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FORMAL AND INFORMAL INNOVATION NETWORKS: A REVIEW

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Abstract. The paper addressed the important problem of systematization of empirical research in the field of formal and informal innovation networks. After an extensive literature study of 65 papers from 2003-2023, four thematic areas were formed: innovation network creation, structure and participants; innovation network evolution, activities and interactions; factors influencing innovation networks; and results from innovation network activities for the participants and third parties. Besides them, several interesting topics were discovered concerning network-specific structural forms, peculiarities of adaptive management, and the knowledge transfer mechanics of contracting for innovation. The systematization also showed several contradictions in the results and gaps in the empirical research, which outline the need for more studies about the intensity of formal and informal contact between participants and their influence on the transformation, development and sustainability of the networks and the contribution of formal and informal networks to the diffusion of knowledge and innovations.

Keywords: innovation; formal networks; informal networks; survey; empirical analysis; systematization

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1. Introduction

The innovation network was defined as a group of agents (e.g., individuals, teams, organizations) connected via relationships that enable exchanging information and/or other resources. (Schilling, 2017). They create opportunities for their members to pool together, exchange ideas, transfer knowledge, and share resources, enhancing the innovative outcomes of all participants and partners. Innovation networks are regarded as a key structural part of the innovation process (including members and their relationships). Still, they were also connected with the cognitive aspects of knowledge diffusion and social interactions in their environment, currently referred to as knowledge transfer or technology transfer (Ahrweiler, Keane, 2013; Ochoa, Arranz, Arroyabe, 2023).

The importance of knowledge transfer for innovation, competitive advantage, and economic growth led to abundant empirical research in innovation networks. They were studied from various perspectives and with diverse methods, both qualitative and quantitative. Among the interesting topics of empirical study were the metrics of innovation output (Owen-Smith, Powell, 2004; Casarin, 2023), the creation of innovation networks (Goyal, 2009), the interactions of networks with their surroundings (Klerkx et al., 2010), especially the social capital and culture (Malecki, 2012), the dynamics of networks, and their development or degradation (Vicsek

et al., 2016), the institutional influence (Schøtt, Jensen, 2016). The factors that affect the network's success were also subject to intensive survey (Voorberg et al., 2015).

Empirical research sometimes explores very narrow topics concerning specific structural forms (Ter Wal et al., 2016), a functional peculiarity of 'adaptive management' (Klerkx et al., 2010), and interesting knowledge transfer mechanics like 'contracting for innovation' (Gilson et al., 2009).

Some attempts to systematize the research were made for strategic alliances (Gulati, 2012) and university-industry alliances (Perkmann et al., 2011). Others just pointed out core ideas for research (Balkundi, Kilduff, 2006), or were concerned with generalized topics (Voorberg et al., 2015). From a theoretical point of view, major innovation network features were studied by Gulati et al. (2012). Theories attempted to respond to the divergent signals that came from empirical observations of different networks in practice – about the models for successful functioning of networks, when a network was sustainable and when it was doomed to failure and collapse. Theoretical works were somewhat restricted, especially when considering the incentives for developing networks, and many gaps remained, like innovation forms, network configuration and third parties' role (Pittaway et al., 2004).

The systematic analysis was lacking, and there is still open space to develop a conceptual framework of the innovation networks analysis that would allow the complex study of the phenomena, its nature, structure, measurement, evaluation, and so on. Thus, the goal of this paper was to create a summary of the research, define major thematic areas and their subdivisions, and outline important topics, thus making an essential step towards developing the network analysis conceptual framework.

2. Materials and Methods

In the present study, the emphasis was placed on innovation networks, which, in the narrow sense of the term, consisted of organizations and individuals aimed at the development of innovative products or services. In the broad sense, innovation networks included, in addition to the participants, also the environment in which organizations in each cluster, hub (or other type of formation) interact to generate, produce, test, or disseminate the result of the innovation process (Latour, 2005).

The main method was an extensive bibliographic review of empirical research in the thematic area of innovation networks. We also used methods of analysis and synthesis, logical processes, comparative analysis, content analysis, and basic statistical methods (statistical tables) to outline major patterns. From the conceptual point of view, in the current study of empirical research on innovation networks, we used a systematic, interdisciplinary approach merging together the traditional approaches of describing static objects and phenomena with the ideas of actor-network theory, social network analysis and structural analysis.

Research interest in the development of innovation networks started at the end of the 20th century. In recent decades, there has been a dynamic transformation of all social systems, which were rapidly evolving. The participants and the relationships between them changed, creating uncertainty and making it necessary for a new perspective and new tools for the study of non-permanent and non-traditional social constructions.

Actor-Network Theory (Latour, 2005) is associated with the ideas of post-structuralism, i.e., it is described as an anti-foundationalist approach (Law, 2009) and is therefore somewhat neglected in empirical research. Actor-Network Theory views a network in a broad sense as composed of actors that are not just people or organizations (Czarniawska, 2006). The so-called nonhuman actors in networks are objects, animals, natural phenomena, facilities, etc. (Sayes, 2014), with which people and organizations interact to create meaningful outcomes. According to Latour, networks are both material and semiotic, as far as part of the network are "strategies for linking different elements together in a network so that they form an apparently coherent whole." Thus, in defining the scope of our analysis, we were concerned with both cognitive and material perspectives of the innovation networks, their creation and participants, members' abilities, goals and established roles in the networks.

As the actor-network theory does not describe the type of networks or their evolution, we also employed some of the ideas of social network and structural analysis.

Social Network Analysis (Borgatti et al., 2009) was undergoing serious methodological development and was widely applied in determining the cohesion potential of networks and the reciprocity of resource sharing. Techniques of relational sociology were also applied, combining qualitative and quantitative research (Vicsek et al., 2016) to delve into more complex topics and phenomena and gain a deeper understanding of the complexity of social relations and their dynamics (Edwards, 2010; Du et al., 2023, Ochoa, Arranz, Arroyabe, 2023). To reckon with the networks' complexity and dynamic nature we explored empirical evidence with strong emphasis put on the innovation networks typology, development, and evolution; their activities and performance; the interactions and major drivers of change; the spatial perspectives and performance results as economic and social benefits for the members and outside third parties.

