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Social network and radical innovation: evidence from the U.S. pharmaceutical and biotechnology industry

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CHAPTER 5

Summary and general discussion

This PhD dissertation aims to unpack the determinants of radical innovation and its social and economic impact in the context of multinational corporations' internal R&D collaboration networks. Specifically, Chapter 2 investigates the social driving forces of radical innovation; Chapter 3 explores the social impact of network structure and the role that radicalness plays in their relationships; Chapter 4 examines the economic impact of different dimensions of radicalness. Driven by three research questions proposed in Chapter 1, this PhD dissertation presents answers in Chapter 2 to Chapter 4. This chapter summarizes the main findings, discusses the implications from theoretical and practical perspectives, and shows the limitations and future research prospects.

5.1 Summary of main findings

Research Question 1: How does network structure affect innovation radicalness?

To address this research question, Chapter 2 studies the relationship between the structure of corporate R&D collaboration networks and radical innovation, more specifically, how tie strength and structural holes collectively affect innovation radicalness at a location within an innovating firm. Chapter 2 separates two faces of weak ties and structural holes: their informational advantages in accessing the diverse knowledge that is needed for radical innovation, and their relational disadvantages linked to a weaker shared understanding and trust. Specifically, Chapter 2 argues (1) tie strength has a negative effect on innovation radicalness because of the informational advantage of weak tie for radical innovation; (2) structural holes have a positive effect on innovation radicalness because of the informational advantage; and (3) there is a positive interaction effect between tie strength and structural holes on innovation radicalness considering the relational disadvantage of weak tie and structural hole for radical innovation.

To test hypotheses, Chapter 2 constructs a unique panel dataset with information about firm R&D locations, their collaboration networks, and innovation outputs. Chapter 2 identifies sampled firms from the 2018 edition of the *EU Industrial R&D Investment Scoreboard* and focuses on U.S. pharmaceutical and biotechnology industry. Patents for each company are retrieved and aggregated at the location level. Building on the data of patent families, Chapter 2 constructs dataset for analysis at the location-time level. The final dataset consists of 16,011 unique locations belonging to 93 companies, with a total number of 19,343 location-time observations. To measure the radicalness of a patent family, Chapter 2 adopts the radicalness index proposed by Funk and Owen-Smith (2017), which captures the degree to which the focal patent destabilizes existing technology trajectories. Tie strength between two R&D locations is captured as their frequency of co-inventing patent families, and structural hole is calculated as the share of missing ties in an egocentric network excluding the ego itself. Besides firm-location fixed effects, confounding variables (e.g., innovation productivity, network size, and collaboration inclination) that may lead to spurious correlations between our focal independent and dependent variables are controlled.

Findings of Chapter 2 show there is a significant negative effect of tie strength on innovation radicalness, confirming the informational advantages of weak ties for radical innovations. On the other hand, Chapter 2 does not observe a significant effect of structural hole in general. More importantly, Chapter 2 observes a significantly positive interaction effect between tie strength and structural hole on innovation radicalness. More specifically, the negative effect of tie strength is weaker when the network is rich in structural holes, and the effect of structural hole is negative when tie strength is weak but positive when tie strength is strong. This suggests that network cohesion is required for mobilizing the informational advantages of weak ties for radical innovation. Similarly, strong ties are needed for mobilizing the informational advantages of structural holes. Chapter 2 enriches the social network and innovation research.

Research Question 2: How does collaboration network structure influence the adoption and future use of its innovation? Would their relationship condition on innovation types (e.g., incremental innovation and radical innovation)?

To answer this research question, Chapter 3 investigates the effects of tie strength and network cohesion and more importantly the moderating effect of innovation radicalness. Chapter 3 contends that when innovation radicalness is low, an innovation is more likely to be successful if its innovator's collaboration network has stronger tie strength. When innovation radicalness is high, an innovation is less likely to be successful if its innovator's collaboration network has stronger tie strength. Similar as tie strength, Chapter 3 argues that when innovation radicalness is low, an innovation is more likely to be successful if its innovator's collaboration network is more cohesive. When innovation radicalness is high, an innovation is less likely to be successful if its innovator's collaboration network more cohesive.

