Chapter

Importance of Social Networks for Knowledge Sharing and the Impact of Collaboration on Network Innovation in Online Communities

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Abstract

Innovation results from interactions between different sources of knowledge, where these sources aggregate into groups interacting within (intra) and between (inter) groups. Interaction among groups for innovation generation is defined as the process by which an innovation is communicated through certain channels over time among members of a social system. Apart from the discussion about knowledge management within organizations and the discussion about social network analysis of organizations on the topic of innovation and talks about various trade-offs between strength of ties and bridging ties between different organizational groups, within the topic of open source software (OSS) development researchers have used social network theories to investigate OSS phenomenon including communication among developers. It is already known that OSS groups are more networked than the most organizational communities; In OSS network, programmers can join, participate and leave a project at any time, and in fact developers can collaborate not only within the same project but also among different projects or teams. One distinguished feature of the open source software (OSS) development model is the cooperation and collaboration among the members, which will cause various social networks to emerge. In this chapter, the existing gap in the literature with regard to the analysis of cluster or group structure as an input and cluster or group innovation as an output will be addressed, where the focus is on "impact of network cluster structure on cluster innovation and growth" by Behfar et al., that is, how intra- and inter-cluster coupling, structural holes and tie strength impact cluster innovation and growth, and "knowledge management in OSS communities: relationship between dense and sparse network structures." by Behfar et al., that is, knowledge transfer in dense network (inside groups) impacts on knowledge transfer in sparse network (between groups).

Keywords: social networks, knowledge sharing, OSS development, collaboration, network innovation, online communities

1. Introduction

In organizational and information science, research topics related to network structure properties (e.g. degree distribution, network tie strength (weak-strong) and network cluster shape (dense-sparse)) have been studied in various articles because of their significant applications including (1) network generation, design and reproduction (e.g. "Emergence of scaling in random networks" by Barabási and Albert [1], "On power-law relationships of the internet topology" by Faloutsos et al. [2]), (2) social network analysis (e.g. "Creating social contagion through viral product design…" by Aral and Walker [3], "Optimal and scalable distribution of content updates over a mobile social network" by Ioannidis and Chaintreau [4]), (3) impact of network structure on network innovation (e.g. "Collaboration networks, structural holes, and innovation…" emphasizing the impact of direct and indirect ties on firm innovation by Ahuja [5], "Network structure of social capital" investigating the impact of sparse network structure on facilitating diffusion of ideas by Burt [6]) and (4) knowledge management among open-source-software (OSS) developers (e.g. "Location, location, location: how network embeddedness affects project success in open source systems" by Grewal et al. [7], "Knowledge transfer within information system development teams: examining the role of knowledge source attributes" by Joshi and Sarker [8]). However, to our best knowledge, there has been no study in the literature which explains impact of network structure on innovation and growth at group or cluster level. We will address this issue in this chapter, and explain the impact of group dynamics on OSS project group innovation (i.e. group intra- and inter-coupling as causal factors for group innovation and growth), also discuss knowledge management and intergroup diffusion of innovation (i.e. influence of knowledge diffusion within dense groups measured by intragroup density, degree centrality and betweenness onto knowledge diffusion between sparse groups measured by intergroup coupling).

We focus on clusters or groups rather than individuals as the level of analysis for both network structure as input and innovation diffusion as output, because (1) clusters represent collective impact on network output rather than individuals' impact, (2) impact of intra cluster couplings on cluster innovation and growth is different from the impact of inter cluster couplings on cluster innovation and growth and (3) trade-offs among dense and sparse network cluster structures are different from those associated with networks of individuals.

As the domain of interest, we have chosen open source software (OSS) collaboration network (or so-called OSS communities), where almost all prior works on OSS are concerned with project success measured by number of downloads or number of concurrent versions system (CVS) commits, and ignores group success measured by group growth and innovation. Group is referred to one including small or big number of developers who work on some or many project tasks. In addition, OSS developer is the unit of analysis, where two developers working on the same project task builds a tie in the network.

2. What is a network?

A network is a set of interlinked nodes, which can be simple, such as a lattice, random network or a complex network (a graph with non-trivial topological features that are not found in simple networks). However, most complex structures can be realized by networks with a medium number of interactions [9]. What is in fact a complex network?