The review covered more than 100 papers published from 2003 to 2023. From all those, 66 were selected to focus on the primary research topic of the survey – the empirical research about formal and informal innovation networks. The papers were published in journals with subject fields in Management, Marketing, Research Policy, Knowledge Transfer, Organizational Science and Technology. All those papers were indexed in Scopus, Web of Science, and global reference databases. The paper selection was performed based on the important terms and categories used in the title, abstract, and author-supplied keywords. The words included 'innovation networks', 'innovation', 'empirical', 'survey', 'statistical', 'regression', 'econometrics', 'study', and 'evidence'.

3. Literature Review

Analysing the research papers that conducted empirical studies of innovation networks, we were able to outline several major thematic areas, covering a) innovation networks creation, structure and participants; b) innovation networks evolution, activities and interactions; c) factors influencing innovation networks; and d) results from innovation networks activities for the participants and third parties.

3.1. *Innovation networks creation, structure and participants*

The empirical research on the topics of the networks' emergence and governing was focused on their creation, antecedents, informal connections, network typology and structure. The networks were always created with certain goals, and the members were joining with inherent motivation connected to but not limited to, the benefits of knowledge sharing and collaboration. Goyal (Goyal, 2009) developed a general theory of network formation and analysed the location of every participant and its connection with the received benefits. Šūmane et al. (2018) explored the role of networking in European sustainable agriculture. They found that the purpose of network formation was to bring access to new and diverse knowledge, new forms of knowledge and new learning processes. The best form was the multi-actor knowledge network that allowed collaboration between farmers (local experience-based knowledge) and the co-generation of ideas and innovations. The complexity and local specificity brought forth the need for flexible knowledge generation, integration and sharing models. The creation of the network was eased or hampered by the presence or absence of pre-existing co-relations between the actors and the availability of formal and informal elements. Pittaway et al. (2004) analysed the link between firm's networking behaviour and innovations. They pointed out the role of networking configurations and the importance of participation and contribution of third parties like professional or trade associations. Giuliani (2013) explored local clusters and how they helped form networks for knowledge transfer and innovations. The analysis of network dynamics and actor-oriented modelling revealed that the cohesion effects and weak knowledge base facilitated the formation of a stable hierarchical structure in time. McEvily et al. (2014) analysed the role of informal and formal elements in organizational activities and interactions. There was conceptual logic in combining formal with informal connections that could improve the reasoning of networks' emergence, development, and functionality.

Networks appeared in different forms and followed different models in their evolution. Volberda et al. (2010) examined the research literature about networks in the context of absorptive capacity and concluded that organizational design and antecedents were not in the focus of the researcher and remained neglected or unclear. Bodas Freitas et al. (2013) explored the two main models governing university-industry relations: institutional

and personal. The former was preferred by the large firms with vertical integration of their R&D, while small firms in the technology field and with open innovation strategies favour personal contractions. Ter Wal et al. (2016) differentiated network configurations into two dimensions – access, where networks could be open or closed, and expertise, which identified specialized and diverse networks. The resulting four combinations (closed-diverse, open-specialized, open-diverse, closed-specialized) offered different potentials for sharing redundant or diverse information and the easiness of interpretation of that knowledge. The empirical study of venture capital investment in the information technology sector (USA) showed a higher success rate of open-specialized and closed-diverse networks that capitalized on the advantages of sharing and interpretation. Hurmelinna-Laukkanen et al. (2021) identified three innovation network profiles by combining fundamental determinant properties (activities and resources) and interdependency between members. The labelled profiles, translatable, transformative, and transcending, strongly impacted the size, density, structure and other essential network properties.

Network structure was explored in various aspects ranging from cognitive to geographical. Cowan and Jonard (2003) considered network structure in relation to the co-innovations and absorption potential. The network structure influenced the patterns and frequency of innovations, with communications structure being of key concern. The small world structure excelled at low absorption capacity, while the large capacity benefited from the organizational structure with a short path length. Owen-Smith and Powell (2004) examined the relationship between network structure (geographical and organizational) and information flows. They found that some nodes dominated the knowledge transfer and determined the state of open or restricted information access. As a result, the benefits from networking were either narrowed to the centre of the networks or spread broadly for many participants. Balkundi and Killduff (2006) considered the network in two dimensions: as cognitive structures and as structures of opportunity. The network activities could be facilitated or constrained by the three types of connections – between leaders, leaders inside the organizations and between leaders as representatives. Tahi et al. (2022) investigated structural holes and personal network efficiency in the biopharmaceutical industry. They found that private actors benefited from the control of knowledge transfer and played a central role in the evolution and development of innovation networks. Li et al. (2023) analysed the resilience of regional innovation networks. They found the vital role of internal connectivities between sub-networks and the important impact of structural heterogeneity that was profound in academic subnetworks compared to the enterprise ones.

3.2. Innovation networks evolution, activities and interactions

Evolutionary research in network development focused on the drivers of networks (Giuliani, 2013) and the context in which they had emerged (Greany, Higham, 2018). How the "life" of a network proceeded, what was the trajectory of its development, and what determined its transience and constant making and re-making (Giuliani, 2013) were questions to which scientific literature continued to seek answers from several different perspectives.

The Spatial Perspective was the oldest perspective for obvious reasons. It allowed the researchers to determine the unit of analysis (including geographically). It originated from the works of Alfred Marshall, who brought out the benefits of spatial grouping. On this basis, the theories of the agglomeration effect of spatially connected economic agents were developed, as well as the centre-periphery models, which examined the relationship between economic centres and less developed places around them (Press, 2006). The spatial perspective in more recent research was primarily associated with clusters, which might be geographically localized (regional clusters) but might also have a global presence (global networks). The factors for developing a given cluster in this case were considered in the literature as related to endogenous development, for example, the presence of social capital in the region where the network was located (Thompson, 2018). Wang and Zhang (2022) estimated regional innovation efficiency in China and found several regional imbalances. The developed provinces were more efficient than the less developed, and the efficiency was better at the R&D phase than in the commercialization stage. Regional conditions and innovation structure were important determinants of innovation investment enthusiasm and needed to be properly addressed by policy and the creation of a stable, transparent environment.

