To Collaborate or Not to Collaborate, this is the Discussion: The Role of Network Structures and Collaboration Characteristics on Inventors’ Output

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Abstract

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Extended Abstract:  
Individuals are the smallest building blocks of any organization. Organizational, as well as individual performance, depends on connections among these components. In the context of innovation, previous literature has demonstrated that a number of network characteristics such as degree centrality, number of indirect connections and existence of structural holes in a firm’s collaborative network affect its innovative performance (Ahuja 2000). It has also shown that benefits of a tie depend on diversity (Sosa 2011) and complexity of knowledge (Sorenson et al. 2006) shared through these collaborations. However, most of the contributions in the field are not concerned by the productivity at inventor level. As a result, the precise mechanism through which collaborations affect the rate of invention remains an open question. The objective of this paper is twofold. First, it aims to identify which characteristics of the individual’s collaborative network explain his/her inventive productivity. Second, the paper further investigates the effects of the nature of shared knowledge through individual’s collaborative network. Combining inventor’s ego-network characteristics with the nature of knowledge shared through collaboration will provide a better understanding of inventor’s productivity compared to the current state of art. Pinning down the mechanism through which collaborations affect inventor productivity has important implications. This will inform inventors on how to optimize their collaborative networks, as well as help
policy makers to design incentive schemes which would maximize organizational performance. This paper theorizes and empirically examines the following two arguments:

1. The role of network structure: The greater an inventor’s number of direct and indirect ties, the greater the subsequent innovation output of the inventor. On the other hand, benefits of direct ties on an inventor’s innovation output will be moderated by the level of the inventor’s indirect ties. Structural holes are proposed to have both negative and positive affect depending on the nature of innovation.

2. The role of nature of shared knowledge: The breadth of diverse knowledge domains acquired through collaborations is positively associated with the innovation output. The relationship between the knowledge cohesion (between co-inventors) and inventive productivity has an inverted U shape, implying a goldilocks effect in the optimal distance between co-inventors in the knowledge space.

To test these hypotheses, we conduct an empirical study. The unit of analysis is a single inventor embedded in the collaborative network. We used the European Patent Office worldwide patent statistical database to construct collaborative networks. Nodes are inventors, co-inventor relations create ties between these nodes. The nature of knowledge created through inventors’ prior work. The analyses include 587 750 inventors and 516 368 unique patents granted by IPO in the period from 1998 to 2006.

Preliminary results show that network characteristics affect inventors’ innovation output. While both direct and indirect ties have a positive effect on innovation output, there is a tradeoff between benefits of direct ties and indirect ties. We show that a high level of indirect ties decreases benefits delivered by inventor’s direct ties. We also find that inventor’s productivity increases when they are surrounded by structural holes and when they have more diverse prior knowledge. The importance of prior knowledge diversity and the positive impact of structural holes point to the importance of tie content and the level of knowledge cohesion. Therefore, as the next step, the innovative performances of solo inventors and the effect of the nature of knowledge on inventor’s productivity will be investigated.

References
To Collaborate or Not to Collaborate, this is the Discussion: The Role of Network Structures and Collaboration Characteristics on Inventors’ Output

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ABSTRACT

Individuals are the smallest building blocks of any organization. Individual performance depends on connections among these components. In the context of innovation, previous literature has demonstrated that several network characteristics such as degree centrality, number of indirect connections and existence of structural holes in firm’s collaborative network affect its innovative performance. It has also shown that benefits of a tie depend on the diversity and complexity of knowledge shared through these collaborations. However, most of the contributions in the field are not concerned by the productivity at inventor level. As a result, the precise mechanism through which collaborations affect the rate of invention remains an open question. The objective of this paper is twofold. First, it aims to identify which characteristics of the individual’s collaborative network explain her inventive productivity. Second, the paper further investigates the effects of the nature of shared knowledge through individual’s collaborative network.

Preliminary results show that, while both direct and indirect ties have positive effect on innovation output, there is a tradeoff between benefits of direct ties and indirect ties. We show that a high level of indirect ties decreases benefits delivered by inventor’s direct ties. We also find that inventor’s productivity increases when they are surrounded by structural holes and when they have more diverse prior knowledge. The importance of prior knowledge diversity and the negative impact of structural holes point to the importance of tie content and the level of knowledge cohesion. Therefore, as the next step, the innovative performances of solo inventors and the effect of the nature of knowledge on inventor’s productivity will be investigated.