2.1 Complex networks

A complex network is composed of nodes and links, or modules and dependencies, where a module is a component whose structural elements are strongly intra-connected and relatively weakly inter-connected to other modules [10]. A complex network is used to model complex systems, where a complex system is "one made up of a large number of parts that interact in a non-simple way; in such systems the whole is more than the sum of parts, at least in the important pragmatic sense that given the properties of the parts and the laws of the interaction, it is not a trivial matter to infer the properties of the whole" ([11], p. 195). Simon viewed firms as hierarchical systems made of subsystems that are loosely coupled vertically and horizontally, and interact based on input and output. Loose coupling implies that interactions among subsystems are much weaker than interactions within subsystems.

2.2 Network clusters

In the context of organizational science, a cluster is defined as an ensemble of various firms and institutions that interact formally and informally via agreements and transactions or informal occasional meetings that collectively contribute to innovation within a given industry. An innovation cluster includes an ensemble of various organizations and institutions "(a) that are defined by respective geographic locations occurring at variable spatial scales, (b) that interact formally and/or informally through inter-organizational and/or interpersonal regular or more occasional relationships and networks (c) that contribute collectively to the achievement of all kinds of innovations within a given industry or domain of activity, i.e. within a domain defined by specific fields of knowledge, competences and technologies" ([12], p. 18). Innovative interaction among clusters is defined as "the process by which an innovation is communicated through certain channels over time among members of a social system" [13].

There are also definitions of industrial clusters: industrial clusters are "geographically proximate firms in vertical and horizontal relationships involving a localized enterprise support infrastructure with shared developmental vision for business growth, based on competition and cooperation in a specific market field" [14]. Clusters and industrial districts are synonymous, whereas the concept of a network is more general, and it does not necessarily entail local embedding, a shared objective, or a specific market ([15], p. 4).

In information systems, the notion of cluster cannot be precisely defined (see [16]); however, a group of data objects is a common definition. The notion of a cluster is determined by different cluster models which themselves vary significantly in their properties. In social networks, Watts and Strogatz [17] have shown that nodes tend to be made of tightly knitted groups identified by a relatively high density of ties with likelihood greater than the average probability of a randomly established tie. Clustering in social network analysis has been discussed by Wasserman and Faust [18] and Opsahl and Panzarasa [19].

2.3 Network structural properties

In network theory, graphs could be classified according to two independent structural features: clustering coefficient and average shortest path length (average node-to-node distance). Purely random graphs, according to the Erdős-Rényi (ER) [20] and Watts and Strogatz [17], feature a small average shortest path length along with a small clustering coefficient, this varies in terms of the logarithm of the number of nodes. According to Watts and Strogatz [17], many real-world networks have a small average shortest path length and high clustering coefficient; they proposed small-world network with the properties (i) a small average shortest path length and (ii) a large clustering coefficient [21].

Using network structure models, one can simulate complex network structure based on analyzing link formation or predict network structure based on link prediction models. There have been primary contributions in the area of network models; Erdős-Rényi [20] presented non-growing randomly connected network model (ER); Watts and Strogatz [17] presented non-growing randomly re-connected network model (so-called small world) (WS) and Barabási-Albert [1] presented a network grow model, so-called preferential attachment model or rich-get-richer (BA). In this model, probability of adding new nodes is proportional to the number of incoming links. According to ER and WS models, the number of nodes in the network is fixed, where the linkages among existing link formation nodes are built. On the other hand, BA model assumes time-homogeneous network growth with a mechanism for preferential attachment link formation. We use this cluster/group concept throughout this chapter.

In the paper "Directed networks' different link formation mechanisms causing degree distribution distinction" by Behfar et al. [22], we discussed the network structural property of degree distribution distinction in different network levels of decomposition from dependency in a cluster of open-source-software (OSS) projects down to software project corpus dependency. We emphasized the importance of the study of in/out degree distribution distinction, and discussed why the type of distribution is significant in terms of (a) structural property of complex networks, (b) statistical property of complex networks, (c) self-organizing property of complex networks and (d) decomposability property of complex networks.