Network Position Perspective was linked with a member's position in the network as a measure of the extent to which a participant was more active in exchanging resources and information with others, regardless of geographic distance. Unlike hierarchical structures, where formal relations in networks determine power, there was no prior distribution of power positions. They depended on the capacity of an actor to attract and communicate with other actors and to be useful in the network. The reciprocity of sharing resources and information was also seen as a factor of network cohesion (Goswami et al., 2023). The heterogeneity of firms in terms of their accumulated resources and capabilities contributed to forming hierarchical network structures where firms with more capabilities occupied privileged positions within the local network (Giuliani, 2013). Companies that established many new connections contributed to the cohesive effect of the network because it became more attractive.

The Digitization Perspective has developed rapidly in recent years. Digitalization has played a huge role in the development of innovative networks. On the one hand, it mediated communications through innovative tools. On the other hand, digital technologies fostered new forms of innovation and entrepreneurial initiatives by integrating digital and non-digital assets and accelerating the creation, scaling and evolution of new ventures (Nambisan et al., 2019). One of the research directions was related to the optimization and/or synchronization of the network development strategy to achieve technical compatibility. For example, Arvidsson and Mønsted reported on optimizing the number of applications in a cluster of 11 hospitals from a region in Norway. As a result of the synchronization, the number of used applications was reduced from 3000 to 700 (Arvidsson, Mønsted, 2018).

In this way, entrepreneurs quickly identified potential and sought new opportunities by re-combining resources in such a way that the development and scaling of new applications was a powerful driver for the development of the network. The flexibility of digital technologies made innovation outcomes increasingly open. Digital transformation changed entrepreneurial business models by stimulating businesses to rethink relationships with other partners and users. The following directions were noted in the analysis: 1) facilitated network collaboration and co-creation among actors for the solution of complex problems; 2) increasing network potential for combining resources; and 3) recombining technologies (Nambisan et al., 2019). In a broader plan, the digital transformation had another effect – related to changing policies to stimulate innovation, respectively to stimulate openness and data privacy protection, and to create an environment for combining digital affordances, spatial affordances, institutional affordances, social affordances (Nambisan et al., 2019). The combination of all new possibilities led to a redefinition of the boundaries of innovation networks and clusters.

Performance Perspective. Networks exist to enable communication between participants, resulting in meaningful outcomes that the agents in the network cannot individually create. Therefore, the performance evaluation should be closely related to whether network members tend to cooperate with other members (Vicsek et al., 2016). The reduction of communication and the exchange of resources and information is a sure sign of a destructive trend. After a certain threshold of need for communication, the network begins to break down. By the same logic, the growth of the network, i.e., attracting new members, should indicate better performance. Access to networks facilitates the easier exchange of information and resources, which is why networks are becoming a major component of markets (Owen-Smith, Powell, 2004). Almeida et al. (2003) compared the performance of networks and transnational corporations in terms of knowledge transfer and innovation. The corporations excelled in the implementation of both formal and informal mechanisms for knowledge building (incl. transborder sharing). Their flexibility facilitated dynamics, integration, and development of technical knowledge. Swan and Scarbrough (2005) explored the innovations that occur at the intersection of collaborating actors. They found that networks excelled in hierarchical and market-based forms in knowledge creation and integration and that the coordination of networks played a more significant role than their formation.

Knowledge Transfer Perspective. Knowledge transfer is one of the most attractive areas for researchers in network studies. The knowledge network provides firms with access to diverse knowledge to develop and improve products (Carnabuci, Operti, 2013), but it is important to how knowledge is integrated into the network, depending on its structure and density. In innovation networks, knowledge transfer was a major reason for gradually rethinking organizational boundaries and their blurring over time (Lawson et al., 2009). Dimitrova and Dakova (2021) explored the knowledge transfer interaction between academics and business. The higher

education innovation centres served as mediators of the process, facilitating the technological transfer from the producers (usually the academic research teams) to the business user implementing the new knowledge in practice. In a wide and diversified network of knowledge, the subjects of innovation could benefit much better from the three stages of knowledge transfer: knowledge transmission, knowledge absorption, and the use of the knowledge (Szilágyi, 2017), and from the lower costs of knowledge acquisition and transformation (Zhou, 2022).

The lack of connections between network participants (aka structural holes) might impede the flow of information. They could be due to a lack of trust or competitive rivalry but might also be caused by normative constraints, e.g., required permissions to access information (Zhou, 2022). Burt et al. (2013) considered structural holes from a sociological point of view as a buffer that was surrounded by different flows of information. The buffer was more often formed because the participants were busy with other activities or tasks and missed direct connections with each other. Bridging structural holes contributed to turning potential connections in a network into actual ones, strengthened the central positions of actors contributing to these new connections (Chen et al., 2019), and could enhance innovation performance (Sun et al., 2022). Structural holes were detrimental to team knowledge sharing and diffusion, as they inhibited the creation of new team knowledge (Li et al., 2017).

3.3. Factors influencing innovation networks

The problems of factors that influenced innovation networks' success encompassed empirical studies about the efficiency and the results of the innovation networks' functioning. These factors were the focus of empiric research activity in co-creation or co-production innovations while the goals and outcomes were somewhat neglected (Voorberg et al., 2015). The area covers knowledge transfer, network management, environment and outside conditions that influence how innovation networks appear, function, develop and/or degrade. In that area we were able to outline several narrow fields of research, pointing to the different factor groups concerning a) the management of networks and knowledge transfer; b) the spatial aspects of knowledge transfer and innovation; c) the connection between the social capital and innovation processes; d) the institutional aspects of knowledge transfer and innovation networks.