INTRODUCTION

Individuals are the smallest building blocks of any organization. Individual performance depends on connections among these components.
Prior work has focused on connections by addressing network theory to explore the speed of career advancement power and influence in the workplace, the instrumental use of network ties in organizations, and organizational as well as individual innovative performance (Rodan, Simon and Galunic 2003; Ibarra 1995; Burt 1995; Podolny and Baron, 1997).

In the context of creativity and innovation, several studies have investigated innovative performance depending on both individual characteristics and interactions among them. It has been showed that some individuals are more creative than others based on some specific factors such as personality, history, or societal factors (Sternberg 1990; Gardner and Gruber 1996; Sosa 2011; Uzzi and Spiro 2005). Moreover, the social view of creativity has described an individual's inventive performance in terms of network position and work environment. Supervisory support and social influences resulting from interactions among individuals have been showed as important antecedents to creativity and innovation (Perry-Smith and Shalley 2003).

A large body of research has established that individual creativity and innovative performance are influenced by structure of individuals’ networks (Burt 2004; Perry-Smith and Shalley 2003; Rodan and Galunic 2003; Obstfeld 2005; Fleming et al. 2007; Sosa 2011; Parachuri 2010) and their direct exchange partners (Nonaka 1994; Cannella and McFadyen 2015; Sosa 2011; Incerti et al. 2019)

More specifically, previous literature has demonstrated that a number of network characteristics such as degree centrality, number of indirect connections, positioning, and existence of structural holes in individuals’ collaborative network affect their inventive, work, and managerial performances furthermore performance of their organizations (Fleming and Chen 2002; Ahuja 2000; Rodan and Galunic 2003).

At the individual level, previous literature has focused on network centrality because it represents the extent of an individual’s capability to reach multiple resources (Sparrowe et al. 2014). In addition to centrality, existence of structural holes which lead to sparse network structure, has been the center of attention.

On one side, innovators who have sparse network structure with a large set of contacts that tend to be disconnected from each other are more likely to invent as they are more likely to reach diverse knowledge (Burt 2004; Rodan and Galunic 2003; Fleming et al. 2007). Alongside, the results clarify how having sparse networks can best invention but then hinder the knowledge diffusion and its use by others (Fleming and Chen 2002). Moreover, disconnection among
individuals may be caused by individuals’ fully disjointed processes (Sparrowe et al. 2014) and having different knowledge demanding processes may provoke attention management problems. Several studies have explained low individual performances with individual level multi-tasking or attention management capabilities. When there are too many tasks or distractors, individuals may shift their focus unwittingly or even worse, they cannot focus efficiently any of their processes or connections (Incerti et al. 2019; Posner and Rothbart 2007; Davenport and Volpel 2001).

On the opposite side, individuals surrounded by closely connected alters are more likely to have trust environment and social traction. These are crucial to getting individuals’ creative ideas to be implemented or adopted by others (Obstfeld 2005; Fleming et al. 2007; Sosa 2011; Ahuja 2000; Uzzi and Spiro 2005)

It has also been shown that benefits of connections depend on some collaboration characteristics such as (Sosa 2011; Rodan and Galunic 2003) and complexity of knowledge (Sorenson et al. 2006) shared through these connections. Previous studies have provided evidence that diversity and redundancy of resources, shared experience and tacit mutual understanding, and prior knowledge have effects on innovation output of individuals (Ahuja et al. 2012; Borgatti and Foster 2003; Cannella and McFadyen 2015). Results have supported that the more diverse knowledge individuals have from their collaborations, the more they increase innovation output (Rodan and Galunic 2003; Podolny 2001).

On the other hand, diversity increase in the shared knowledge may decrease the innovation output at low level of network cohesion which represents the redundancy of resources (Sosa 2011).

While prior studies largely point to the importance of an individual’s network structure, attributes of individuals, and benefits of connections; most of the contributions in the field are not concerned by the joint effect of network structure and the nature of shared knowledge among actors. As a result, the precise mechanism through which collaborations affect innovative performance remains an open question. The main question to answer is how many and which collaborations, inventors should give attention more than others to increase their innovative performances.

