



The impact of multilevel networks on innovation



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ABSTRACT

Different from previous studies analyzing the influence of network structure on actors' performance by using a single network perspective, this article explores the impact of multilevel networks on innovation. Using a sample of 41,007 patents in the field of alternative energy of the USPTO database, we construct inventor collaboration networks at city and as well as country levels. In the empirical analysis, we use panel data and negative binomial regression models with fixed effects. To keep our results reliable, we use an instrumental variables approach to solve potential endogeneity problems and perform a series of robustness tests. The results show that inter-country collaboration network structure moderates the relationships between inter-city collaboration network structure and innovation performance. Our findings show that when country's centrality and structural holes are high, the positive effects of city's centrality and structural holes on innovation performance are enhanced, and the negative effects of city's clustering coefficient are weakened. Implications of the findings for complex innovation network theory and innovation policies are discussed.

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1. Introduction

We live in an increasingly globalized world leading to extensive interconnection between countries (Scellato et al., 2014). For instance, with rising awareness of environmental protection, rapid development in green technologies has substantially stimulated collaborations at the international and national level (Melville, 2010). Meanwhile, the popularization of email and inexpensive international communication enable cross-country collaboration in researches (Ding et al., 2010). Cooperation and research networks are the key to enhance the competitiveness of regions (Cooke et al., 1997). In recent years, the need to know the consequences of climate change has increased greatly (Paschen and Ison, 2014) as climate change has impact on economic development, population growth and poverty (The United Nations Framework Convention on Climate Change). Technology has an important role in enabling industry worldwide to make the transition toward more environmentally sustainable modes of operation (United States Patent and Trademark Office) and such sustainable technologies ensure that resources are used more efficiently and harmful emissions are reduced (Bohnsack et al., 2014). Various forms of collaborations between countries or cities in the area of technologies relevant to address climate change each play an essential role. Recent

studies have highlighted, for instance, the importance of strengthening cross-national cooperation to develop alternative energy technology (Philibert, 2004). The researches of these technologies must be deployed and adopted on a global scale which will involve producers, regional and national innovation systems in nations around the world (Mowery et al., 2010). Participants form these collaborations for spreading the costs of huge investments, sharing and pooling risks, and to gain access to complementary abilities and resources (Marquardt, 2013). International collaborative linkages have the capacity to transfer disembodied knowledge over long distances (Herstad et al., 2014). It is clear that, from a long-term development perspective, a collaborative network encourages close relationships and creates more value among partners (Adegbesan and Higgins, 2011). Not surprisingly research on collaboration networks has increasingly attracted the attention of scholars (Chen and Guan, 2010; Wagner and Leydesdorff, 2005).

Although previous studies have explored collaboration networks at the country level by analyzing several international scientific data sets (Cantner and Rake, 2014), there is still relatively little empirical evidence on the global technological collaboration network (De Prato and Nepelski, 2012). Some scholars suggest that it is worth considering sub-national or regional systems of innovation to fully understand innovation process (Feldman and Florida, 1994). However, many existing collaboration network studies focus on country, regional, organizational and industrial innovation networks, but they rarely include city collaboration networks (Fleming et al., 2007; Gay and Dousset, 2005; Phelps, 2010). Cities are not

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only basic units in economic competition but are also important targets for government policies. Cities are centers for the integration of human capital and incubators of invention (Bettencourt et al., 2007). Economic and political regimes are not only operative at national and global scales, but also at local, regional and city's scales. Cities utilize local tax to develop, create and concentrate knowledge which increases their attractive pull for highly skilled and creative individuals who, by locating in urban centers, contribute in turn to the generation of further knowledge spillovers (Florida, 2005). Certainly considerable progress would be made if data sources identifying innovation activity at the city or county level were made available (Audretsch and Feldman, 1996). For this reason innovation collaboration at a city level should receive more theoretical and empirical attention (Neal, 2011). In the past few decades, research on networks at a city level has mainly focused on the transportation network and most of them approach this problem from a geographical perspective (Singh and Marx, 2013).

