of the innovation cluster on its performance (efficiency) and sustainability. Such information is crucial for external partners, especially venture capitalists and other external financiers, who also need to achieve the desired social and economic goals without having to seek attractive returns.

The risk structure of an innovation cluster is complex and somewhat different from the risk of a classic investment portfolio: one part depends on the nature of the innovation and the specific uncertainty associated with it, the other on the structure and level of organisation of the innovation cluster. Partially due to the mathematical difficulties in describing the behaviour of correlated defaults, this risk analysis is not given enough attention in scientific literature, although it is a practical problem. Therefore, the aim is that the structure of the cluster that carries out innovative activities should be defined and analysed in as much detail as possible.

The goal of this paper is to provide a model of evaluation of systemic risk in innovation cluster considering its structure and the relevance of each of its entities to the overall innovative activity. The aim is to answer the question about the impact of the activities of an individual member on the overall systemic risk of an innovation cluster, considering the extent of networking. In addition, objectives of research are related with the determination of systemic risk in the context of asymmetric information and higher uncertainty due to the creation of innovation and its commercialisation. Also, it is necessary to analyse the resilience mechanisms and examine, what structure of the innovation cluster should be optimal considering the systemic risk and asymmetric information.

The paper is structured as follows: Section 2 is dedicated to the analysis of networking in innovation cluster and its relation to business risk. Section 3 spillover effect and the origins of systemic risk of innovation cluster is investigated, in Section 4, the model of systemic risk evaluation considering the structure of innovation cluster is presented. In Section 5, the analysis of systemic risk and its features considering the structure of innovation cluster and the positions of entities in networked structure are examined while the conclusions are presented in the last section.

2 Interaction, network structure, and risk

Cluster entities acting independently usually have a limited ability to fit their business models and therefore their performance is impacted by industry factors (Wixted, 2008). Usually, managers of business entities understand that companies can not survive in a vacuum. Therefore, they maintain sharing of their knowledge to other entities, so that in turn they may profit from the others' competencies and develop in such a way their social capital and level of competitiveness. As a result, in the cases when cluster entities seek for information about specific technical problems usually representing the weakness of their activities and for which they have no own solution, they naturally try to select those partners, which are the most likely to provide some suitable solutions of their problems (von Hippel, 1987; Schrader, 1991). On the other hand, expertise from a limited field of knowledge only is often insufficient to develop an innovative product in technology-intensive sectors (for example, the failure of Malaysia Science Park (for more details, see Baily and Montalbano, 2017)). Therefore, innovation cluster is interested to promote fast and direct knowledge sharing through the exchange of competencies. As a result, the cognitive distance between innovation cluster entities appears as an important factor impacting the optimality of cluster performance. In order to achieve an effective result, it is necessary to cooperate within the cluster, to know what tasks are being pursued and to achieve gradually those tasks. Cluster entities should seek an optimal level of cognitive distance which is closely related to information asymmetry which can also affect the commercialisation of innovation, i.e., achieving the main goal of activity of innovation cluster. Several cases have been analysed proving that mutual trust between business partners, together with the elimination of the substantial part of information asymmetry helps to reduce transaction costs (Bol and Lill, 2015). Following Nooteboom (2005), one of the crucial tasks of innovation cluster entities is to reduce sufficiently the cognitive distance, including moral categories, to implement successfully innovation. The cognitive distance between business entities can be decreased to the level that they have engaged in continued interaction and, as a result, this reduces the novelty value of a partner's cognition, with a diminution of innovation performance (Nooteboom, 2005). In a special case, it can be argued that the technology transfer process is the most complicated aspect of collaboration since it is strongly related to the uncertainty that has an impact on both sides of agreement and which is closely related with risk of inadequate evaluation and competitiveness in the future.