The objective of this paper is twofold. First, it aims to identify which characteristics of the individual’s collaborative network explain her inventive productivity. Second, the paper further investigates the effects of the nature of shared knowledge through individual’s collaborative network. Combining inventor’s ego-network characteristics with the nature of knowledge shared
through collaboration will provide a better understanding of inventor’s productivity compared to the current state of art. Pinning down the mechanism through which collaborations affect inventor productivity has important implications. This will inform inventors on how to optimize their collaborative networks, as well as help policy makers to design incentive schemes which would maximize organizational performance.

**NETWORK CHARACTERISTICS and INNOVATION**

Despite the growing agreement that networks have a place in individual performance, the specific effects of network structure on individual performance still deserves for further investigations.

Network theory tells about the antecedents and consequences of network structure and build a ground to understand flows, connections (ties), opportunities, advantages and constraint of resources embedded within the structure (Borgatti and Halgin 2011; Burt 1995; Ahuja 2000; Cannella and McFadyen 2015). Network theory predicts that the strength of ties which facilitates interaction and productivity. The magnitude of benefits through ties of one’s network is a function of the alters’ resources and their distance to the focal inventor. (Zaheer and Bell 2005; Ahuja 2000). Also, the quality and the value of resources of alters form an upper limit to productivity of the focal inventors (Zaheer and Bell 2005).

In addition to the strength and the benefit of ties, network theory also informs about advantages and opportunities derive from the level of structural density. The more one’s alters have many connections which give a body to densely embedded networks, the more an inventor interact, learn, trust and perform. According to an alternate view, structural advantages stem from the brokerage opportunities created by disconnected alters therefore structural holes (Burt 1992). As it is known that direct and indirect ties provide different types or amounts of benefits, the substitutability of direct and indirect ties may be bounded (Ahuja 2000). Thus, examining the benefits of direct and indirect ties need to be investigated separately and relative to each other.

To sum up, inventors’ direct ties, indirect ties, and connectedness of her alters are expected to influence individuals’ innovative performance. While direct ties potentially provide both resource-sharing and knowledge-spillover benefits with maintenance costs, indirect ties likely to provide access to knowledge spillovers without paying the costs of network maintenance for these ties. Finally, the degree of connectivity among an individual’s connections as illustrative of structural holes, is predicted to influence resource sharing. Structural holes also provide an access to novel information with high communication and attention costs (Burt 1992). The study will
enhance the understanding of the effects of direct ties, indirect ties and structural holes at inventor level.

1. Direct & Indirect Ties

An inventor’s innovative productivity is positively affected by her number of direct ties as they provide two essential benefits. First, direct ties empower knowledge sharing. Second, collaborations enable to combine complementary experience and knowledge of different inventors (Ahuja 2000; Sosa 2011). Innovation processes generally need the simultaneous use of different knowledge elements, technological combinations and experience (Kogut and Zander 1992; Ahuja 2000; Fleming and Sorenson 2004). Thus, collaborators (co-inventors) can enjoy diverse knowledge and experiences without investing in themselves. On the other hand, inventors who have too many collaborations may be negatively affected by direct ties after a threshold. The more direct ties that an inventor maintains, the more multiple collaborators and/or projects require attention.

**Hypothesis 1:** There is an inverted U-shape relationship between an inventor's subsequent innovation output and the number of direct ties that an inventor maintains.

An inventor’s direct ties bring knowledge and experience from their own direct ties to the focal inventor, and vice versa (Gulati and Garguilo 1999). In other words, the wealth of resources accessible through one's direct ties is a subject to resources provided by the alters of her direct ties (Gulati and Garguilo 1999; Ahuja 2000; Zaheer and Bell 2005).

In this case, it is certain that the benefits of indirect ties need to be considered to explain subsequent innovative performance of focal inventors. On the other hand, treating all indirect ties equally is not the best way to analyze their effects on innovation output. First, because the knowledge diffusion performance depend on the distance between co-inventors, the shortest path length will vary the benefits of ties (Sorenson et al. 2006). Second, the distance being equal, the potential knowledge to be shared through collaborations will change the benefits of ties depending on the possessed knowledge by collaborated inventors (Ahuja 2006).