Recent studies have utilized social network to understand the influence of an innovator's network structure on its innovation performance (Rost, 2011; Bercovitz and Feldman, 2011). However, recent work has exclusively focused on the benefits that innovators obtained by occupying advantageous positions (Gilsing et al., 2008). There is still a gap which neglects to test the impact of the higher level network structure on the lower level innovation processes. Attempts to integrate these levels, either empirically or theoretically (Pan et al., 2012) or study interactions of two levels (Schwab, 2007) hardly exist. A great deal of research regarding multiple levels is concerned with the effect of individual-organizational interactions on individual outcomes (Hrebiniak and Alutto, 1972; Paruchuri, 2010). Some scholars argued for multilevel models provide insights into a richer perspective innovation helping us to understand innovation phenomena at and across different levels (Gupta et al., 2007). Combining this issue we observe that, in spite of their evident importance, surprisingly little attention has been devoted to city-country interactions. Our research is designed to fill this gap by putting forward new proposals that concern both city and country levels. The analyses at one level are linked to those at the other, and the innovation mechanisms may be different at each level. Relationships among cities bring collaborative trust and information on a small scope. Collaboration among countries can bring some fresh and heterogeneous knowledge in a broader scope. Thus, we will study the interaction of the two levels of collaboration networks.

Acquisition of knowledge is crucial for the economic development of cities and from there for the growth and innovation of regions (C. Phelps et al., 2012). The structure of networks in which actors are embedded influences their potential for knowledge acquisition (Gonzalez-Brambila et al., 2013; Gulati, 2007; Schilling and Phelps, 2007). A good position occupied by a city presents advantages which let a central city enjoy profits in terms of information collection and processing (Zaheer and Bell, 2005). Given the above-described problem, the effects of domestic and of foreign knowledge on technology innovation are different (Almeida, 1996), and prior study argued that geographical distance influence knowledge flows (Crisuolo and Verspagen, 2008). Yet, a holistic view is needed taking domestic as well as global networks into account. This raises the following questions: Does the structure of inter-country network influence collaborations among cities in inter-city network? If so, what network structure of inter-country will enhance a city's innovation? We aim to examine how the effect of a city's position on its innovation activities varies with the country's position in the inter-country collaboration.

This article, studying to above mentioned problems, is organized as follows. First, we offer a review of the major literature on network structure and innovation. Second, a model and hypotheses are proposed to account for the mechanisms and processes underlying

innovation at multiple levels. A sample of 41,007 patents in the field of alternative energy taken from the USPTO is collected to test the hypotheses. Afterwards, characteristics of the collaboration networks of inter-city and inter-country are obtained with the help of methodologies derived from network analysis. Finally, conclusions are given and specific literature contributions are discussed.

2. Theory and hypotheses

To understand the process of innovation, we explain the nature of innovation in views of the Schumpeterian re-combinatory perspective, which view the innovation as novel recombination of existing knowledge (Cantner et al., 2011). Previous work suggested that innovation is essentially liable to be embedded in a way that the innovativeness will be affected by external and extra factors (Freel, 2003) and explores innovation using this notion by recombining resource within and outside boundaries (Belussi et al., 2010). Collaboration and the establishment of a composite knowledge base are very important for innovation processes (Hölzl and Janger, 2014). As cities form and maintain collaborations with each other, they weave a network consisting of extensive communication ties (Ynalvez and Shrum, 2011). Central cities have more opportunities for knowledge transfer and learning. However, the benefits from the central position in inter-city collaboration network would be influenced by the national-level characters. Prior research did not explore the effect of a nation's position on its internal innovative performance.

This study explains the theory about how cities and nations are connected at the network level from two perspectives. On the one hand, we explain these from internal and external innovation theory. Prior studies demonstrated that internal and external knowledge acquisition activities are complementary for innovation (Cassiman and Veugelers, 2006). Today, we need to expand the external use of innovation to conduct purposive inflows and outflows of information and knowledge to accelerate internal innovation (Poot et al., 2009). A nation's internal innovation activities are carried out by innovation cities connected in an inter-city collaboration network. It is noted that international collaboration network brings the country external information flows which would influence its internal innovation network. To be specific, inter-country ties act as channels of communication that provides knowledge spillovers from other countries. Furthermore, the influence of external information flows on its internal network relies on the amount of spillovers coming from the inter-country network, which in turn depends on the country's position within the network. These flows within the nations in turn differentially influence the ability of cities and regions to assimilate and process information, thereby changing their innovation activities. Thus, we combine inter-country collaboration and the inter-city collaboration at the network level. On the other hand, we explain these from interaction theory. Environmental influences all operate as interacting determinants that influence each other bidirectionally (Bandura, 2001). Thus, innovation activities would be influenced by the interaction between innovators and their environmental contexts. Given the above-described reality, the innovation cities are involved as actors and at the same time embedded in the broader environment (i.e. national context). Thus, from these views, we connect cities and nations at the network level, and investigate their interaction effects.

2.1. City's network structure and innovation output

In an inter-city innovation collaboration network, actors with different egocentric network properties have different opportunities to acquire new knowledge, essential to innovation activities

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