We distinguished between in and out degree distributions, and claimed link formation mechanisms as a causal factor for this distinction. First, we discussed the importance of directed networks, and why outlinks are important, which have been often neglected in the previous studies. Second, we identified the causal factors for distinction between in and outdegree for the sample network of OSS projects as well as the Java software corpus as a network. Third, we analyzed whether this distinction holds for different levels of decomposition from project-project dependency to package-package dependency and down to class-class dependency. We proved our hypotheses both analytically and empirically and concluded that in/outdegree dependencies do not follow similar types of degree distributions, where indegree dependencies follow power-law distribution, in some cases power-law with flat-top or exponential cut-off, while outdegree dependencies do not follow power-law/heavy-tailed distribution, in most cases they follow exponential distribution.

3. What is innovation in a network perspective?

Innovation is shown to be interactive, cooperative and cumulative [5] and it emerges through a combination of many sources of knowledge connected through a network. Innovation could be (1) incremental (creative accumulation), which is always based on already existing innovation or (2) radical (creative destruction), which is created by combining all new skill sets [23]. For new product development as products become modular, collaboration becomes essential, since individuals do not possess all the required knowledge to accomplish innovation [24] and knowledge is distributed among individuals within a complex system.

Rogers [13] defined "innovation diffusion as the process by which an innovation is communicated through certain channels over time among members of a social system". There have been papers in the literature in various topics e.g. diffusion of innovation in manufacturing and service industries, healthcare and education [25]. Rogers also gave the first typology of innovation diffusion covering innovation, diffusion networks and rate of adoption in different social systems. Generally, the study of innovation, see Rogers [13], covers new product, process or market generation, adoption and implementation.

Inside organizations, units can learn from each other and knowledge diffusion can provide new mutual opportunities for units as well as the whole organization. Huber [26] suggested that organizational units transfer knowledge and learn from other units, in case those units have the capacity to access to new knowledge, which can be obtained and improved by networking. Other authors such as Hansen [27] attempted to model an organization as a complex network where units are inter-connected; knowledge transfer within this organization can be investigated by analyzing this complex network. Kogut and Zander [28] and Tsai [29] also modeled organizations as a social network and suggested that social networks facilitate the creation of new knowledge within organizations. Moreover, Tsai [30] also discussed how organizational units can gain useful knowledge from other units to improve its innovation and performance, also emphasized the role of strong ties in intra-corporate and strategic alliances. Apart from strong ties within organizations, Hansen [27] investigated transfer and sharing of knowledge and emphasized the role of weak ties in organizations.

In the field of knowledge sharing, for example, Ma and Agarwal [31] discussed the role of perceived identity in augmenting knowledge sharing and Ren et al. [32] investigated the role of similarities in direct reciprocity and design of online communities. As an alternative approach, DiMaggio and Powell [33] argued that under conditions of doubt or uncertainty, innovation occurs through inter-organizational imitation because organizations learn from similar organizations or from industry leaders. Researchers have investigated the importance of networks for knowledge sharing and the impact of collaboration on overall network performance. Knowledge-sharing network model elements are represented in **Table 1**.

3.1 Open source software (OSS) communities

OSS projects are accounted as a significant economic, social and cultural phenomenon [34]. Initially there were doubts over the quality of OSS products, which software industry was struggling to find innovative methods to develop quality products; at the same time, Linux and the Apache server attained a big success and demonstrated a new approach to produce reliable and high-quality products that are also inexpensive [35]. Due to these advantages, OSS development claimed to have the potential to compete with traditionally produced software, also to replace traditional development methods [36].

In fact, OSS communities provide alternative strategies for knowledge creation and growth, implement innovations and new product development [34, 37]. Nevertheless, software developers are now facing new labor market, where participation in OSS

Network node	Organization (SMEs)
Tie	Knowledge-sharing activity
Tie strength	Frequency of activity
Tie diversity	Type of activity (joint team, project collaboration)
Tie content	Knowledge (know-how, information, asset)

Table 1.
Details of knowledge-sharing network model.

projects could lead to increased salaries and improved job security. In fact, three forms of competitive advantage have emerged: verifiable technical skills, peer-certified competencies and positional power, as stated by Riehle [38].