**Hypothesis 2:** There is an inverted U-shape relationship between inventor's subsequent innovation output and indirect ties in an inventor’s network – overall and first order indirect tie count, distance weighted indirect ties, distance and information weighted indirect ties.
On one hand, the benefit of indirect ties for a focal inventor is subject to the number of the focal inventor's direct ties. Inventors with few direct ties are expected to have more benefits from their indirect ties compare to inventors with many direct ties. On the other hand, the benefit of direct ties for a focal inventor is subject to the number of the focal inventor's indirect ties as well. Inventors with few indirect ties are expected to have more benefits from their direct ties compare to inventors with many indirect ties.

To support this idea, there are two arguments. First, the relative addition to benefits through indirect ties is expected to be more for inventors with few direct ties compare to for inventors with many direct ties. For inventors with few direct ties, the information brought by indirect ties may lead to an important contribution to the focal inventor's innovative performance, although inventors with many direct ties can already access substantial part of knowledge flows through their direct ties. The supplementary access to information brought by inventors' indirect ties may be representative of a slight addition to focal inventors' innovative performances. Second, inventors with many direct ties may be bounded to benefit from the knowledge of their indirect ties (Ahuja 2000).

**Hypothesis 3:** The impact of indirect ties on an inventor’s subsequent innovation output will be moderated by the level of the inventor’s direct ties and vice versa: the greater the number of direct ties (indirect ties), the smaller the benefit from indirect ties (direct ties).

### 2. Structural Holes

Structural holes exist between alters linked to the same focal inventor (ego) but not linked to each other. In other words, disconnections among alters create some gaps in information flows which are called as structural holes (Ahuja 2000; Obstfeld 2005). High level of structural holes in an inventor’s network magnifies ego’s access to diverse knowledge. Moreover, to the extent that inventors’ direct connections do not collaborate with one another, they are more likely to think differently and have diverse insights and perspectives. Consequently, these advantages enhance the innovative performance as they provide a greater potential to combine different technologies (Fleming et al. 2007; Burt 1995; Obstfeld 2005; Ahuja 2000; Cannella and McFadyen 2015).

On the contrary, because the level of knowledge redundancy decreases in networks with many structural holes, communication costs among ego and her alters significantly increases. Furthermore, because alters are mostly disconnected, they are less likely to detect the diversity and quality of resources available in networks (Sorenson et al. 2006; Cannella and McFadyen
2015). Additionally, many structural holes may promote attention management problems and build a ground for an inventor positioned between two disconnected parties to manipulate or to exploit those parties for her benefit (Burt 1995; Obstfeld 2005; Ahuja 2000). In this sense, the relationship between structural holes and subsequent innovation output of inventors may be expected to be positive as they indicate diverse knowledge.

**Hypothesis 4:** The greater the structural holes spanned by an inventor, the greater the inventor's subsequent innovation output.

**COLLABORATION CHARACTERISTICS and INNOVATION**

The importance of the balance between common prior knowledge which is the main reason for redundancy at high levels and diversity of knowledge took our attention to collaboration characteristics.

Studies about the collaboration characteristics the most important thing is the nature of shared knowledge among collaborating inventors. The first idea that comes to minds after the arguments mentioned above is the existence of a tradeoff between the level of knowledge similarity and the level of knowledge diversity of co-inventors. Additionally, assuming nonlinear relationship between innovation output and the numbers of direct & indirect ties, the selection of collaborations an inventor should give her attention becomes an interesting question. The role of collaborating inventors’ knowledge cohesion is needed to be focused to determine the preferred collaborations.

From a knowledge point of view, ties that have a wide range of knowledge (rather than narrow) increase the innovative performance when the knowledge transition happen actively and attentively. On the other hand, co-inventors can benefit in the most efficient way from these ties if and only if co-inventors share some common understanding such as knowledge, experience etc. A high level of network cohesion does not only hinder the increasing performance but also decreases the performance. Despite an increase in the network cohesion is likely to increase the redundancy of the information exchanged, it also increases the ease of group thinking (Sosa 2011; Zaheer and Bell 2005; Rodan and Galunic 2003; Emden et al. 2006). In this case, the hypotheses to be investigated are as below:

**Hypothesis 5a:** The breadth of diverse knowledge domains acquired through collaborations is positively associated with the innovation output.
**Hypothesis 5b:** The relationship between the knowledge cohesion (between co-inventors’ prior knowledge) and inventive productivity has an inverted U shape, implying the goldilocks effect in the optimal distance between co-inventors in the knowledge space.