Companies belonging to innovation cluster compete for innovation resources and they also promote each other, helping each other adapt to the pressure of competition. In addition, in usual cases by cooperating with big corporates, small or weak entities can improve their innovation ability (especially by setting new tasks), technology, and management level. However, this kind of cooperation does not drive the development of big corporates on a large scale. Finally, under the pattern of proto cooperation, the business entities in the cluster form a tight and mutually beneficial cooperation alliance (Wang and Liu, 2016). In fact, each element of the structure is relevant for competition of the cluster. First, core companies hold know-how and are leaders in developing business ideas. Other cluster entities can be less known. Competitiveness of relevant entities of cluster strongly depends on the activity of other partners in the cluster, i.e., typically suppliers who deliver raw materials, products, provide additional services, etc. and know-how holders that provide relevant technological solutions and define the potential of future demand. As a result, the quality of the supplier has a strong impact on the well-being of the whole cluster (Babkin et al., 2013). On the other hand, in most cases, rational companies are reluctant to share their knowledge since they seek to protect their commercial secrets. Some researchers emphasise that the output and success of industrial cluster activities depend on the structure of both its local and trans-local linkages (Lorenzen and Mudambi, 2013; Turkina et al., 2016). However, following Treado and Giarratani (2008), cluster entities can improve companies' ability to transfer their capabilities therein together with access to new markets. Knowledge as one of the most relevant assets generated due networking and output of collaboration is largely codified and mature, often it develops along the process innovation, and it is transferred essentially by the direct personal communication, social and political lobbying, backward and forward linkages (Iammarino and McCann, 2013). Core and supporting companies, social and hard infrastructure as the most relevant clique is a subset of innovation cluster that interacts within groups of entities through complementary relations and closely linked value chain activities. Proper interaction and transfer of technologies and the management of the potential problems associated with the divergence of views define the evolution of activity in the next stages. Therefore, it has a substantial impact on the performance of the cluster in the following stages of activity.

Networks of innovative business entities are not necessarily characterised by geographical proximity (Lazzeretti and Capone, 2016; Greenhalgh, 2013). Despite the fact that endowment of natural resources or the geographic location close to trading routes showed their relevance in cluster performance, understanding that the diversity of activities and competencies in the same location would increase the individual innovativeness of the companies located within the cluster is challenged by some authors (Hamdouch, 2007). In addition, Baptista and Swann (1998) showed that if business entities are more likely to innovate if the labour resources are available, the robust relationship between the activity diversification of cluster and the total innovative propensity of the companies does not exist. Following Simmie (2004) and von Tunzelmann (2003), there is a huge difference in the systems of innovation governance between new and old social networks. In addition, the relative character of new knowledge is generated by the cooperation between commercial entities and other institutions: the openness and therefore the rise of new insights, rules, and standards, etc. are closely related to the importance of external sources of knowledge, and all this happens under the pressure of global competition. In the case of the old social network type, the overall coordination of the innovative activities within innovation cluster is based on the cooperation and competition, and there is not necessarily any hierarchical structure. Due to technological advances, the dissemination of knowledge is ever less impacted by the geographical location, but the legal system and the state-implemented innovation policy and support options are strongly dependent on the geographical location. These factors complicate the quantifying of the efficiency and optimality of the innovation cluster's activity. In addition, access to support can distort rational economic behaviour of business entities. These factors are specific, of a qualitative nature and necessitate expert evaluation, but their relevance is deciding if it is worth investing in the long run in cluster activities and in the development of innovation cannot in all cases be reasonably determined, therefore, it is advisable the application of quantitative methods.

According to Everett (2011), the sequence of individual stages of the process generating added value is therefore increasingly shifting into an extensive vertical and horizontal networking among various business entities, other institutions and individuals collaborating in the whole chain of generating added value. This promotes competitors to develop and maintain interconnections in areas of common interest and to create and maintain networking in a niche of the process to generate new added value, i.e., to establish a clique in innovation cluster (Gibbert and Durand, 2007). However, following Giuliani (2015), empirical analysis shows that the structure of the knowledge sharing in the cluster as a networked structure is closely related with the heterogeneous distribution of knowledge bases and interactions (that can reflect the clique-based structure) and, in addition, knowledge flows are not co-occurring frequently. Typically, in such cases, one needs access to entities that can provide complementary knowledge, but one does not know what namely elements of knowledge will be crucial when a dominant design will develop. In addition, it is not known what cluster entities and their competitors will survive if the implementation of innovations will be failed. As a result, the network of collaborations for exploration and for exploitation must be dense.