To test hypotheses, Chapter 3 constructs a unique panel dataset with information about firm R&D locations, their collaboration networks, and innovation outputs. Same as Chapter 2, Chapter 3 identifies sampled firms from the 2018 edition of the *EU Industrial R&D Investment Scoreboard* and focuses on U.S. pharmaceutical and biotechnology industry. Patents for each company are retrieved and aggregated at the location level. Innovation success is measured as the average number of patent family citations that a focal location received in a 5-year window, following the social definition of success in terms of acceptance and adoption by future users (Amabile, 1983; Fleming et al., 2007). Tie strength is captured as the frequency of collaboration based on a three-year window, and network density measure is adopted to calculate network cohesion. As measured in Chapter 2, Chapter 3 measures innovation radicalness by adopting the consolidation-or-destabilization (CD) index developed by Funk and Owen-Smith (2017). Firm-location and year fixed effects are included. Chapter 3 also control for network size, innovation productivity, and collaboration inclination.

Empirical results of Chapter 3 confirm our hypotheses. Trust, fine-grained information exchange, and reciprocity norms associated with strong tie and network cohesion facilitate innovation diffusion. Comparing the results of Chapter 3 and Chapter 2, this provides empirical evidence that the weak tie and structural hole that is conducive for producing a creative idea hamper its diffusion. We also observe that the findings only hold for incremental innovation, which consolidates existing technologies and confirms the reciprocity norms. The opposite is true for radical innovation that disrupts existing technologies and has an impact on network partners that is not aligned with reciprocity norms. In addition, the lack of diverse information hinders the identification of new applications for the radical innovation. Findings of Chapter 3 contribute to the literatures of social networks, creativity, and innovation.

Research Question 3: How does the private value of a patent depend on its radicalness? Would destructiveness and dissimilarity have the same effect on private value?

This research question focuses on how the private value of a patent depends on its radicalness. To address this research question, Chapter 4 differentiates between two dimensions of radicalness: destructiveness and dissimilarity. Chapter 4 argues that the private value is lower for patents that are more destructive to existing technology trajectories, because of their higher risk and uncertainty, longer road to profit, and incompatibility with existing firm capabilities. On the other hand, the private value is higher for patents that are more dissimilar to the exiting knowledge, due to the reception reward to dissimilarity and ambiguity. Furthermore, dissimilarity makes it difficult for the market to understand the patented invention and therefore weakens the negative effect of destructiveness.

To test the hypotheses, Chapter 4 integrates several datasets, which are the dataset developed by Kogan et al. (2017), PATSTAT (2019 Autumn Edition) database, and the patent dataset developed by Arts et al. (2021). In total, the sample covers 1,066,637 USPTO utility patents that were granted between 1980 and 2010. The private value is retrieved from the patent dataset developed by Kogan et al. (2017), which is measured as the abnormal stock market return. Following Funk and Owen-Smith (2017), the calculation of destructiveness of a patent is based on citation networks. More specifically, this destructiveness index examines whether patents citing a focal patent also cite its references. Following Arts et al. (2021), the measure of dissimilarity is based on text similarity between a patent and all prior patents filed in the five years before the focal patents. To absorb variation across fields and year dimensions, technology class-grant year pair-level fixed effects is included. The number of patent references and the number of patent citations are controlled.

Descriptive statistics, nonparametric analysis, OLS regression, and quantile regressions are conducted. Findings presented in Chapter 4 show there is a negative relationship between patent destructiveness and private value. This suggests that destructive innovation might bring lower private value for the innovating firm due to its high levels of risk and uncertainty, the longer road to profit, and the incompatibility between destabilize innovation and innovating firm’s existing capabilities. In contrast, Chapter 4 finds a positive association between patent dissimilarity and private value. This indicates that the market prefers dissimilar inventions because they have a higher possibility to create new markets. Furthermore, patent dissimilarity leads to more difficulties for the market to understand the patented invention and therefore weakens the negative effect of destructiveness on patent private value. Chapter 4 confirms the different dimensions of radicalness have distinct effects on private value and makes an important contribution to the literature of radical innovation.