To summarize, it has been assumed that minimum number of direct and indirect ties with maximum benefits will create the best productive collaborations. In other words, while number of direct and indirect ties needs to be low for attention management, the nature of shared knowledge needs to have diversity and enough redundancy for the best innovation output. The combination of optimum number of direct ties, optimum level of redundancy and diversity will let inventors to focus their attentions more efficiently and will help them to choose the most promising collaborations.

**METHODOLOGY**

**Setting and Data**

To test our hypothesis and to answer -which collaborations, inventors should give attention more than others to increase their innovative performances- an empirical study is conducted. As we would like to test the effect of network and collaboration characteristics on inventive performances, the unit of analysis is a single inventor embedded in the collaborative network.

It is obvious that there are measurement errors in patent data. Misspecifications are because individuals, as well as companies, may avoid sharing their inventive activities or may limit their patent submissions for their best inventions (Fleming and Sorenson 2004). Despite these imperfections, patents are the best quantitative measure to observe invention processes. Also, patents are rich in information such as regions, ids, technologies, citations, year, affiliation etc. Therefore, European Patent Office worldwide patent statistical database is used to construct collaborative networks. The sample is composed of all patents in France in the period from 1998 to 2006. We study ego networks, defined as an individual (ego) and the set of others (alters) to whom he or she is directly and indirectly tied. When nodes are inventors, co-inventor relations create ties between these nodes. The analyses include 587 750 inventors and 516 368 patents granted by IPO.
Measures

Dependent Variable

Dependent variable of the study is innovative performance. Innovative performance is measured as the number of citations that a patent receives up to the 5 years following its application date.

Forward citation count is a significantly representative measure of inventive performance because each patent should cite highly related previous patents by law. Moreover, prior investigations demonstrate that the number of citations a patent receives is significantly correlated with its technological importance, as measured by experts, social value, and industry. Forward citations also indicate the economic value of an invention (Trajtenberg et al. 1997; Fleming and Sorenson 2004; Harhoff et al. 1999).

As the study would like to capture the effects of network characteristics on subsequent innovation output, forward citation counts are measured with one-year lag to the network creation year. For instance, if the network is created by co-inventor relationship in the patents granted in year t, the innovation output is measured by total forward citation count of patents in year t+1. The dependent variable is named as forward citation count.

Independent Variables

Direct tie count is measured by an inventor’s degree centrality in the network. This variable represents the number of directly connected inventors (co-inventors) of an inventor.

Indirect tie count is measured with four alternative ways. The first one is the simple count of indirect ties of an inventor in case co-inventors are connected in any path length. This variable is named as indirect tie count. The second variable of indirect ties is the simple count of indirect ties whose path length is two. This variable will be called as first order indirect ties as they are the closest indirectly connected co-inventors.

In previous sections, it is assumed that longer path length connecting inventors is likely to decrease the benefits of ties compare to shorter ones. Third alternative measure of indirect ties captures distance effect on benefits of ties. This variable is named as distance weighted indirect tie (dw) and measured as in the previous study of Ahuja (2000). We first determine the strength of indirect ties by using their distance to the focal inventor and then weighted the number of
indirect connections with the strength of their ties. The longer distance leads to the weaker ties and vice versa.

The fourth indirect tie variable is called as distance and information weighted indirect ties (diw). In innovation networks, some inventors create more than others, therefore, connecting with some inventors lead to increase innovation output more than others. In other words, even if the shortest path lengths to ego are same for two co-inventors, the benefits of them to the focal inventor change based on their own productivity. We first tried to capture the productivity of co-inventors by total patent count in year t. Note that patents in year t are used to create networks and innovative performance is measured based on patents in year t+1. Then, we took the multiplication of the quality of co-inventors and the distance weighted tie strength as Burt has described (Ahuja 2000).

Once indirect and direct variables are measured, the variables to observe interaction effect of direct and indirect tie variables are created. There are four alternatives of the interaction variables based on four version of indirect ties. We called these variables as direct x indirect, direct x firstOrder, direct x dw, direct x diw. To be sure that indirect ties and their interactions have similar effects on innovative performance in four alternative scenarios, we have investigated their effects by adding them to separate models.