The willingness of institutions with some future expectations to be open and exchange ideas makes an innovation cluster special case of collaboration. In such way innovation cluster entities in some cases tackle similar goals to solve some problems of clients, similar tasks and similar implementation processes, making them more minded to share their social capital together with potential customers. On the other hand, connectivity among cluster entities only does not take place for improving competitiveness for optimisation of business processes and generating additional value.

In some cases, the need to include the final customer in the process of generating more added value appears. Open and trust-based collaboration in the cluster would provide more opportunities for product suppliers to know their customer than a regular supplier-client connection. Direct analysis of needs and the search for technological opportunities through co-operation with suppliers and customers create favourable conditions for new opportunities to emerge and therefore there is also a significant cluster's intrinsic potential to shape the demand for its innovative production itself.

Networking of collaboration is characterised in terms of complementarity and graph nodes: the crucial notion is embedding that can be institutional, structural and relational and that are described in the literature (Nooteboom, 2005). Institutional embedding should regard to external conditions: regulation and norms of conduct, financial support, tax, and legal system, infrastructure, education, R&D activities, state of the labour market, etc. Structural embedding can be characterised by some quantitative indicators. For example, structural properties of networks are volume, density, variously defined centrality or systemic relevance, and stability of structure considering the process of implementing innovations and related systemic risk. Also, it is necessary that the structure of the networkensuresflexibility in the case of uncertainty. Relational embedding is treated as the strength and stability of connections. Considering embedding, an adequate understanding of innovation cluster efficiency demands an understanding of social networks and networking of institutions, and problems of technology transfer from R&D sector to business entities.

Another implication concerns the duration of partnerships. Highly stable collaboration between innovation cluster entities may be favourable for mutual trust and efficiency of exploitation, but it is not favourable for exploration. The failure of The Nordic Climate Cluster due to the lack of stability is an example demonstrating how it is important (for more details, see Sarasini, 2015). It is necessary to maintain variety in order of exploration and, as a result, the generation of new ideas and the opportunities to co-operate. Some researchers state that the more lasting the established relationship is the more stable the networking should be, what is beneficial for the establishment of mutual trust relations between cluster entities and a shared code of conduct and strengthen the exchange of knowledge and other information between entities (Ahuja, 2000; Salman and Saives, 2005). On the other hand, following a lot of other studies, the relationship of business entities in innovation cluster should not be too long due to the risk of being locked by this relationship and ossification that leads to the lack of new knowledge and ideas and, as a result, to recession of the cluster (Tolstoy and Agndal, 2010). Also, it means that lasting network relationship is not so suitable for the requirement of flexible specialisation. They propose a path hypothesis on how link property influences the impact of cluster entities' restructuring resilience on cluster resource collaboration and integration. The claim of a negative effect of the duration of a relationship is characterised by the condition that the companies involved have no contacts outside the relation, pertaining to the subject of collaboration. On the other hand, when both collaborating cluster entities have relations outside cluster with non-overlapping networks, they have an opportunity to refresh their competences with novel insights that keep their relation within the cluster with more potential vibrant (Nooteboom, 2005).

Flat and efficient structures are crucial for successful performance in international markets where quick feedback and organisational innovations are substantial (Gumilar et al., 2011). Therefore, one can expect that cognitive distance is more appropriate in cliques and as a result in the whole innovation cluster as it helps to reduce operational risk and costs. In decentralisednetworks, in most cases, the scope of cooperation extends only to a narrow, 'noncore' segment of company functions, and the partners are more or less equal in their cooperation.