Considering the significance of this phenomenon, researchers have widely used social network analysis (SNA) to model behavior of communication intra and inter groups in OSS communities. According to Jackson [39], the positions and relationships among developers in a social network are significant in the efficiency of the network, where they use different tools and techniques such as SNA. Grewal et al. [7] and Singh et al. [40] also state that success of many OSS projects is closely related to the communication structure in OSS network. Also, according to Grewal et al. [7], the distinguished feature of the OSS development is that cooperation and collaboration among members cause various social networks to emerge.

Many companies such as IBM, Google, Sun Microsystem and Oracle have decided to integrate OSS projects into their business operation. Other firms are also looking for business opportunities associated with OSS projects [37]. Moreover, public or private institutions also attempt to incorporate open source software in their business model. On the other hand, reliance on open software systems increases concerns over software security, and whether we can trust different platforms. OSS success should also help policy makers to better understand and implement their strategies considering different opportunities and threats [41].

3.2 Network ties and coupling

Granovetter [42] proposed a network theory which links micro and macro levels of sociological theory through analysis of weak ties bridging groups otherwise connected by strong ties. In a simple definition, strong ties are relationships with individuals whom we know very well, on the other hand, weak ties provide bridges over which innovations cross over boundaries of social groups, which are in fact strongly tied.

Weick [43] initially defined the concept of loose coupling; Orton and Weick [43] made a literature review on loose coupling, continued research on the topic, mentioned more and useful interpretations. Based on Granovetter definition of weak-vs.-strong ties and Weick definition of loose coupling, Girvan and Newman [44] defined the concept of "community structure" as a new property of sociological and biological networks, where nodes join together in tightly knit groups which are loosely connected to each other.

Granovetter [42] argued that we can separate our relationship networks into a circle of close friends with strong ties and a circle of acquaintances with weak ties. Strong ties lead to clusters of communities, while weak ties connect those communities. Weak ties are significant for content dissemination due to the graph-theoretic effect of edge expansion. Weak ties could accelerate diffusion of job information [42], adoption of new technology [13] and coordination of collective action. The concept of strong and weak ties has been extensively used in organization systems, for example, Hansen [27], Kogut and Zander [28] and Tsai [29, 30].

3.3 Network ties and innovation

Some studies in the literature attempted to link network structure and innovation output by analyzing the impact of tie strength on innovation [27, 29, 42]. In addition, Hansen [27] thoroughly discussed the impact of weak versus strong ties, and investigated moderating effect of knowledge complexity on project time completion. Hansen concluded that weak ties reduce project time completion, but this effect is moderated by knowledge complexity. Ahuja [5] investigated the impact of direct and indirect ties on firm innovation, and concluded that the more direct ties that a firm possess, the greater would be the firm's subsequent innovation output, on the other hand the more indirect ties, the greater the innovation output. Shane [45] investigated network relationship among firms which could impact on the rate of innovation; this permits knowledge sharing and information flow. There are also other studies in the network literature focusing within topic of knowledge sharing and innovation adoption; in these studies, importance has been rendered to the number of firm linkages and geographical proximity impacting rate of adoption [46, 47].

Some studies have shown that innovation generation benefits from network structural holes, moderated by type of innovation and type of firm. Some types of new technology diffusion require trust and cooperation between firms, which corresponds to fewer structural holes. For some other types of firms where information brokerage is the primary business, more structural holes are necessary for knowledge sharing [5, 48]; other scientists have investigated the distinction between sparse and dense network structure to promote network innovation. Walker et al. [49] argued that strong ties are required for the exchange of complex knowledge, while a dense network structure impacts on the implementation of ideas within each group. Burt [48] stressed that a sparse network structure facilitates diffusion of ideas and argued that strong ties within a dense network due to lack of diversity in resources are inefficient to acquire external knowledge.

Moreover, Cowan et al. [50] wrote that many empirical studies investigating creation of knowledge demonstrate that innovation to a large extent is obtained via recombination of existing knowledge. They examined the evolution of networks when innovation is resulted from agents accumulating their knowledge endowments, based on the assumption that agents freely form pairs in a globally stable balance, and that paired agents combine their existing knowledge to create new knowledge.