The last independent variable to be measured as network characteristics is structural holes. For structural holes measurement, first, effective size is computed as an intermediary variable. The effective size of an ego network is subject to the concept of redundancy. As it is already explained redundancy occurs to the extent that an ego’s alters are connected to each other. In addition to this, effective size is the nonredundant part of an ego’s relationships. The effective size of ego u which is denoted as e(u) of an ego is calculated as below:

\[
e(u) = \sum_{v \in N(u) \setminus \{u\}} \left( 1 - \sum_{w \in N(v)} p_{uw} m_{vw} \right)
\]

N(u) is the set of neighbors of u and p_{uw} is the normalized mutual weight of the edges (direct and indirect ties) between u and v, for each dual u and v. The mutual weight of v and w divided by v’s highest mutual weight with any of its neighbors is denoted as m_{vw}. The mutual
weight of \( u \) and \( v \) is the sum of the weights of edges. In the study, edge weights are assumed to be one as graphs are unweighted (Burt 1995, Borgatti 1997).

Following the measurement of effective size, it is divided by the overall co-inventor count (Direct tie count + Indirect tie count) of an inventor for her network’s effective size. The variable structural holes may take a value from 0 to 1. A lower value for structural holes means fewer existence of structural holes. If the variable is equal to one, this shows that all of co-inventors are disconnected to each other. For inventors who has zero connections, this variable is equal to 0.

To test hypothesis 5a and 5b about the effect of collaboration characteristics on innovation output, additional measurements will be performed in the next version of the paper.

**Control variables**

We also controlled for the experience of focal inventors and their prior knowledge diversity up to the year \( t \). First, the variable experience is measured by looking the first patent year of focal inventors. Experience of an inventor is the subtraction of year \( t+1 \) and year of her first patenting activity. Secondly, the variable prior knowledge diversity is the simple number of different technological classes which are assigned to focal inventor’s previous patents. Finally, we put year dummies for each period to control their effects on innovation output over time.

**Model Estimation and Econometric Issues**

To investigate the relationships and to control for a variety of factors, we estimated fixed effects negative binomial models of forward citations. Because the dependent variable takes on only whole number values and observed overdispersion in the data, using a linear regression admittedly will create inefficient, inconsistent and biased coefficients. Additionally, as we wanted to take advantage of the data, we would like to use a negative binomial fixed-effect model specifically for panel data. This estimator allows controlling for overdispersion—where the variance quite bigger than the mean—which the data exhibit. It also allows us to control broadly for differences across individuals by defining fixed effects at the level of inventors. Despite we are aware of the necessities and advantages for this estimation model, we couldn’t manage to use a negative binomial fixed-effect model for panel data because of computational problems. These barriers showed up as encountered convergency deficiencies, discontinuation of inventors, therefore, inadequacy in algebraic computations. Because of computational restrictions, we went forward with negative binomial regressions by pooling the data. Once we pooled the data, the
necessity of fixed-effect is lost. Since we suspected the bias of the negative binomial estimator, we compared the available results of negative binomial fixed-effect model for panel data with the results of the negative binomial regression model. Eventually, it is observed that the coefficients and the relations are similar for both estimators.

RESULTS

Table 1 provides the descriptive statistics of main variables. In period the 1995-2005, every inventor has four collaborators on average. According to descriptive statistics, inventor’s experience is in the range of from 1 year to 115 year which is not acceptable. This let us to see, we still have dirt in our data, and it needs to be cleaned more. The only explanation of this kind of measurement errors such as upper limit of direct ties or experience means that we have some observations belong to the organizations instead individuals.