The management of networks and knowledge transfer are key factors because the networks were created and functioned through the interactions of their members. While the innovation networks were studied in detail regarding their structural properties (Swan, Scarbrough, 2005), there were other problems linked to their development or degradation and to the specific forms and ways to share knowledge. Swan and Scarbrough (2005) examined the roles of network structure and politics of network development dynamics. They found that the coordination of the network was more important than its formation. Liu et al. (2022) explored the relationship between the innovation outcomes of SMEs, planning and execution capability, and operational improvement capability. They found that operational improvement impacted innovation output more than planning and execution. While exports and formal business networks presented different knowledge opportunities, the latter amplified the effect of planning and execution on innovation, and the former reduced the benefits of planning and execution on innovations. Savino et al. (2017) pointed out the key role of knowledge search and recombination in innovation development. The quality of knowledge plays a more significant role as variety and diversity of knowledge proved crucial for achieving breakthrough innovations. Knowledge impact importance was reinforced by Lungeanu et al. (2022) when exploring expertise diversity and its relation to quality and innovation output. Their findings presented evidence that the success of product and service innovation relied on the diversity and complexity of both private and public actors' complementariness and interdependencies in various fields of knowledge.

An interesting moment was marked by Gilson et al. (2009) when exploring interfirm collaboration and seeing vertical disintegration. They found that the firms developed a new form of contracting - 'contracting for innovation' to support iterative cooperative innovations along the supply chain. Yenyurt et al. (2014) analysed the North American automotive industry. They found that co-innovation was influenced by communication along the supply chain, expected long-term returns, and the development of mutual trust and interdependence.

Adaptive innovation management was surveyed considering the interaction between innovation networks and their environment and the limited abilities of the networks to influence and change the environment (Klerkx et al., 2010). Special attention was given to the constant reflection of the innovating actors and to the so-called flexible support instruments and their role in effectively managing environmental change.

The influence of management and spatial aspects of knowledge transfer and innovation was focused on the location of the network's members. Geography plays a significant role in developing innovative networks, while digitalization presents new opportunities with the ability to change the entire image. Gittelman (2007) studied the connection between spatial disposition and innovations based on the collaborative research projects of small biotechnology firms. Two types of links were discovered. In the first, the research teams were closely clustered and created innovative knowledge that was implemented in the practice, resulting in high citations of their patents. The second type of cooperation connected team members through longer distances, providing better geographical coverage in sharing knowledge and disseminating scientific findings, resulting in more publications citing scientific papers. Morrison et al. (2013) modelled the connection between innovations, the growth of clusters, and global pipelines. The diffusion and accumulation of knowledge were found to be supported by the global pipelines in limited situations with high-quality clusters or in small and knowledge-poor ones. Binz et al. (2014) analysed the innovation processes at different spatial scales – national and regional. Using data from social networks about publications on membrane bioreactor technology, they found that when knowledge transfer was concerned, the spatial characteristics of the cooperation varied substantially, even in short periods. Liu et al. (2022) explored the cultural industry clusters and the influence of geographical, technological, and social proximity on the evolution of innovation networks. They found that the innovation networks improved their centrality and interconnections, and social proximity remained a pivotal factor in the development of cultural industry networks, while geographical proximity impact was diminishing. Digitalization and the ongoing processes of social and entrepreneurial conversion can transform the role and significance of location as digital technologies present new opportunities to achieve openness, affordability and generativity (Nambisan et al., 2019).

The impact of social capital on innovation processes was studied from several points of view, including the role of culture as an essential element of it. Hinrichs et al. (2004) used data from 1999 survey in US states of California, New York and Iowa. They found that social learning through interactions with customers and vendors was a crucial factor in marketing innovations, although moderated by structural factors and human capital. Mu et al. (2008) analysed social capital, the transfer of knowledge and the role of interfirm networks. They presented a mechanism explaining how weak ties develop trust and lead to solid inter-firm relationships, enhancing the interaction process and accelerating knowledge flow. Kaasa (2009) explored the impact of social capital on innovative activity at the regional level. While the significant role of social capital in promoting innovations was confirmed, the various aspects of social capital were found to have dissimilar effects on innovation intensity. Cheung et al. (2010) examined the resource sharing between suppliers and buyers, the inter-firm collaboration in learning and value creation. They found that when strong ties were created in the supply chains, the propensity to share knowledge between the partners was not influenced by cultural distance, even in cross-border cases.

Malecki (2012) considered social capital the culture of communication, learning, trust, and openness toward external ideas. The extraordinary pool of social capital – quality and quantity, was the basis for regional growth, innovation conducive environment, and building an economy based on knowledge. The cultural distinction of different regions – the culture of trust, learning, and interaction between peoples and organizations was related to knowledge transfer, the formation of an innovation-beneficial environment, and regional economic growth. Yun et al. (2020) studied the role of culture when considering the dynamics of open innovations. They noted two problems – 1) the requirement to understand diverse cultures, and 2) the need to control the complexity of open innovations. Examining the different entrepreneurial dimensions of interactions (novice, existing and organizational), they found the various aspects and roles that culture plays in boosting open innovations. Barroso-Méndez et al. (2020) analysed the interaction between business and non-profit organizations and established that the partnership's outcome depended on the partner's characteristics, such as the complementarity of their resources and the sharing of common values. Satisfaction and achievement of goals developed trust and more commitment, helping develop regional capital. Mukherjee and Jain (2022) explored the impact of social

brokerage on innovation networks' output and found that the relation exhibited a U-shaped form. The biggest and the smallest social brokerage was associated with higher innovation scores as perceived by the other community users. Wand and Zhu (2022) explored the relations between social capital, industry-university-research networks, and innovation performance in the petroleum industry. Empirical research showed evidence that social capital and innovation performance were benefitted by the centrality of the cooperation network as well as its strength, while, at the same time, the network scale had no significant impact on either social capital or performance. Social capital, per se, showed a mediating effect between centrality and performance.