Lerch et al. (2008) showed that companies simultaneously exploring and exploiting regional networks of different relational dimensions are more efficient in transferring knowledge in innovation activities and are likely to be more innovative than other firms within the cluster that keep an only single connection to different partners. In segmented clusters, cliques are formed within the network, within which the linkages among the cliques are weak, occasional or completely non-existent (Futó, 2014). Following Futó (2014), segmentation in the innovation cluster may develop, if certain cliques evolve particular culture or if some more relevant entities of the cluster develop linkages with only a subset of entities. In such cases, cooperation is satisfactory within several cliques, but weak or non-existent between these groups of companies. As a rule, segmentation within a cluster may evolve:

- if the cluster involves well identifiable subgroups of companies with characteristically different industrial cultures
- if the cluster is organised around some strong companies which are more interested to cooperate with their traditional subcontractors, which are entities of the cluster as well, than with other cluster entities.

3 Origins of systemic risk and spillovers in innovation cluster

According to research literature, systemic risk is characterised by a 'domino effect' (or cascade) that can be triggered by initial shock (which may be due to various attributes and, in the case of an innovation cluster, partly due to unknown factors) and strong interdependence. There are interconnected network-based phenomena that contribute to the overall vulnerability of an innovation cluster:

- Structure of assets of cluster entities. In many cases, the assets of innovative companies are not liquid, and in many cases, they are also high-risk. In many cases, the members of the cluster have significant financial liabilities, which in some cases have to be met in a very short period. In addition, usually only a small fraction of the assets is liquid (not fully integrated into the value creation process). Such a share could lead to a cluster firm becoming illiquid or even collapsing if it were to fulfil its liabilities exceptionally quickly and it would not take time to turn illiquid assets into financial capital.
- Relationships between cluster entities through financial transactions, knowledge exchange, and technology transfer, purchase-sale transactions, etc. If a liquidity shock hits one cluster entity, investors may run on other companies as well, even if they are perfectly solvent, if they fear of lacking reserves of liquid assets in the cluster. In this case contagion arises from unforeseen liquidity shocks, i.e., investors withdrawing their capital at other cluster entities.
- Individual failure of business plan (commercialisation of idea) and default of any business entity belonging to innovation cluster.

One of the examples of failure innovation cluster is the disappearance of a Norwegian boat-building cluster (for more details, see Isaksen, 2018). Information on innovation technology and related trade secrets and related know-how may also be a source of systemic risk. One aims to create a fundamental and economically and technologically sound potential for the successful commercialisation of the idea in the future using this type information. In addition, the goals and business routines of the entities of innovation cluster are mostly based on expectations of future revenue streams. However, when uncertainty or doubts about the reliability of existing assets, the idea being commercialised, or the new knowledge and technologies created and applied increases, the expectations of cluster members, even with their perception that innovation and commercialisation are inherently risky activities, other investment decisions or seeking to withdraw invested capital as soon as possible.

Table 1 The contagion path in innovation clusters

Channel	*Contagion path in innovation cluster*	*Type*
1	Business entity – business entity	Direct. Typically, spillovers result from the usual interdependence among cluster entities. This interdependence means that shocks, whether of a global or a local nature, can be transmitted within innovation cluster due to their real and financial linkages.
2	Business entity – cluster management – business entity	Non-direct mainly due to asymmetric information, uncertainty and imperfect decisions.
3	Business entity – external partner (non-financial) – business entity	Non-direct due to common creditor or information and expectations about possible unfavourable developments in the future.
4	Business entity – external creditor – business entity	Non-Direct. Financial (liquidity) shortage is not linked to changes in macroeconomic or other fundamentals but is solely the result of the behaviour of investors or other financial agents. Under this definition, contagion arises when a co-movement occurs, even when there are no external or even global shocks and interdependence and fundamentals are not factor.

