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# How do inventor networks affect urban invention?

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ABSTRACT

Social networks are expected to matter for invention in cities, but empirical evidence is still puzzling. In this paper, we provide new results on urban patenting covering more than twenty years of European patents invented by nearly one hundred thousand inventors located in France. Elaborating on the recent economic literatures on peer effects and on games in social networks, we assume that the productivity of an inventor's efforts is positively affected by the efforts of his or her partners and negatively by the number of these partners' connections. In this framework, inventors' equilibrium outcomes are proportional to the square of their network centrality, which encompasses, as special cases, several well-known forms of centrality (Degree, Katz-Bonacich, Page-Rank). Our empirical results show that urban inventors benefit from their collaboration network. Their production increases when they collaborate with more central agents and when they have more collaborations. Our estimations suggest that inventors' productivity grows sublinearly with the efforts of direct partners, and that they incur no negative externality from them having many partners. Overall, we estimate that a one standard deviation increase in local inventors' centrality raises future urban patenting by 13%. We also find that geographically close relations are up to two third more beneficial to inventors than distant ones.

## 1. Introduction

It is well known that invention and R&D activities are highly concentrated geographically, even more so than manufacturing employment (Audretsch and Feldman, 1996; Buzard and Carlino, 2013; Carlino et al., 2007). The literature highlights that a critical force for the agglomeration of inventive activities is knowledge spillovers between workers specialized in innovation tasks. Long ago, Marshall (1890) already highlighted that ideas can be shared locally through social and professional interactions. The role of these interactions has since been shown to be crucial in many successful technological clusters (e.g. Saxenian, 1991; Porter, 1998). Jaffe et al. (1993) argue that knowledge flows diminish with geographical distance as citations are more likely to come from the same metropolitan area (MSA) as the cited patents.[1] Other authors make it clear that social and professional connections between inventors who are most often geographically close (Breschi and Lissoni, 2005; Carayol and Roux, 2007) are key determinants of knowledge diffusion (Singh, 2005; Agrawal et al., 2006; Breschi and Lenzi, 2016).

Those findings suggest that social networks between inventors are an important source of disparities in inventive productivity across cities or regions because they facilitate knowledge diffusion. However, to date, the main empirical studies that have exploited the availability of patent data to assess this influence have produced contrasting and somewhat puzzling conclusions. Fleming et al. (2007) and Lobo and Strumsky (2008), using nearly identical US patent data from the late 1970s to 2002, regress, at the MSA level, patent counts against network variables built using co-invention patterns and other controls. Breschi and Lenzi (2016) use EPO patent data of inventors located in US MSAs to build network variables prior to 1999 in order to explain patenting in year 2009. These three studies converge to stress the positive effect of inventor agglomeration. However, they find that the structural characteristics of the co-invention networks[2] have only small effects on urban patenting. Lobo and Strumsky (2008) even find a negative effect of network density on urban invention. Local social proximity, that is, the average of the inverse social distance between a city's inventors, has a small positive effect for Fleming et al. (2007) but no

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[1] Much other direct or indirect evidence has been provided for the fact that knowledge spillovers arise over small geographical distances (for a recent survey, one may refer to Carlino and Kerr, 2015).

[2] Such networks are built by drawing a link between two agents when they are both listed as inventors of the same patent application.

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significant effect according to Breschi and Lenzi (2016). Both articles argue that combining local social proximity (for knowledge diffusion) and social cliquishness[3] (for cohesion and cooperation enforcement) should positively affect invention, but their results again diverge as the former study concludes negatively while the latter concludes positively.[4] Breschi and Lenzi (2016) find that network proximity between a city's inventors and the inventors located outside the city does not correlate significantly with invention, only that its interaction with local proximity is positive.

These results challenge our conception of how networks affect urban invention. We would have expected that, in urban areas, denser and well architectured webs of connections clearly spur the diffusion of information and ideas between participants, and eventually stimulate their inventive productivity. But does knowledge really (even imperfectly) flow in networks, so that cities which are more connected and which minimize between-inventors distances invent more? A bunch of recent empirical studies suggest that a slightly different story may be true. Azoulay et al. (2010) shows that, following the sudden death of a 'superstar' scientist, his/her direct collaborators face a significant and long-lasting decline in their productivity, and that this effect increases with their intellectual proximity. Using the dismissal of Jewish mathematics professors in Nazi Germany as a source of exogenous variation in university quality, Waldinger (2010) concludes that the mentor's quality affects both the short-term accomplishments and the long-term career achievements of the former PhD students. Borjas and Doran (2015) stress that among the mathematicians remaining in the former Soviet Union after 1990, the only ones who significantly suffered from the loss of their colleagues emigrating to the West were those who lost direct collaborators. These findings highlight the importance of direct and intense collaborations with high-quality partners. They are consistent with the idea that professional networks stimulate knowledge production and invention mainly because, in direct professional collaborations, they emulate early discussions and confrontations of ideas between very active and committed peers, and less because they act as channels for knowledge diffusion.