Table 1. Descriptive Statistics

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>S.D.</th>
<th>Min</th>
<th>Max</th>
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<tbody>
<tr>
<td>forward citation count</td>
<td>1.07</td>
<td>14.13</td>
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<td>direct tie count</td>
<td>4.97</td>
<td>11.60</td>
<td>1.00</td>
<td>1204</td>
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<td>Indirect tie count</td>
<td>12280</td>
<td>17167.86</td>
<td>0.00</td>
<td>45598</td>
</tr>
<tr>
<td>first order indirect ties</td>
<td>117.86</td>
<td>239.26</td>
<td>0.00</td>
<td>7013</td>
</tr>
<tr>
<td>distance weighted indirect ties</td>
<td>5342.28</td>
<td>7491.42</td>
<td>0.00</td>
<td>20389.42</td>
</tr>
<tr>
<td>distance &amp; information weighted indirect ties</td>
<td>16675.56</td>
<td>23120.28</td>
<td>0.00</td>
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<td>direct tie count$^2$</td>
<td>159.18</td>
<td>6826.98</td>
<td>1.00</td>
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</tr>
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<td>Indirect tie count$^2$</td>
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<td>0.00</td>
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<td>first order indirect ties$^2$</td>
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<td>281736.00</td>
<td>0.00</td>
<td>49200000</td>
</tr>
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<td>distance weighted indirect ties$^2$</td>
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<td>130000000</td>
<td>0.00</td>
<td>416000000</td>
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<td>distance &amp; information weighted indirect ties$^2$</td>
<td>813000000</td>
<td>1190000000</td>
<td>0.00</td>
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<td>Direct tie count x indirect tie count</td>
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<td>388912.90</td>
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<td>direct tie count x firstOrder</td>
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<td>richness of structural holes</td>
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</table>
Table 2 provides the results of negative binomial regressions for four models which have *indirect tie count*, *first order indirect ties*, *distance weighted indirect ties*, and *distance and information weighted indirect ties* respectively. Interaction variables and the square of indirect tie variables are also included subject to version of indirect tie.

The results do not support for hypothesis 4. Also, second hypothesis is only acceptable for *first order direct ties*, *distance weighted direct ties* and *distance and information weighted direct ties* unlike *indirect tie count*.

For the first hypothesis, positively significant correlation with *direct tie count* and negatively significant relation with *direct tie count*² proves that there is a nonlinear relationship between the number of co-inventors and subsequent innovation output on focal inventors.

For the second hypothesis, the coefficient of *indirect tie count* is positive and significant, but the square of *indirect tie count* is negatively nonsignificant. In this case, we don’t have enough evidence to say that there is a non-linear relation between *indirect tie count* and subsequent innovation output. On the other hand, the coefficients of indirect ties (for weighted versions and for the first orders) indicate that there is a non-linear relationship between indirect ties and subsequent innovation output. When the importance of distance and variety of available knowledge in our collaborations are considered, we still can say that the more indirect ties inventors maintain, the more inventors increase their innovative performances for low level of indirect tie counts. After a threshold the benefits of indirect ties will disappear and furthermore start to decrease the subsequent innovative performances.

For the third hypothesis, the interaction effect of *direct tie count* and *indirect ties (for all versions)* are all negatively correlated with the innovation output.

For the effects of structural holes, we proposed two the hypotheses 4. The results show that having few structural holes is associated with increased innovation output. In other words, a high level of structural holes decreases the subsequent innovative performance of inventors.

Having diverse prior knowledge and having experience have positive and significant relationship with innovative performance. On the other hand, the square of experience is negatively correlated with innovation output which shows that experience also has a nonlinear relationship with innovative performance.
### Table 2. Negative Binomial Regression Results (N = 780 210)