Besides the well-known risk of traditional business cyclicality, there are specific sources of risk in the case of an innovation cluster. in particular, technological risk due to innovative activity implemented by other market players and information asymmetry in technology transfer transactions. Contagion in innovation cluster can typically be divided into direct and indirect contagion (see Table 1). Direct contagion arises because usually business entities are financially exposed to one another, both through the banking (or payment) system and other type of financial deals such as outright loans, repurchase agreements, etc. Indirect contagion can arise mainly through two channels. Firstly, markets may assume that direct contagion effects exist, even where this is not the case. Secondly, if one business entity has financial problems, one may expect that other cluster entities will be hit by the same problem, which in turn can lead to the other business partners suffering a run by investors. Conation in an innovation cluster can also stem from information. A cluster member with liquidity problems may cause investors in other cluster entities with similar assets structure to suspect their potential future difficulties. In such cases, the following vulnerabilities shall be considered as key vulnerability criteria for each member of a cluster:

- number of connections in the cluster
- volume of liabilities and asset claims
- distance to remaining members of the cluster
- the relevance (centrality) of counterparties within cluster
- location (in(out)-closeness) in the cluster structure (network).

Thus, an epidemic in an innovation cluster due to interactions may have two effects: the problems of the partner-debtor may lead to the loss of the other partner-creditor (credit effect). This contagion may also threaten the liquidity of the potential partner debtor. Thus, at a critical period, one partner may increase the credit and liquidity risk of other cluster partners. Both effects can occur through the impact of each member of the cluster in direct and, in most cases, indirect ways.

Centralised (it is a special case of non-homogeneous structure) cluster structure is distributed according to exponential law, i.e., there are several entities of the core of cluster with relatively many positions in other entities of the cluster and that there are many relatively small business entities of the cluster with few positions in other partners within cluster core. This property of asymmetry of the inhomogeneous cluster structure is favourable for securing and maintaining the stability of the cluster activity in case of unexpected breakdown of the individual cluster entities. On the other hand, centralised cluster structure increases dependence on the core of cluster, which in turn increases the risk of a cluster existence if the kernel companies are in crisis.

Macroeconomic cycles, which ultimately affect the financial position of businesses, may be at the root of the systemic risk. In such cases, the investment decisions of cluster entities transforming liquid but low-yield assets into assets with limited liquidity but higher rates of return, i.e., commercialised innovation, play a particularly important role. In the context of systemic risk of innovation cluster, it is meaningful to use the formula proposed by Shepard (1995) as a generalisation of autoregressive Poisson processes by incorporating latent data into a logarithmic scale whose modelling results in an analytical formula describing the dependence of failures of related business entities (in special case – banks) on macroeconomic factors and earlier enterprise failures in previous periods:

$$z(y_t) = \beta u_t' + \sum_{r=1}^{p} \gamma_r z(y_{t-r}) + \varepsilon_t,$$

whereε_t is the model noise, y_t the quantity of failed business entities during the period t, u_t – the vector of macro variables, $z(y_t) = \ln \lambda_t + (y_t - \lambda_t / \lambda_t)$, λ_t – the Poisson process parameter. Parameters β and γ_r, $r = 1, 2, \ldots, p$, can be treated as the elasticity coefficients of the macroeconomic factors and the previous rth firms' failure rates, respectively.

4 Model of evaluation of systemic risk in non-homogenous cluster

Treating the innovation cluster as a network in which nodes are business companies and other business entities and edges represent the commercial relations identified above, the core question regards the impact of the network features on the extent of magnitude of contagion: is the local properties of the nodes (i.e., balance sheets) such that the initial distress of one or several entities could propagate to a large fraction of the network, or this network is resilient, and the distress propagation will stop? Therefore, the following aim is to apply the approach of evaluation of networked positions. Consider that a network model taking into account various types of relations and in which one can model cascades of defaults or illiquidity cases and following feedback effects to the external conditions like a sudden price jumps of necessary assets (Degryse and Nguyen, 2004). We consider that the failure of a cluster entity means that it does not realise its commercialised idea or, for various reasons, does not more contribute to the activity of innovation cluster. Collapse of the first cluster entity can be contagious and can disrupt the overall performance or liquidity shock of the entire cluster. This could also lead to a cascade of failures of other entities of the cluster or even to the collapse of the entire cluster. The contagion in innovation cluster can occur due to illiquidity. On the other hand, it can occur due to external investors (typically venture capital institutions) expectations: when one group of investors face the withdrawal of another group of investors, they also can try to withdraw their investments which are motivated by the uncertainty about the future development of innovative activities and fear, that later they withdraw, the less probability is that entities of the innovation cluster can satisfy their expectations and claims. The contagion in innovation cluster is described by the $N \times (N + M) -$ order matrix X of bilateral exposures in order to analyse the propagation features of defaults of innovation cluster entities. The matrix of bilateral exposures evaluated in financial amounts summarises the bilateral exposures of cluster entities toward the other $(N - 1)$.