The institutional impact on knowledge transfer and innovation networks received less attention even if the institutional role was major catalyser for innovation networks in any stage of their development, and institutional actions could have as much beneficial as detrimental effects. Spielman et al. (2011) explored the innovative abilities of rural stallholders in Ethiopia. They found that smallholder networks were strongly influenced by public administration, sometimes even at the expense of market-based enterprises and civil society. Schøtt and Jensen (2016) used data from the Global Entrepreneurship Monitor (18,880 firms in 68 countries) and found that institutional support did not increase the quantity of networking. On the other hand, the process and product innovations benefited from institutional support for networking. Godlewska et al. (2022) explored the influence of institutions on the innovation process in Poland. They found that previous cooperation between local governments and special local institutions improved network participation. Moreover, formal networks were better than informal ones in limiting undesirable behaviour like opportunism, distrust, rent-seeking, instability, and a lack of compliance with established rules.

3.4. Results from innovation networks activities for the participants and third parties

Innovation networks have played a significant role in economic development and social transformation. The resulting innovations from the network's performance created important benefits for the network's members and other stakeholders. The co-innovation effects were studied in connection with supply chains (Wang, Hu, 2020; Lawson et al., 2009), cultural and creative industries (Santoro et al., 2018), investment companies (Ter Wal et al., 2016), aerospace, ceramics, information technology and software, textiles and healthcare (Tomlinson, 2010), automotive equipment (Yeniyurt et al., 2014), semiconductors (Ansell, 2000).

Measuring the effect of networking between companies and universities was focused on the use of easily quantifiable outcomes, e.g. patents and scientific publications (Perkmann et al., 2011). The other outcomes were difficult to quantify and included participant satisfaction with the knowledge transfer process and innovation outcomes, the long-term benefit of the generation of scientific knowledge.

Pittaway et al. (2004) conducted a systematic review of the connection between networking and innovation capacity and derived the primary benefits for the stakeholders. Financial and legal benefits were expressed in improved risk management, safeguarding property rights, and practical ones, such as easy access to new markets and speeding the products to the market. At the same time, the sharing aspects included knowledge transfer and pooling complementary resources. On the other hand, when firms didn't engage in cooperation activities, their long-term knowledge base was restricted, and their potential for future exchange was reduced.

Perkmann et al. (2011) commented on the rising number of official alliances between businesses and universities pointed towards innovations. Some benefits were specific for the industry branches – pharmaceutical firms gained information about new diseases; IT engineering gained advantages in software development. Common benefits included easy communication with the students and the development of new technologies; increased financing due to government support for the R&D programs; efficient consulting from the academic experts for the problems in R&D activities in the firms; improved reputation and attractiveness as employers and partners; access to the academic networks.

Yeniyurt et al. (2014) pointed to the firm's benefits from networking when finding needed competency, experience, technologies and product elements. Co-operation with suppliers for innovations led to increased productivity, a decrease in time for the development of new products, improvement in the quality of existing products, a decrease in production costs, and access to new markets and technologies. Further, good relations with suppliers increase trust between the partners and encourage continuous cooperation for innovation.

According to Wang and Hu (Wang, Hu, 2020) the synchronization of the abilities and advantages among the partners led to great practical benefits from the co-innovations. Collaboration through the supply chain (suppliers, producers, distributors, service providers, clients) accelerated the development and quality of new products and services.

Tomlinson (2010) pointed out inter-firm ties as leading to innovation promotion because they complement the firm's internal resources in product and process innovation. Although there is some heterogeneity in the results obtained from the study for different production sectors, it is proven that vertical connections (upward and downward) have a positive and significant impact on the innovation performance of firms. Fostering closer links across a range of activities (from product co-design to marketing and distribution) between firms along the value chain facilitates knowledge transfer and organizational learning and can improve innovation outcomes.

Santoro et al. (2018) found that informal ways were preferred in the collaboration between firms and cultural and creative industries. These industries were a source of innovation for the firms because they provided different/specific knowledge and new creative approaches, methods, and solutions that supported successful competition. Informal networks benefited firms more than formal ones because they enabled faster and more flexible use of knowledge to improve their innovation performance. At the same time, cooperation with companies from other industries benefited the cultural and creative industries, as they lack the necessary resources and opportunities to develop innovative ideas, although they have a large volume of creative knowledge and ideas. Networking enhanced the creativity and innovativeness of firms, which positively impacted their competitiveness. It is noted that the cooperation of companies with the cultural and creative industries increased corporate social responsibility, promoted marketing strategy, the creation of new products and services and, ultimately, innovations. Ochoa, Arranz and Arroyabe (2023) explored innovation networks in relation with the European Mission on Climate-neutral and smart cities (2030). They found that innovation networks with more members and complex yet balanced interconnections had greater success rates, especially when led by research institutions or private enterprises.

Bellavitis and Kamuriwo (2014) examined start-ups in the UK that were funded with venture capital. The enterprise network connects companies from different industries with the same investor. The study results showed that the network in which a company participates strongly impacts its success. External ties were directly and positively related to a firm's probability of successfully exiting the market, while internal ties negatively impacted firm performance. The optimal balance of connections could lead to an increase in the efficiency of the enterprise. Another special case was small and medium-sized enterprises. Lasagni (2012) found that when an enterprise was the active party in its relations with innovative suppliers, users and customers and purposefully used its capabilities and advantages, its innovation performance was higher than in enterprises that just wait to be asked to work together. Due to the limited resources typically available to SMEs, Tomlinson and Fai (2013) highlighted the availability of access to a wide range of technological capabilities. They could be provided through exchanging information and pooling resources thanks to the connections between enterprises within an established network. The research found that close cooperation in production activities between network participants increased the capacity of enterprises for both product and process innovation. At the same time, cooperation with competitors didn't significantly impact innovation activity.