By now, we have discussed definition of innovation in a network perspective, OSS communities, network ties and coupling and network ties and innovation in order to investigate impact of network structure on group innovation within domain of open source software. While prior researches have given insights into performance of OSS projects, they usually ignore impact of network structure on group innovation. Therefore, we claim that there is a need for a new conceptualization composing of different factors influencing on innovation and growth at group level. These factors include network embeddedness or structure parameters, for example, intra- and inter-cluster coupling, structural holes and tie strength impact group innovation, which we have addressed in the paper "Network tie structure causing OSS group innovation and growth" by Behfar et al. [51].

Open Source Software (OSS) project collaboration constitutes a new means of producing goods and services by self-organizing groups within worldwide virtual networks, and represents a new form of partnership between businesses and customers. More companies are now attempting to establish relationships to benefit from these potential value-creating groups. This makes it essential to investigate these communities further and see how to improve their success rate. Hahn et al. [52] investigated the personal factors causing a new developer to join a project, whereas in this study we are only concerned about network structural factors that influence developers to join existing projects or initiate new projects within a group. In other words, we investigated network structure as causal factor influencing both new project initiation within a group (representing group innovation) as well as new developers joining existing projects within a group (representing group growth).

We discussed three aspects of network structure—tie strength, group coupling and structural hole—as impacting innovation output. At the same time, we provided four hypotheses: (1) intra-group coupling has a positive impact on group growth, (2) inter-group coupling has positive impact on group innovation, (3) inter-group structural hole has a positive impact on group innovation and (4) there is a trade-off between the effects of inter-group structural hole and inter-group coupling on group innovation. We discussed the logic and provided empirical analysis to validate these hypotheses. Developers contributing to project tasks in groups other than their own can access novel ideas for new project creation, whereas developers contributing to project tasks inside their group exploit ideas to improve those existing projects with better inside-group search possibility. This demands more developers to existing projects.

Project managers could target different goals within software development teams including increasing project success rate, bolstering innovation within teams or attracting more developers to join existing projects. Targeting task contribution between groups or intergroup structural hole make achieve more group innovation, whereas targeting number of task contributions inside a group or number of users per task makes achieve more group growth. The number of developers contributing to each task indicates how popular each project task is; and the more popular each task is the higher the number of developers contributing to the task, which indicates group coupling, and this could lead to group innovation.

4. What is knowledge management in a network perspective?

Baer et al. [53, 54] performed a meta-analysis of literature on innovation and social networks and presented various trade-offs between strength of ties and bridging ties among other things. Tsai [29, 30] stated that social networks facilitate creation of new knowledge within organizations, also discussed how organizational units gain useful knowledge from other units to enhance its innovation and performance. Huber [26] investigated knowledge transfer among organizational units, and concluded that not all units have access and capacity to learn knowledge and apply it; they require external access and internal capacity [26]. Moreover, Ahuja [5] discussed firm's network relationship impacting the rate of innovation, where network allows for knowledge sharing and information flow.

4.1 Knowledge diffusion within open source software communities

Cooperation and collaboration among OSS community members is the distinguished feature of any development model, which explores OSS as a social network. It is interesting to know that OSS groups are more networked than the most organizational communities; in OSS network, programmers can join, participate and leave a project groups at any time, and in fact developers can collaborate not only within the same project but also among different projects or teams. One distinguished feature of the open source software (OSS) development model is the cooperation and collaboration among the members, which will cause various social networks to emerge.

Some studies investigated social network structure of open source software, and used long-term popularity as a measure to conclude that previous ties are generally an indicator of past success which would lead to future success [55]. Crowston et al. [50, 56] based on their analysis of social structure of open source software development teams and the interactions among 122 large and active projects, and found out that some projects are highly centralized, and others are not. Other authors also discussed knowledge sharing between team members based on similarity-attraction paradigm; where it was proposed that knowledge sharing more likely happen between same demographic team members [57].

4.2 Network innovation trade-offs

There are different studies in the literature which attempted to link network structure and innovation; where they mention some ambiguities:

1. One ambiguity in studies of the impact of tie strength on innovation concerns the distinction between strong and weak ties [27, 29, 42]. Granovetter [42] initially proposed a theory of weak versus strong ties, which link micro and macro levels of sociological theory through an analysis of various types of weak ties bridging groups otherwise connected by strong ties. Strong ties are relationships with individuals whom we know very well, but weak ties provide bridges which allow innovations to cross boundaries between social groups, which themselves are strongly tied.