<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>direct tie count</td>
<td>0.103***</td>
<td>0.104***</td>
<td>0.103***</td>
<td>0.0844***</td>
</tr>
<tr>
<td>direct tie count²</td>
<td>-5.25e-05*** (1.85e-06)</td>
<td>-5.41e-05*** (1.80e-06)</td>
<td>-5.39e-05*** (1.80e-06)</td>
<td>-7.32e-05*** (1.57e-06)</td>
</tr>
<tr>
<td>Indirect tie count</td>
<td>1.48e-05*** (2.31e-06)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Indirect tie count²</td>
<td>-0 (5.99e-11)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>direct x indirect</td>
<td>-1.27e-06*** (7.88e-08)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>first order indirect ties</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>first order indirect ties²</td>
<td></td>
<td>-4.93e-07*** (3.33e-08)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>direct x firstOrder</td>
<td>-2.55e-06*** (3.49e-07)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>distance &amp; information weighted indirect ties</td>
<td>1.76e-05*** (2.26e-06)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>distance &amp; information weighted indirect ties²</td>
<td>-1.37e-10*** (0)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>direct x diw</td>
<td>-9.77e-07*** (6.26e-08)</td>
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<td></td>
</tr>
<tr>
<td>distance weighted indirect ties</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>distance weighted indirect ties²</td>
<td></td>
<td></td>
<td></td>
<td>-8.13e-10*** (3.15e-10)</td>
</tr>
<tr>
<td>direct x dw</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>structural holes</td>
<td>-0.556*** (0.0383)</td>
<td>-0.549*** (0.0383)</td>
<td>-0.551*** (0.0383)</td>
<td>-0.604*** (0.0374)</td>
</tr>
<tr>
<td>prior knowledge diversity</td>
<td>0.105*** (0.00278)</td>
<td>0.105*** (0.00278)</td>
<td>0.105*** (0.00278)</td>
<td>0.110*** (0.00280)</td>
</tr>
<tr>
<td>experience</td>
<td>0.0769*** (0.00276)</td>
<td>0.0771*** (0.00276)</td>
<td>0.0769*** (0.00276)</td>
<td>0.0750*** (0.00277)</td>
</tr>
<tr>
<td>experience²</td>
<td>-0.00110*** (0.00010)</td>
<td>-0.00110*** (0.00010)</td>
<td>-0.00110*** (0.00010)</td>
<td>-0.00108*** (0.00010)</td>
</tr>
</tbody>
</table>

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1
Finally, for the last two hypotheses which are 5a and 5b a set of complementary measurements and analyses will be implemented in the next version of the paper.

**DISCUSSION and CONCLUSION**

The objective of this paper first, to identify which characteristics of the individual’s collaborative network explain her inventive productivity. Further, the paper will investigate the effects of the nature of shared knowledge through individual’s collaborative network.

Results show that network characteristics affect inventors’ innovation output. Both direct and indirect ties have positive effect on innovation output up to a threshold. This means that inventors should not give their attention after a certain level of collaborations.

Moreover, according to the results while *indirect tie count* has only a positive linear relationship, the weighted indirect ties have nonlinear relationship with the subsequent innovation output. This may be explained by the quality or potential benefits of ties come to the forefront instead their quantities as in the *indirect tie count*. When we looked at quantity, having too many indirect ties looks like important. Conversely, when the benefits of collaborations are investigated, there is always an inverted U-shape relationship between indirect ties and innovation output. This is a support for the validity of weighted indirect ties as a relevant metrics in our models and emphasizes the importance of choosing contentful co-inventors.

There is also an evidence of a tradeoff between benefits of direct ties and indirect ties. Our results suggest that, after a certain threshold indirect ties decreases the benefits provided by inventor’s direct ties as they distract the direct connections’ attention and vice versa. Another support for attention management problems is the existence of a threshold for direct ties. Moreover, the reason for high level of experience decrease the innovation output may also be caused by the attention management problems of managers who are expected to have more experience.

Finally, we also find that inventor’s productivity decreases when they are surrounded by many structural holes and when they have more diverse prior knowledge. The similar results have obtained by Ahuja for the firm level networks. The explanation of structural holes’ negative effect has been the opportunistic behaviors of partners. Contrary, we don’t explain the same result in the same way as it does not make too much sense at inventor level. Our understanding promotes the attention management problems of inventors once again. In the networks that have been created based on patenting activities, structural holes are somehow the indicators of disconnected
projects that a focal inventor gets involved. This means that, structural holes are the indicators of multi-tasking problems, too many separated projects, high communication and information transaction costs which are expected to be negatively correlated with innovative performance of an inventor.

In this manner, one last time the importance of optimum number of collaborations with maximum benefits comes to the mind. The importance of prior knowledge diversity and the interpretation on negative impact of structural holes point to the importance of balances between the number of collaborations and the level of knowledge cohesion/diversity. Therefore, as the next step, the effect of collaboration characteristics -the nature of knowledge- on inventor’s productivity will be investigated.

REFERENCES


Obstfeld, David. “Social Networks , the Tertius Iungens Orientation , and Involvement in Innovation Author ( s ): David Obstfeld Source : Administrative Science Quarterly , Vol . 50 , No . 1 ( Mar ., 2005 ), Pp . 100-130 Published by : Sage Publications , Inc . on Behalf O.”