5.2 Implications

5.2.1 Theoretical implications

This dissertation contributes to and extends the existing literatures of innovation and social networks in several ways. First, our study adds to the fast-expanding literature about radical innovation by exploring the social determinants of radical innovation in the organizational and social environment (Chapter 2), how network effect depends on the radical nature of innovation (Chapter 3), and the impact of different dimensions of radical innovation on patent private value (Chapter 4). Prior studies have extensively investigated the technological origin of radical innovation. Chapter 2 examines the social determinants of radical innovation, particularly the characteristic of collaboration networks, which enriches the existing radical innovation literature. Results show that there is a significant negative effect between tie strength and innovation radicalness. More importantly, we observe a significantly positive interaction effect between tie strength and structural hole on innovation radicalness. Chapter 3 explores how network effect depends on the radical nature of innovation. While there is an extensive literature about network effect on idea diffusion, less studied and understood is that these effects might depend on the type of the innovation (Ozer & Zhang, 2019; Vanhaverbeke et al., 2012). Contribute to this research line, Chapter 3 investigates how tie strength and network cohesion of an innovation site's collaboration network shapes the success of its innovation. More importantly, Chapter 3 examines how these effects are contingent on the radical nature of innovation. Findings show that different types of innovation need different network conditions for diffusion. In particular, we observe opposite network effects for incremental and radical innovations. Chapter 4 contributes to radical innovation by unpacking the abstract concept of radicalness and making an important distinction between destructiveness and dissimilarity, which affect patent private value in distinct manners and interact with each other. This provides a useful approach for reconciling seemly conflicting empirical findings in previous literature (Cohen et al., 2013; Fitzgerald et al., 2021; Hirshleifer et al., 2013, 2018). Radical innovation is a complex and composite concept, and explicitly differentiating its dimensions is essential for a better understanding of it.

Second, we contribute to the long-standing debated about which kinds of networks are more advantageous: strong tie vs. weak tie, and network cohesion vs. structural hole. One promising direction to reconcile competing theories and empirical evidence is to separate different stages of the creative process, and the consensus seems to be that non-redundant information provided by weak ties and structural holes are necessary or beneficial for generating novel ideas, while reciprocity norms, trust, and fine-grained information exchange associated with strong ties and network cohesion facilitate idea implementation, transfer, and adoption (Burt, 2004; Fleming et al., 2007; Perry-Smith & Mannucci; Reagans & McEvily, 2003; Tortoriello & Krackhardt, 2010). Our study in Chapter 2 contributes to the debate by proposing a two-faced view of network structures separating informational and relational aspects, and investigating the interaction between different network properties. The results show that the same network structure (i.e., weak tie, structural hole) may present both informational advantages and relational disadvantages at the same time. In addition, the informational advantages of weak ties can be mobilized if there are network cohesion to mitigate the relational disadvantages of weak ties. Similarly, the informational advantages of structural hole can be mobilized if there are strong ties to mitigate the relational advantages of structural holes. This provides a promising direction for reconciling competing theories about network effects (Burt, 1992; Coleman, 1988; Granovetter, 1982; Granovetter, 1973; Uzzi, 1996, 1997). Chapter 3 contributes to the debate by shedding light on the complexity of network effects. Previous research has shown that the same social structure that is conducive for producing a creative idea might hamper its diffusion. Chapter 2 and Chapter 3 provide empirical evidence that weak tie and structural hole contribute to the generation of radicalness but hinder the transformation of new ideas into successful innovations. More importantly, Chapter 3 confirms that different types of innovation might need different network conditions for diffusion. In particular, we found opposite network effects for incremental and radical innovations. More specifically, results show that reciprocity norms are not always beneficial but can become a burden for some agents in some contexts, where the desirable behavior misaligns with reciprocity norms. In particular, the adoption of radical innovation is hinder because of its destructive impact on existing technologies and the collaboration network. We highlight the complexity that there might not be clean separation in the network effect between the idea production and diffusion stages.

Third, our study contributes to the R&D location decisions literature. Prior studies have long investigated factor driving multinationals' overseas R&D location choices and strategies for coordinating subsidiaries (Alcácer & Zhao, 2012; Belderbos et al., 2021; Du et al., 2022; Kuemmerle, 1997; Lewin et al., 2009). Complementing the literature of R&D locations decisions, Chapter 2 explores how the structure of firm R&D networks affects its ability of producing radical innovation, and Chapter 3 investigates how the collaboration network structure of an innovation site affects the adoption and future use of its innovations.