In this article aiming to empirically analyze how the social networks of inventors affect their performances, we propose microfoundations which are consistent with those basic ideas. We rely on games in which each agent's payoffs essentially depend on his/her action (typically level of effort) and on those of his/her directly connected agents.[5] In this approach, the emulation between connected partners is basically captured by the complementarity between partners' strategies, that is, the productivity of each agent's efforts increases with the efforts of his/her partners. Ballester et al. (2006) first showed that when actions are linear strategic complements (and under some boundary conditions), there exists a unique Nash equilibrium in which agents' actions are equal to their Katz-Bonacich centralities.[6] Technically, our model is more general in that effort complementarity is not necessarily linear.[7] More specifically, our model contains three adjustable basic ingredients: *connectivity*, *synergy* and *rivalry*. *Connectivity* simply presumes that inventor productivity is directly and positively affected by being connected to other inventors. *Synergy* posits that the productivity of an inventor's efforts depends positively on the efforts that his/her partners put into knowledge production. *Rivalry* captures the idea that agents may not benefit a partner's efforts as efficiently when the number of his/her connections increases.[8] In this set-up, equilibrium inventors' outcomes are proportional to the square of a certain form of their network centrality, which, as we will show, is itself parametrized by the degrees of connectivity, synergy and rivalry. This form of centrality is generic, as it nests existing centrality measures such as Degree, Katz-Bonacich and Page-Rank (Katz, 1953; Bonacich, 1972; Brin and Page, 1998).

By bringing this heuristic model to the data, we seek to identify which premises on the way agents affect their neighbors' research productivity, typically which degree of *connectivity*, *synergy* and *rivalry*, best predict future inventions. Our data concern nearly one hundred thousand French inventors and their collaborations for the period 1981–2003, previously cleaned and disambiguated (Carayol et al., 2015), the related information on European patents for the same period, the forward citations made to those patents until 2008, as well as mandatory company survey data from 1985 to 2003. We identify network effects at the level of the local community of inventors by pooling all information at the level of the urban French employment areas (EA) combined with the broad technological field.[9] We estimate a model in which the future patent production of such communities is a function of the average network centrality of their inventors. The structure of the data allows us to include various sets of controls such as EA-technology and time-technology fixed effects as well as several other variables capturing agglomeration economies, which have proven to be important determinants of invention in cities (Fleming et al., 2007; Lobo and Strumsky, 2008; Breschi and Lenzi, 2016).

The results show that the inventive productivity of cities is positively and significantly affected by the network structure of its inventors. Our preferred estimation indicates that a one standard deviation increase in local inventors' centrality raises future invention in an urban area and technology field by 13%. Further, no rivalry effect is found but a strong synergy effect is. According to our microfoundations, the results suggest that keeping all other factors constant, a ten percent increase in the efforts of the direct connections of an inventor would raise the social component of his/her productivity of efforts by five percentage points on average.

These results hold across a long series of robustness checks. One of the main concerns we deal with is that, thought we have a rich set of covariates, time-varying unobserved variables might still affect both present network centrality and future invention. However, the effect of inventors' network centrality is robust to the introduction of current performances for predicting a city's future invention, which limits

[3] Often measured by the frequency of closed triangles over the frequency of connected triples. Also called global clustering in the literature.

[4] Notice that different studies in specific contexts (scientific or artistic productions for instance) are not more conclusive concerning "small-world" effects (e.g., Uzzi and Spiro, 2005; Guimera et al., 2005; Smith, 2006).

[5] There is a broad and long lasting literature in economics on team work, from Marschak and Radner (1972) who focused on communication channels and decision, to others that have considered free riding in groups (for instance Adams, 2006 in a CES production function framework). The network approach has lead to reconsidering this view using graphical games, that is games in which agents interact with their direct neighbors on the graph (see Jackson, 2008 for an overview).

[6] Helsley and Zenou (2014) explore some interesting theoretical implications of this model concerning social interactions in cities. The questions they address are however very different from ours as they compare the periphery and the center and endogeneize the location decision, whereas we focus on the form of complementarity between agents.

[7] Several recent articles have sought to explicitly model the way agents efforts combine in partnerships. Cohen-Cole et al. (2017) have considered the case in which agents interacting in networks exert efforts in different activities. Hsieh et al. (2017) generalize this model allowing linear complementarities between agents' project-specific efforts. Those models use linear production functions.

[8] This idea is reminiscent of the "co-author model" introduced by Jackson and Wolinsky (1996) in which agents divide their time equally in joint bilateral projects undertaken with each of their direct connections.

[9] Recently, regression techniques have been introduced to overcome the estimation issues (such as the reflection problem, Manski, 1993) that arise in individual level estimations (e.g. Bramoullé et al., 2009; Lee et al., 2010; Patacchini et al., 2016; Lindquist et al., 2015). However, in urban and regional economics, scholars often do not work at the individual level because proper identification would at least require the use of rich covariates that are only available at a more aggregated level. We are following this approach.