$$X = \left[\begin{array}{ccccc|ccc} x_{11} & \cdots & x_{1j} & \cdots & x_{1N} & w_{1N+1} & \cdots & w_{1M} \\ \vdots & \ddots & \vdots & \iddots & \vdots & \vdots & & \vdots \\ x_{i1} & \cdots & x_{ij} & \cdots & x_{iN} & \vdots & & \vdots \\ \vdots & \iddots & \vdots & \ddots & \vdots & \vdots & & \vdots \\ x_{Ni} & \cdots & x_{Nj} & \cdots & x_{NN} & w_{NN+1} & \cdots & w_{NM} \end{array}\right]$$

where x_{ij} means the gross exposure of the ith cluster entity to the jth cluster member, w_{ij} means the gross exposure of the ith cluster core entity to the jth periphery member (or external business partner) a_i represents the assets of ith entity within innovation cluster, l_j represents the domestic liabilities within innovation cluster of jth entity, and e_i represents the external claims of ith cluster member:

$$\sum_{j=1}^{N} x_{ij} = a_i; \sum_{i=1}^{N} x_{ij} = l_j \text{ and } \sum_{j=N+1}^{M} w_{ij} = e_i.$$

The matrix of bilateral exposures X is unknown due to confidentiality of business deals and therefore must be estimated. The systemic risk of innovation cluster means the impact of the failure (or default) of each of the N entities belonging to the core of cluster and each of the *M* periphery entities for a fixed loss given default. The initial failure is supposed to be a cause of the following failure when the exposure of one innovation cluster member to failed entities is large enough to offset its capital. In addition, the *i*th entity of innovation cluster collapses due to previous failures when

$$C_i - \theta\left(\sum_{j=1}^{N}\mu_j x_{ij} - \sum_{j=N+1}^{M}\mu_j w_{ij}\right) < 0;$$

where C_i means the capital of *i*th cluster entity, θ means the loss given default rate and μ_j is a dummy variable:

$$\mu_j = \begin{cases} 1, & C_j \le 0 \\ 0, & C_j > 0 \end{cases}.$$

Suppose loss given default rate to be identical for all failed entities of the innovation cluster. The initial default of any cluster entity may cause several rounds of following failures. Assuming that usually in the bankruptcy situations of business entities the netting procedures are quite rare, the gross exposures of respective entities x_{ij} and w_{ij} are used rather than net exposures $x_{ij} - x_{ji}$. The contagion, i.e., the propagation of systemic risk stops when cluster entities that failed during the last round do not cause any following defaults, i.e., when the structure of remaining part of innovation cluster represented by collaboration network, becomes again stable.

The approach of aggregate exposures is based on the observed aggregate parameters a_i and l_j, which provide only incomplete information on bilateral liabilities and exposures between cluster entities, i.e., the sum of the elements of respective column and a row of the matrix *X*. This information is partial only, therefore it is necessary to assume that cluster entities seek to maximise the dispersion of their activities. With the appropriate standardisation, it would be equivalent to assuming a matrix X^0 such that $x_{ij} = a_i l_j$. This is equivalent to minimising the distance function (measured by the relative entropy) between X^0 and the constrained matrix: $\min \sum_{i=1}^{N}\sum_{j=1}^{N} x_{ij} \log_e\left(x_{ij} / x_{ij}^0\right)$ subject to constraints $\sum_{j=1}^{N} x_{ij} = a_i$ and $\sum_{j=1}^{N} x_{ij} = l_j$ and $x_{ij} \ge 0;$ $x_{ij} = 0$ when $x_{ij}^0 = 0$ and the assumption that $(0 \log_e(0/0)) = 0$.