2. Ahuja [5] investigated the impact of direct and indirect ties on firm innovation, and reported that more direct ties lead to greater firm's innovation output; and more indirect ties also leads to greater innovation output of the firm. Finally, there is a trade-off between impact of indirect ties and direct ties level on a firm's innovation output.

3. There is also ambiguity regarding the benefit of structural hole which promotes innovation generation moderated by types of firms, and even types of innovation. For some new technology diffusion, trust and cooperation between firms is required, which corresponds to fewer structural holes, whereas for firms where brokerage of information is the primary business, more structural holes are needed (see Burt [48], Ahuja [5]).

4. Lastly, there is also ambiguity concerning the impact of sparse and dense network structure to promote network innovation. Walker et al. [49] stated that dense network structure impacts implementation of idea within each group, and argued that strong ties within dense networks are required for exchange of complex knowledge; on the other side, Burt [48] stressed that a sparse network structure facilitates diffusion of ideas where strong ties within dense network are inefficient to obtain external knowledge because they do not bring diversity in resources.

After discussion over knowledge management in a network perspective, knowledge sharing in OSS communities and network innovation trade-offs concept, we investigate network innovation trade-offs further in order to explore impact of knowledge sharing within dense network structures on knowledge sharing between sparse network structures. Although we focus on the domain of open source software, but the scope is not constrained to OSS, and could generally encompass all group-like structures.

In the paper "Knowledge management in OSS communities: Relationship between dense and sparse network structures" by Behfar et al. [58], we discussed whether knowledge transfer in dense network (inside groups) has an influence on knowledge transfer in sparse network (between groups). For this purpose, we distinguished mechanisms influencing on knowledge transfer within groups as opposed to between groups.

To investigate how intragroup density affects intergroup coupling, we used utility function for each project based on benefit and cost of new link formation. We showed that when initial link is formed between two groups, subsequent link formation is always cost-wise beneficial to be formed, which indicates that intragroup density leads to subsequent intergroup coupling. The reason includes awareness or common neighborhood, which makes this link formation cost-wise beneficial.

In addition, we conducted an empirical analysis to validate the relationship between intragroup density and intergroup coupling using regression model on the OSS data. The results concluded that intragroup density has a positive and significant influence on intergroup coupling. This implies that betweenness has an insignificant influence on intergroup coupling; and degree centrality has a significant but negative influence on intergroup coupling, which indicates that users with high degree centrality do not participate in inter group projects, rather collaborate more with other developers for projects within a group. Our results demonstrate that when users in a group have a lot of in-group tasks to contribute to, given number of users as a constant, the users would be more likely to contribute to tasks in other groups.

The results of this paper could have significant implications for project managers in open source environment, such as IBM and Sun Microsystems actively working in open source projects with decision to sponsor project tasks to promote knowledge transfer between groups. This indicates that to achieve more knowledge transfer between groups, one needs to target number of developers within each group. Consider that the number of developers contributing to project tasks implies how popular each project task is, attracting more developers who can contribute to project tasks which corresponds to more intragroup coupling, leads to more knowledge transfer between groups.

5. Conclusion

This chapter in general was focused on the impact of network structural factors as a proxy for collaboration inside online communities (OSS groups in particular) onto network group innovation and growth. We have already published three papers in this topic, to which we hanged on in order to explain very different subjects in this limited number of pages. We aimed to answer questions (1) how social network of OSS projects influence on new users joining existing projects, or new project initiation within a group, and what kind of strategies should be used to improve it and (2) how knowledge sharing inside dense groups affects knowledge sharing between sparse groups.

We briefly discussed degree distribution distinction as a network structural property, then explained the impact of group dynamics on OSS project group innovation (i.e. group intra- and inter-coupling as causal factors for group innovation). Finally, we reported how knowledge transfer within and between groups are related, in that we explored how network tie density, centrality and betweenness inside groups influence on intergroup coupling. We also mentioned the practical implications, where companies adapt to the threats and opportunities of OSS movements, and exploit those specific strategies to take advantage of OSS projects.

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