5.2.2 Practical implications

The findings of this dissertation also have implications for innovating firms and management. First, innovating firms should be careful about network structure configuration when develop radical innovation. Chapter 2 suggests that having weak ties are generally more conducive for radical innovation, but it is especially beneficial when weak ties are accompanies by network cohesion. On the other hand, structural holes are beneficial for developing radical innovation if there are strong ties to mitigate its relational disadvantages.

Second, our findings also have important implications for innovation management, especially across geographically dispersed sites. The structure of collaboration network plays an important role in the process of turning a creative idea into a successful innovation. Chapter 3 informs what types of network structure are more beneficial for the adoption and future use of incremental versus radical innovations. When restructuring the network is not feasible, then the managers should pay attentions to how to bring other management interventions to magnify desirable underlying mechanisms and mitigate undesirable ones.

Third, our study helps firms to understand the economic consequences of different types of innovation. The negative association between destructiveness and private value warns companies about risks and uncertainties associated with conducting destructive innovation. Companies that engage in such innovation need to carefully manage its higher level of risk and uncertainty, longer time period needed to make it profitable, and potential incompatibilities with existing capabilities. Chapter 4 also sheds light on potential biases and sources of mispricing in the stock market. Consistent with prior studies (Cohen et al., 2013; Fitzgerald et al., 2021; Hirshleifer et al., 2013, 2018), Chapter 4 suggests that it is difficult for the stock market to understand patented inventions, especially dissimilar ones, for assessing its implications on firm value. Investors should be aware of these difficulties and carefully mitigate associated biases. Innovating companies should also pay attention to how to disclose their innovation and manage market expectations.

5.3 Limitations and future research

Notwithstanding its contributions, this PhD dissertation has some limitations. First, although patent data avoid response bias and capture a more complete collaboration network than surveys and interviews, it is important to acknowledge that our study suffers from the unavoidable limitations of patent data for studying innovation. For example, many unimportant inventions are failed to be patented, and some breakthroughs may be missed due to firms' strategic reasons (Fleming, 2001). While granted patents are not a perfect archive of technological innovations, the data still represent a considerable share of invention outputs with varying degrees of radicalness. Future research adopting a broader set of innovation outputs would be valuable to expand beyond patents to other innovative outputs. In addition, patent data do not provide direct information for measuring the underlying mechanisms. For example, informational advantages and relational disadvantages of weak ties and structural holes, as well as trust and reciprocity norms associated with strong ties and network cohesion, cannot be measured using patent data. Future research should address this issue and explore alternative data sources for a more direct test of the theory.

Second, like most network studies, our study focuses on the structural aspect of the network but does not account for the characteristics of nodes or the content of things that are exchanged in the context of the tie. Future research should incorporate these aspects for a better and more complete understanding of the relationship between collaboration networks and radical innovation.

Third, our study mainly retrieves data from companies with high R&D investment in pharmaceuticals and biotechnology industry in the United States, which may limit the generalizability of our findings to other industries or other countries. Future research should collect data from broader industry contexts as well as a larger and more diverse sample.

Fourth, we follow Kogan et al. (2017) in measuring patent private value as the stock market reaction to the news that the patent is granted. This measure is only available for patents of publicly traded firms, while patents of private companies, non-profit organizations and governments are ignored. Caution should be taken when generalizing our findings to non-listed companies or institutions, and it may be interesting for future work to test whether our findings are applicable to other types of organizations. In addition, it is difficult to evaluate the exact stock prices for each patent, because the same stock prices are allocated to all patents of the same assignee that were granted on the same day. Future research may further improve the accuracy of the patent private value measure.

Fifth, we focus on two dimensions of radicalness: i.e., destructiveness and dissimilarity, while radicalness may encompass other aspects or dimensions, it would be interesting for future studies to explore other dimensions and related mechanisms.

Sixth, we do not capture the dynamic process through which the technological, economic, and societal impact of a patent invention unfolds. We only study the short-term private value of a patent depending on its dissimilarity and destructiveness. It would be interesting to investigate effects of dissimilarity and destructiveness in longer terms and beyond the innovating firm (i.e., social value).