This exercise of evaluation can be solved numerically by applying the RAS algorithm (see Blien and Graef, 1991). This model let us treat an innovation cluster as a risky set of entities, impacted by external shocks, which, as a social network that shares the trust and resources of each individual member, influences the viability to the entire cluster thus a risk becoming not only idiosyncratic but systemic. In this case, however, it is difficult to establish the degree of interconnection between cluster entities or the likelihood of related insolvencies on the basis of empirical data, as data are largely unavailable mainly due to the relatively rare occurrence of related insolvency events. Unlike as in the case of the square matrix, in this model, the cluster structure is assumed to be non-homogeneous and consisting of two parts: the core that generates a major impact on the entities of the innovation cluster and the periphery entities which are less significant to the common activity. The structure of the innovation cluster described by presented formulas also corresponds to the risk-sharing in the innovation cluster. In addition, this model can be used to describe systematic risk when cluster shares its risk with external partners. It would not be useful for the success of the commercialisation of the cluster, but in the event of failure, the risk-sharing would provide more opportunities to continue the creation of innovations and their commercialisation activities.

The structure of the matrix bilateral exposures provides a variety of interpretations of this model. For example, this model can analyse the interactions between the core and the periphery of innovation cluster. Also, it is possible to treat this model in another way: to divide the cluster structure with regard to transfer of specific academic knowledge and new technologies: the core of the cluster should represent the R&D sector providing necessary information for business entities belonging to the periphery of innovation cluster in terms of knowledge sharing. On the other hand, this model can describe the interaction between cluster and its external partners in terms of liabilities and exposures of positions and their impact on systemic risk.

Remark:

1. The proposed model adequately reveals the relevance of individual entities of a cluster. If the enterprise belonging to the innovation cluster core has collapsed, then the consequences of its collapse for the cluster are much more relevant than the collapse of the entity from the cluster periphery.
2. In graph theory, there are more numerical characteristics that can be applied to describe the relevance of an individual innovation cluster to the entire cluster activity.

5 Systemic risk structure and the problems induced by higher volatility due to the various and numerous sources of risk

Systemic risk is often accompanied by structural change in economic fundamentals. In terms of the asset allocation and asset pricing research, contagion has the potential to substantially change the investment opportunity set. Contagion is, to a large extent, driven by extreme shocks in the return of certain assets. Besides the well-known risk structure determined by the regulators of financial sector (Basel III), there exist additional sources of risk in the innovation industry, namely, higher than usual uncertainty and volatility in an innovative case. This is namely what determines the involvement of venture capitalists and the attitude towards the business they create as a high-risk and fast-growing investment opportunity. All of these risks can, to an appropriate extent, lead to systemic risk in the innovation cluster. This is due to the technology transfer process, inevitably accompanied by information asymmetry, numerous additional risks associated with the demand for the commercialised product, technologies, etc., technological risks (potential competitors create more advanced technology or applied new technologies can be pirated, etc.

Performance of enterprises, the capture of resources and other actions can be treated as the function where the enterprises lie in the innovation network. Following Qian et al. (2010), different network positions represent different opportunities of business entities to acquire new knowledge and resources and different level of systemic relevance in the extent of the innovation cluster. In addition, Owen-Smith and Powell (2004) also stated that enterprises occupying dominant positions in a network can consolidate different entities through their positions to acquire and control resources to ensure complementarities in innovative activities. A well-known feature of structure centrality characterises the level of opportunities within cluster and coordination of activities. Core and supporting companies, social and hard infrastructure interact within a related cluster through complementarity. Typically the core set of complementary entities having the biggest potential to innovate is at the network centre, i.e., having the highest systemic relevance (highest centrality) and they serve as the critical core of the cluster (in the special case – the most relevant clique), and display distinctive characteristics that are unique in the extent of activities of innovation cluster. In addition, the more centrally the core entities locate in the cluster network, the more conducive the transformation and growth of the core enterprises is to integration and coordination of cluster resources and collaboration and, as a result, it might lead to structural changes of development of innovative activities and generate systemic risk. A central position reflects the dominance, but possibly also constraints on behaviour due to the possibly divergent interests (Krackhardt, 1999) and the necessity to coordinate activities.