Knowledge sharing was one of the most reported effects for network participants. It was a prerequisite and outcome of collaborative planning and implementation of innovation activity in the network and positively impacted innovation outcomes. The conclusion of Wang and Hu (2020) was that "without a high level of knowledge sharing, the desired level of innovation performance cannot be guaranteed by engaging in joint innovation activities alone." Knowledge sharing has been empirically shown to partially mediate the relationship between collaborative innovation activities and firm innovation performance. According to Tzabbar et al. (2008) the pooling of knowledge of several actors enabled knowledge to be combined and linked and led to greater returns than the aggregate result when each firm acted on its own. Laursen and Salter (2013) discuss the contradiction between openness and commercialization. On the one hand, there is the need for cooperation and the sharing of ideas between different entities in creating and introducing innovations, which is necessary to share information outside the organization. On the other hand, when striving to achieve the maximum return on investment in innovation, the firm must protect its secrets. Lawson et al. (2009) explored the transfer of

knowledge between buyers and suppliers and the resulting social ties and inter-organizational development through formal mechanisms. Product development managers are encouraged to build teams, increase knowledge flow, and improve both product development outcomes and financial performance.

4. Results

The temporal distribution of all the 66 analysed papers is presented in Table 1. The patterns in the development of the empirical study showed that the interest grew substantially after 2005, and in the later years, research activities remained strong with a continuous increase in level.

Table 1. Temporal structure of empirical research of innovation networks

Time period (years)	Publications included (Number)	Publications included (Number per year)
Before 2005	5	2.50
2005 – 2014	30	3.33
2015 – 2023	31	3.88
Total:	66	2.13

Source: Authors' calculations

Systematization of the empirical research in the aforementioned 66 publications (Table 2) led to formation of 4 major research areas, each with its own subdivisions. The first area (14 papers) covered the creation of innovation networks (5 papers), typology (5 papers) and structure (4 papers). The second area (19 papers) included publications about development, activities and interactions of innovation networks in spatial (3 papers), networks position (2 papers), digitalization (2 papers), performance (3 papers) and knowledge transfer perspective (9 papers). The third area (26 papers) encompassed factor influencing innovation networks performance with four topic – management and knowledge transfer factors (8 papers), spatial factors (5 papers), social capital (10 papers), and institutional factors (3 papers). The fourth area (16 papers) was focused on the outcomes from the innovation networks' activities summarized in three topics – direct economic benefits (8 papers), indirect economic benefits (4 papers), and social effects (4 papers).

The research focus was concentrated on the factors, fact also mentioned by Voorberg et al. (2015), followed by the networks' activities, while the topics of major research interest were knowledge transfer and direct economic benefits. Empirical studies were concerned with the means of knowledge diffusion and the resulting economic gains. Network typology, structure and members' position inside the network received relatively less research attention.

Table 2. Summary of empirical studies of formal and informal innovation networks

Area	Topic	Authors	Interesting Ideas
Innovation network creation and structure	Creation	Pittaway et al. (2004); Goyal (2009); Giuliani (2013); McEvily et al. (2014); Šūmane et al. (2018)	Šūmane et al. (2018)– flexible models. Pittaway et al. (2004)– third parties' contribution. Giuliani (2013)– hierarchical structure.
	Forms and models	Volberda et al. (2010); Bodas Freitas et al. (2013); Ter Wal et al. (2016); Tahi et al. (2022); Hurmelinna-Laukkanen et al. (2021).	Ter Wal et al. (2016) – access and expertise.
	Structure	Cowan & Jonard (2003); Owen-Smith & Powell (2004); Balkundi & Killduff (2006); Li et al. (2023)	Li et al. (2023). – structure heterogeneity and crucial role of linking between sub-networks
Innovation networks development, activities, interactions	Spatial Perspective	Press (2006); Thompson (2018); Wang & Zhang (2022).	

	Network Position Perspective	Giuliani (2013); Goswami et al. (2023)	Cohesion vs. hierarchy.
	Digitization Perspective	Arvidsson & Mønsted (2018); Nambisan et al. (2019)	
	Performance Perspective	Almeida et al. (2003); Swan & Scarbrough (2005); Vicsek et al. (2016)	Vicsek et al. (2016)– communication role. Controversy – networks vs. market forms.
	Knowledge Transfer Perspective	Lawson et al. (2009); Burt et al. (2013); Carnabuci & Operti (2013); Li Mingze et al. (2017); Szilágyi (2017); Chen et al. (2019); Dimitrova & Dakova (2021); Sun et al. (2022); Zhou (2022)	
Factors, influencing innovation networks performance	Management and knowledge transfer factors	Swan & Scarbrough (2005); Gilson et al. (2009); Klerkx et al. (2010); Yenyurt et al. (2014); Voorberg et al. (2015); Savino et al. (2017); Lungeanu et al. (2022); Liu et al. (2022)	Voorberg et al. (2014) – factors were the primary focus of innovation networks empirical research. Savino et al. (2017); Lungeanu et al. (2022) – the importance of the diversity of knowledge. Gilson et al. (2005) – vertical disintegration and contraction for innovation. Klerkx et al. (2009)– adaptive management.
	Spatial factors	Gittelman (2007); Morrison et al. (2013); Binz et al. (2014); Nambisan et al. (2019); Liu, Fang, & Chi (2022)	Nambisan et al. (2019)– digitalization vs. localization. Liu, Fang, & Chi (2022)– diminishing geography impact
	Social capital factors	Hinrichs et al. (2004); Mu et al. (2008); Kaasa (2009); Cheung et al. (2010); Zheng (2010); Malecki (2012); Barroso-Méndez et al. (2020); Yun et al. (2020); Mukherjee & Jain (2022); Wang & Zhu (2022)	Mukherjee & Jain (2022)– U-shaped impact form
	Institutional factors	Spielman et al. (2011); Schøtt & Jensen (2016); Godlewska et al. (2022)	
Results from innovation networks activities	Direct economic impact	Pittaway et al. (2004); Lawson et al. (2009); Tomlinson (2010); Bellavitis et al. (2014); Laursen & Salter (2014); Yenyurt et al. (2014); Santoro et al. (2020); Wang & Hu (2020)	Laursen & Salter (2014)– contradiction openness vs. commercialization.
	Indirect economic impact	Tzabbar et al. (2008); Perkmann et al. (2011); Lasagni (2012); Tomlinson & Fai (2013)	
	Social impact	Perkmann et al. (2011); Yenyurt et al. (2014); Santoro et al. (2020); Ochoa, Arranz, & Arroyabe (2023)	Ochoa, Arranz, & Arroyabe (2023) – transitioning toward climate-neutral urban objectives

