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Co-invention networks and inventive productivity in US cities

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ABSTRACT

The role of collaboration networks within and across cities as drivers of urban creativity and new knowledge creation is increasingly acknowledged in the literature. We propose that the combination of (1) high internal social proximity between co-inventors within a city and (2) local cliques of inventors in which interaction is dense allows a city to achieve greater inventive creativity. Internal social proximity allows knowledge to circulate quickly across a larger pool of sources; dense cliques promote trust, cooperation, and a more effective use of the acquired knowledge. Moreover, social proximity between a city's inventors and inventors outside the city contributes to enriching and renewing a city's knowledge base by facilitating faster access to fresh external knowledge. We find evidence to support these propositions in a study of the inventive productivity of 331 US cities.

1. Introduction

The role of collaboration networks as drivers of regional and urban innovation has gained paramount attention during the last decade. The idea that social ties and inter-personal contacts mediate the transmission of knowledge and are key explanatory factors of the urban concentration of innovative activities is not a new one and has been widely debated in the literature on agglomeration economies (Beaudry and Schiffauerova, 2009; Glaeser and Gottlieb, 2009). However, until recently, a lack of micro-level data and formal network models has prevented a rigorous empirical evaluation of social networks' effects on innovation. According to Duranton and Puga (2004) and Puga (2010), in fact, the micro-foundations of the learning mechanisms upon which knowledge spillovers are based remain relatively less developed with respect to the development of the theoretical and empirical micro-foundations of other agglomeration economies. The use of patent data as relational data can offer an empirical contribution in this direction, as patent data can be employed to map the socio-professional networks in which inventors are embedded (Ter Wal and Boschma, 2009).

The extant literature does not offer conclusive evidence on the importance of social networks for inventive performance. Social proximity has been found to explain a great deal of the tendency for knowledge to diffuse locally (Agrawal et al., 2006 and 2008; Breschi and Lissoni, 2004; Singh, 2005). However, several studies have consistently shown that knowledge creation and inventive performance in a metropolitan area depend more on the agglomeration of inventors and creative individuals than on any structural property of the co-invention network (Bettencourt et al., 2007; Fleming et al., 2007; Lobo and Strumsky, 2008).

This paper provides an empirical contribution to the literature on knowledge-related agglomeration economies (Rosenthal and Strange, 2001) and the micro-foundations of learning mechanisms and knowledge spillovers (Duranton and Puga, 2004) by proposing a more careful examination of the relative importance of agglomeration forces versus social networks (and their structural properties) on a city's inventive performance. Importantly, this work accounts for not only the network structure within a metropolitan area but also for the ties and the related knowledge flows linking inventors located in different cities. Non-local sources of knowledge have been found to provide a significant contribution to the diffusion of ideas and to patenting growth at the local level (Agrawal et al., 2008, 2010; Kerr, 2010).

In particular, we argue that a city will achieve higher inventive productivity when its co-invention network presents a combination of two key properties: high social proximity between network members in the city, i.e., *internal social proximity*, and local cliques of co-inventors in which interaction is dense, i.e., *clique density*. In this context and throughout the paper, social proximity is high when interactions quickly link back to individuals participating in the network. For example, suppose that A interacts with B, B interacts with C, and C interacts with D. In this instance, two members of the network, B and C, separate A from D. Therefore, the social

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proximity between A and D is much greater than if, for example, ten other individuals were to separate A and D. Using this same example, additional cross-interactions between network members increase the sense in which the network is more prone to the formation of cliques and in that respect is denser. This would be the case if, for instance, A and C also interact directly. In this case, A and C would both have a direct tie to an additional network member, more than in the original example. Moreover, A, B, and C would represent a clique, namely a cohesive group of individuals who are directly connected to one another. In addition, we propose that the impact of internal social proximity on a city's inventive performance also critically interacts with the social proximity of metropolitan inventors to inventors in other cities, i.e., *external social proximity*.[1]

We test our hypotheses on a database covering 331 US Metropolitan Statistical Areas (MSAs)[2], their inventors, and the respective patents applied for at the European Patent Office (EPO). A major concern in our empirical exercise regards the possible endogeneity between the patenting rate and network variables, which may arise if inventors are attracted to and develop network ties in cities that are already highly innovative. To address this issue, we adopt the following strategy. First, we attempt to mitigate the problem by taking a significant time lag between our dependent and independent variables. Specifically, the dependent variable measures patent productivity in 2009, whereas network variables are computed in the time window 1995–1999. Nevertheless, this approach cannot completely rule out the possibility of endogeneity and the resulting bias in the estimated coefficients. For this reason, after providing OLS estimates, we check and control for possible endogeneity using the instrumental variable technique proposed by Lewbel (2012). This approach identifies structural parameters in regression models affected by endogeneity by supplementing available external instruments with generated ones that are uncorrelated with the product of heteroskedastic errors.