The phenomenon of systemic risk in the innovation cluster is similar to that of the banking sector systemic. Examples of systemic risks of the banking sector (Cont et al., 2010) show that a star-forming can be riskier network structure, i.e., when a large-scale innovation-driven business is in the process of developing a cluster-based structure that can protect itself from the domino effect in the cluster. When the entire clique fails, but other entities (another cliques) of the cluster are saved the cluster part depends on one or more significant agents (such as those with the highest commitment to other innovation cluster entities) whose failure or failure can have a significant negative effect on other cluster entities and in some cases cause a chain reaction of failures in the context of banking systemic risk known as domino. In principle, the systemic risk phenomenon in the cluster is like that of the banking system's systemic risk in the public finance system. On the other hand, in this case, another component is also significant: if innovation activity is too risky and as a result, the main cluster entities suffer significant losses, and this effect may overcome other cluster entities depending on the activities of the main cluster entities, possible domino effect. Resilience to internal and external negative effects of the star cluster structure is not optimal, and optimal would be as homogeneous as possible, i.e., when all cluster entities are generally considered to be approximately equivalent. However, in such cases, cluster management would suffer: when an organisation is composed of roughly equivalent entities in negotiation, it is likely that it would be more difficult to make decisions and reach compromises and agreements, making it difficult to negotiate and coordinate the process. Due to these reasons, the problem of the optimality of the activity (and structure) of the innovation cluster that creates the innovation can be treated as a problem of optimal portfolio management. In special cases, the clique-based and partly 'homogenised' innovation cluster structure can protect against the so-called domino effect in the cluster (when the entire clique fails, but other entities (forming other cliques) are saved. However, decomposition of activities and systemic risk management sometimes can be controversial issues in order to ensure the viability of the cluster's activities and the development of innovation.

6 Conclusions

Author proposes to treat a systemic risk as a generalised risk framework of whole activity of innovation cluster as a networked structure. Systemic risk as a generalisation of all types of risk of innovation cluster activity is not sufficiently analysed in research literature concerning innovation clusters.

The systemic risk mainly characterised by contagion effect (usually initiated by the credit risk or liquidity risk or the flows of negative information about future developments) as a generalised risk approach in order to evaluate quantitatively the resilience of an innovation cluster to internal and external shocks can be modelled using the algorithms applied to collaboration networking in banking sectors (interbank markets).As in the banking sector, the risk of an innovation cluster is determined by a variety of factors that depend on both external (economic behaviour and reliability of business partner, external creditor or macroeconomic developments) relationships and internal (innovation cluster structure). The lack of real data limits the ability to assess more accurately the specific characteristics of an innovation cluster structure that determines its resilience to critical shocks, especially given the nature of its innovation commercialisation activities. Nor does the scientific literature provide unambiguous insights as to what network structure would be optimal in terms of resistance to systemic risk in the case of an innovation cluster. This could be a serious subject for further research.

The proposed model of evaluation of systemic risk can be treated in various ways regarding the formulation of exercise and the structure of innovation cluster: it is possible to model the weights of inter linkages between core and periphery of innovation. On the other hand, using the same model, it is possible to evaluate systemic risk between commercial entities and R&D institutions implementing new technologies. Finally, it is possible using the same formulas to model the systemic risk of the innovation cluster as an impacted by other external collaborating entities. The proposed model does not describe the origin and causes of systemic risk. Also, this model is useful for evaluation of resilience of systemic risk regarding the structure of innovation cluster. A proper assessment of the systemic risk of innovation clusters provides a lot of valuable information on the risks of commercialising innovation in a networked environment and should be useful for innovation and innovation clustering policy makers.

The future research is related with the weakening of some assumptions. The model of networking could be generalised under assumptions that the value of commercial relation between innovation cluster entities can be treated as stochastic processes, the number of entities also can be stochastic. On the other hand, it is necessary to develop further indicators determining the stability of networking taking considering internal and external factors.

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