Source: Authors' contribution

With the accumulation of empirical data and the advancement of concomitant theoretical research, the focus of the empirical studies shifted (Table 3). In the first period – before 2005, research was concerned with the establishment and functioning of the innovation networks – 83.3% of the publications were in the areas of innovation network creation and structure, and innovation network development, activities and interactions. In the second period – 2005-2014, the focus moved to the factors influencing the performance of the networks and the outcomes for the participants and third parties – 66.7% of the publications were in the areas of factors influencing innovation networks performance and results from innovation networks activities. In the third period – 2015-2023, the interest in factors continues to be strong, while the focus shifted back from the outcomes to the functioning of the networks – 72.7% of the publications were in the areas of factors influencing innovation network performance, and innovation networks development, activities and interactions. Overall, the factors remained the most explored area, followed by the innovation networks development, activities and interactions.

Table 3. Detailed Temporal & Ares structure of empirical research of innovation networks

Area	Till 2004	2005 – 2014	2015 – 2023	Total
1. Innovation network creation and structure	3	6	5	14
1.1. Creation	1	3	1	5
1.2. Forms and models	0	2	3	5
1.3. Structure	2	1	1	4
2. Innovation networks development, activities, interactions	1	6	12	19
2.1. Spatial Perspective	0	1	2	3
2.2. Network Position Perspective	0	1	1	2
2.3. Digitization Perspective	0	0	2	2
2.4. Performance Perspective	1	1	1	3
2.5. Knowledge Transfer Perspective	0	3	6	9
3. Factors influencing innovation networks' performance	1	13	12	26
3.1. Management and knowledge transfer factors	0	4	4	8
3.2. Spatial factors	0	3	2	5
3.3. Social capital factors	1	5	4	10
3.4. Institutional factors	0	1	2	3
4. Results from innovation network activities	1	11	4	16
4.1. Direct economic impact	1	5	2	8
4.2. Indirect economic impact	0	4	0	4
4.3. Social impact	0	2	2	4

Source: Authors' calculations

The main findings of the empirical studies gravitated around common consolidated topics while in some particular cases were identified interesting and peculiar novelties.

The formation of networks, whether formal or informal, was the result of the participants' desire to share and draw on knowledge and experience, which collectively generated a synergistic effect on their organizational development. From here, it can be concluded that networks were regarded as a means of achieving a multiplier effect in various economic and social systems. Economic and social impacts on network participants were the main motivators for membership, with formal networks being more resilient and informal networks being more flexible. To a large extent, the density of the network and the participants' expertise were the basis of good interaction and rapid knowledge transfer. At the same time, the previous participation of some agents could act as a catalyst for the intensity of transfer and absorption, as well as for the degree of cooperation between them.

The development of both formal and informal networks implied such interaction as to satisfy the participants. Practice has shown that open specialized and closed diverse networks are much more productive than closed specialized and open diverse networks. This fact should be considered when building and developing networks. The factors that influence the success or failure of innovation networks were linked on one side to the internal structure and development of the network itself and on the other – to the network's surroundings and interaction with it. Internal factors outlined by the empirical research were the management of network structure and knowledge sharing, as well as the spatial aspects of innovation networks. External factors consisted of social capital and its cultural elements, as well as institutional role in supporting innovation networks.

The main outcome of the innovation network functioning was knowledge transfer. Although knowledge was the primary goal of any network and the collaboration between the participants, many of them were also concerned with the application of that knowledge and its consequences – the direct and indirect economic benefits and social impact. The enterprises were interested in the economic effects that included lowering the cost of production and speeding product development, achieving better product quality, developing faster market access, and, as a whole, increasing the firm's competitiveness. Indirect economic benefits included human capital improvement, resource complementation, organizational learning, and higher creativeness. At the same time, social were connected with the development of trust among the participants, increased desire for cooperation, cultivating networking culture, getting access to academic networks and expertise, improved reputation, and formalization of connections.

5. Discussion

Systematization of the research topics and results of empirical studies pointed out several interesting problematic areas where no consensus was achieved. Instead, the results of different authors were contradictory, establishing the peculiarity of the regions, which were influenced by different factors and developed in different conditions.

Goswami et al. (2023) pointed out that innovation networks had no well-established hierarchical structures. On the other side, Giuliani (2013) observed formation of the hierarchical structures in regional clusters. At first glance, there was a contradiction between the results of these two studies, but closer examination revealed that they were, in fact, in consent with each other. The results of Goswami et al. were influenced by the specifics of the firms and networks in the study – they were homogeneous, and there was no prior distribution of power positions among them. In contrast, when networks were to be formed with some already existing connections among the participants, their relative abilities may differ, and their resource abundance and communication experience could lead to asymmetrical relations. Giuliani observed such heterogeneity in regional clusters, where the firms with more capabilities occupied privileged positions within the local network. The hierarchical structure proved beneficial to the network as the stronger companies were able to establish many new connections, which increased both the network's attractiveness and its cohesive effect. That is, the hierarchy is in close relation to the diversity of the participants, their fundamental determinant properties (activities and resources) and interdependency (Hurmelinna-Laukkanen et al., 2021), the heterogeneity and regional specifics (Li et al., 2023). The private actors could benefit from the control of the knowledge transfer flows (Tahi et al., 2022), facilitating network development, resulting in the heterogeneous network developing a hierarchical structure easier than a network with symmetrical relations and equally important participants. Still, a dominating opinion has not been formed on when an informal network should be transformed into a formal one, what the characteristics of this transition are, and what the tools are for its effective management. Formal networks often have an informal hierarchy that has arisen naturally in the context of individual participants' activity and intensity of communication, and the history of ties prior to involvement. At the same time, formal networks often have overlapping hierarchical systems that combine formal and informal, with the informal dominating within network initiatives and interactions. Some latest research revealed that formal networks were better at limiting the hampering behaviour of the public administration (Godlewska et al., 2022).