The remainder of the paper proceeds as follows. In the next section, we conceptually derive from the literature the research hypotheses to be verified. Section 3 describes the construction of our key network variables. Section 4 presents the empirical models to be tested and the data. Section 5 discusses the empirical results and comments on the robustness checks to detect and control for possible endogeneity. Finally, Section 6 concludes.

2. Co-invention networks and inventive productivity

Inventive activity in the US is a predominantly urban phenomenon (Carlino et al., 2007; Feller, 1971). Approximately 94% of all patent applications made by US organizations in the period 1990–2009 were generated within MSAs, with the ten most prolific cities accounting for approximately 48% of all patenting activity in the period. The tendency for innovative activities to cluster in selected cities has been attributed to the importance of agglomeration economies. Agglomeration economies, especially knowledge-related ones, are the basis of enhanced economic performance and creativity in cities (Glaeser, 1999; Glaeser et al., 1992; Henderson, 2003; Rosenthal and Strange, 2001; Rosenthal and Strange, 2008; Glaeser and Gottlieb, 2009).

Metropolitan settings are key engines and incubators of new knowledge creation processes because they facilitate intellectual linkages among individuals through social proximity and face-to-face contacts. As discussed by Glaeser and Gottlieb (2009), the thick web of social interactions in cities creates agglomeration economies, which can lead to considerable variation over time and space in innovative episodes. The co-location of creative individuals within the same region or urban environment is credited with facilitating both formal interactions and informal or serendipitous encounters in which the tacit knowledge relevant for inventive creativity is transmitted and exchanged. This network of relationships generates pervasive localized knowledge flows among individuals and firms and guarantees the rapid diffusion of ideas at the local level, which in turn boosts the inventive productivity of all local actors (Jaffe et al., 1993).

Recent literature suggests that two specific network structural properties (and their combination) are particularly desirable for knowledge diffusion and creation (Schilling and Phelps, 2007; Uzzi and Spiro, 2005). First, the actors in the network are able to reach other actors in the network through a relatively low number of intermediaries; i.e., on average, they are socially proximate. Second, the actors in the network are locally clustered in the sense that they tend to create tightly knit groups (i.e., cliques) characterized by a relatively high density of ties (Watts and Strogatz, 1998).

In the context of a co-invention network, knowledge and information tend to diffuse more rapidly, and with less noise, when relatively few intermediaries separate inventors (i.e., when internal social proximity is high), than when members are connected by longer chains of ties (i.e., when internal social proximity is low). As a consequence, new information or ideas generated within the network may rapidly reach (or flow to) all other members of the network and be recombined with their own knowledge, thereby improving inventive productivity.

Furthermore, when inventors are embedded in cohesive cliques, in which an actor's partners also collaborate with one another, information spreads quickly, and more important, its usefulness and reliability is verified along multiple pathways (Schilling and Phelps, 2007). Moreover, the high density of linkages within a clique creates conformity (Patacchini and Venanzoni, 2014) and a common code of communication, which stimulates collective learning, an argument also suggested in the debate on knowledge-related agglomeration economies (Glaeser and Gottlieb, 2009). Finally, dense cliques may allow network members to monitor opportunistic behavior, which promotes trust and reciprocity among partners, thereby encouraging higher levels of collaboration (Schilling and Phelps, 2007; Uzzi, 1996). Therefore, denser cliques allow knowledge to be shared and used rapidly, spurring greater knowledge creation.

Thus, we would expect metropolitan inventive performance to improve where there is a combination of (1) high internal social proximity between network members and (2) local cliques of actors in which interaction is dense. When a network's internal social proximity is low, dense collaborative cliques may find it difficult to maintain high levels of invention because there are few between-clique or between-team links that promote the transfer of knowledge and ideas generated elsewhere in the larger network. Similarly, when internal social proximity is high, the lack of dense cliques and of the redundancy of ties may be equally detrimental to invention. Although information may circulate rapidly, it is not being spread through known and trusted sources, which may lead to a less effective exploitation of new ideas. Thus, we posit the following:

[1] Following Fleming et al. (2007) and Lobo and Strumsky (2008), we will use the term metropolitan network or internal co-invention network to denote the subset of inventors, and the ties among them, in a given city; we will refer to the metropolitan network's structural properties as its internal structure. Accordingly, social proximity among inventors in a city is labeled *internal social proximity*. We will use the term external ties to denote links connecting metropolitan inventors with inventors located in different cities. Accordingly, social proximity among inventors across cities is labeled *external social proximity*.

[2] MSAs are defined by the US Office of Management and Budget (OMB) as urban core areas of at least 50,000 people, plus adjacent counties that have a high degree of social and economic integration with the core, as measured by commuting ties. The choice of using EPO rather than USPTO data is fully discussed in Appendix A.