Another contradiction was the comparison between networks and other organizational forms emerging from market relations. Almeida et al. (2003) found that multinational corporations outperformed innovation networks in successful knowledge transfer and implementation. Swan and Scarbrough (2005) discovered that networks possessed distinct advantages over market-based forms. The contradiction could be attributed, first, to the different scopes of the studies. Almeida et al. (2003) research covered only one particular economic segment – semiconductor companies, while Swan and Scarbrough's (2005) case study concerned only three enterprises. In the second place, while Swan and Scarbrough established that networks outperform due to the knowledge becoming more widely distributed and innovation increasingly occurring at the interstices of collaborating groups and organizations, this was not common in the semiconductor sector where new knowledge was heavily guarded and rarely subject to the open innovation policy. Third, Swan and Scarbrough found that the

coordination of networks played a particularly crucial role, and that's the place where multinational corporations excelled, with strong abilities to use flexible mechanisms of knowledge transfer and simultaneous movement, integration, and development of technical knowledge. Thus, the relative performance of networks and corporations depends on the knowledge openness and level of coordination, with the regional development level also playing an important role (Wang, Zhang, 2022). When networks were well coordinated and an open innovation policy was present, they could potentially outperform market forms. At the same time, in areas with intense competition and less knowledge sharing, corporations take the lead with their superior abilities to muster and utilize more resources faster and efficiently.

The pivotal role of social capital in the formation, development, and success of innovation networks was well established in different aspects of research. The diversity of members expertise and available knowledge, the complementarity of the resources and the centrality of the networks assisted innovation performance (Barroso-Méndez et al., 2020; Lungeanu et al., 2022; Wang, Zhu, 2022). At the same time, results showed that private enterprises preferred non-diverse, in-depth technical cooperation (Du et al., 2023).

The mechanics of knowledge transfer was the focus of the empirical research in relation to the policy development, supporting factors and organizational forms that facilitated the reliable and successful implementation of the new knowledge. The findings were somewhat controversial and pointed out to the need of further research in the area. The dyads and other subgroups influenced the resilience of the networks and the knowledge transfer (Barroso-Méndez et al., 2020). Social brokerage was beneficial in the extremes – either as well established, that was both logical and expected but – unexpectedly, also when was almost non-existent (Mukherjee, Jain, 2022).

The balanced connections facilitated knowledge sharing in bigger networks led by private enterprises or academic institutions (Ochoa, Arranz, Arroyabe, 2023).

A gap in the studies was that most of them focused on analysing individual cases and processes but did not thoroughly examine the impact of digitalization on the development of networks. In those few, concerning digital innovations (Nambisan et al., 2019), the critical role of digital transformation of the economy at both macro and micro level was emphasized with the benefits of increasing the speed in knowledge transfer, development of new opportunities, removing some restrictions, accelerating innovation implementation, assisting the reengineering, and facilitating the openness and cooperation.

Besides digitalization, interesting areas for empirical and also theoretical research could be derived from the summarized studies, like the psychological peculiarities of the people who engage in network activities more than others and benefit from the contacts in which they are embedded (Burt et al., 2013); the possible relation between business size, stage of its life cycle and motivation to participate in networks (Almeida et al., 2003); the balance between formal and informal contacts and factors influencing it; the relation between the type of network and innovation results (Santoro et al., 2018); the impact of network topologies on industrial and regional development (Owen-Smith, Powell, 2004); the role of universities in innovation hubs (D'este, Perkmann, 2011);

Conclusions

Innovation networks emerged at the intersection of helixes when the participant's desire to share knowledge and experience was combined with pre-existing cooperation. Networks' performance, resilience, and flexibility were studied closely in relation to knowledge transfer. A strong focus was found on the factors influencing innovation networks with social capital as the primary cause for success or failure, followed by the importance of management and the spatial aspects of networks and knowledge sharing. Results from the activities of the innovation networks were considered with emphasis on the economic benefits for the enterprises and the development of networking culture in the society.

Issues related to the intensity of formal and informal contacts between participants and their influence on the transformation and/or development of the network, as well as the contribution of formal and informal networks to the diffusion of knowledge and innovations, have been poorly researched and are the primary topic for further study. Another interesting problem is the dependence of the network's sustainability on the number of participants and the intensity of the connections between them.

Research Novelty. The research showed that some seemingly opposite views regarding the development of innovation networks complemented each other, suggesting a more in-depth analysis of the prospects for developing formal and informal innovation networks. The structuring of up-to-date scientific knowledge on the subject provides a starting point for the search for solutions for intervening impact on the factors that influence network development, as well as for the search for an appropriate toolkit to increase the direct, indirect and social impact of the functioning of networks. Promising areas for future research have been outlined based on the systematization of the accumulated scientific knowledge. As such, the process of transformation of networks and the influence of the intensity of formal and informal contacts between participants can be indicated, as well as their impact on the sustainability of networks and their impact on innovation potential and the development of an innovation culture.

Research Limitations. The study presents an overview of the author's research in the field of formal and informal innovation networks in four thematic areas: creation of innovation networks, structure and participants; evolution of innovation networks, activities and interactions; factors affecting innovation networks; results of innovation network activities for participants and third parties. Issues related to digital transformation, artificial intelligence, and their place in the functioning of the network and the interaction between network participants remain outside the scope of the article. Tools for intensifying interaction, creating new knowledge and its transfer, as well as approaches to ensure sustainability are also beyond the scope of this analysis. Systematization also showed several inconsistencies in results and gaps in empirical research that outline the need for more research.

Practical Implications. The systematization of already accumulated knowledge showed the multidisciplinary problem in the context of the wide application of innovation networks and outlined similar impacts under different factor conditions. In practical terms, this means that, to a large extent, the lessons learned and good practices can be transferred to different case studies without requiring narrow specifications and practice adaptation. The regional approach should be considered in the context of the dependencies the authors identified in the network's development and sustainability. This implies an analysis of regional differences and degree of cohesion and, on this basis, the application of practically working tools in a similar environment to a specific innovation network.

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