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New Cooperation and Novel Innovations:

The Role of Regional Brokerage and Collaboration Intensity

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Abstract

Along with the increased importance of technology innovation, the importance of collaboration has been highlighted for conducting the innovation. This study discusses the importance of brokerage role of regions in co-inventor collaboration for establishing novel innovation and new collaboration. In addition, we address how regional collaboration intensity interacts with the brokerage role, highlighting its mediating effect. For this purpose, empirical analysis has been conducted with EPO PATSTAT database and European Regional Database (ERD) covering the European regions between 1986 and 2015. Our finding shows that the brokerage roles contribute to the extension of collaboration network, but are not efficient for the creation of new invention. Collaboration intensity, however, helps both novel innovation and new collaboration, and especially it positively interacts with brokerage role indicating that a region can take the benefit from being broker in collaboration.

JEL Classification: O31, R11, D85

Keywords: brokerage, co-inventor collaboration, collaboration intensity, novel innovation, new collaboration

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1. Introduction

Along with the increasingly importance of technology innovation, the central role of collaboration has been highlighted for research and development (R&D) activities. As a geographical unit of knowledge production, the level of collaboration made by local inventors is an important proxy for capturing a region's innovation activities.

The relationship between regional collaboration and innovation can be explained with a network perspective where individual actors with different knowledge sources are connected. As if a centroid in the network shows greater competitiveness in accessing and using other's resources, a region interacting more with diverse partners can easily access the new knowledge and face unexpected opportunities. In this sense, a region whose collaboration network is not densely connected may experience inefficiency in innovation activities (Ahuja, 2000a; Coleman, 1988; Jiang et al., 2019; Seo, 2019). On the other hand, a region which connects two or more disconnected regions also has an advantage (or sometimes even greater).

The idea that network connectivity is central helps explaining the advantages gained by regions acting as brokers within the global innovation network, as well as the mechanism they exploit to achieve better performances. According to the structural hole theory (Burt, 2005), a so-called broker can control the knowledge flows and bridge different knowledge sources from other agents. With this potential advantage, broker can take the advantage of accessing the new network (Granovetter, 1973). From this point of view, it is also possible to assume that more bridging regions have an advantage in innovation activity.

Despite extensive theorization carried out both at individual and firm level (Broekel, 2012; Leick & Gretzinger, 2020), it remains a knowledge gap in the understanding of how brokerage entails when applied to regions. This paper aims to address this issue by applying a network perspective to the study of regional innovation.

In addition to the brokerage role in collaboration, what matters for innovation activity is the regions' overall tendency in conducting collaboration. The literature has largely investigated whether geographical proximity promotes better innovation or not, particularly in the case of co-inventorship relation (for a critical assessment, see: Boschma, 2005). Geographical proximity influences the effectiveness of collaboration as inventors closely located can more easily share the knowledge and collaborate. At the same time, this can only provide very limited resources as collaborating inventors may already have common or similar knowledge with each other. Although it may not necessarily be very efficient, collaboration with inventors that are apart from each other might allow the access to new knowledge. In this regard, collaboration intensity can play a role in determining the effect of brokerage positions, since the accessibility of new knowledge may differ depending on the collaboration intensity.

To the best of our knowledge, brokerage role and collaboration intensity have not been considered together to see how they interact and influence innovation activity at the regional level. To fill this research gap, this paper aims at generating a more accurate understanding of the brokerage role of regions, both with theoretical and policy implications, addressing the following research questions: How do regions conduct collaboration and what are the top brokerage regions? Which type of brokerage positions of regions enhance new innovation and new collaboration? What is the mediating effect of regional collaboration intensity on brokerage, and how does this affect innovation and collaboration outcomes?

In order to do so, we make use of EPO PATSTAT database and European Regional Database (ERD) to conduct an empirical analysis with the European regions between 1986 and 2015. To measure the region's participation in brokerage roles, co-inventor collaboration measured by the share of co-inventors participating to patent development is aggregated to construct a weighted regional collaboration network. With this approach, the size effect caused by the number of inventors in a region participating to the single patent can be controlled. Based on this, the region's bridging capability for collaboration is measured by three brokerage role measures proposed by Gould & Fernandez (1989). While the originally proposed brokerage roles are designed upon a directed network, only the brokerage roles that do not take into account the direction are selected, namely: coordinator, consultant (or itinerant) and liaison. Collaboration intensity is measured by the O-I index by defining outward as inter-region collaboration and inward as intra-region collaboration.

Using these key variables, we explore the collaboration patterns defined by European regions in order to see how these regions are located in the collaboration network. In addition to this, we examine the impact of brokerage positions on both novel innovation and new collaboration. Collaboration intensity is used as a moderator to investigate which is its role in affecting the relationship between brokerage roles and both novel innovation and new collaboration.

Our results can be summarised in three main findings. Firstly, we confirm previous findings about brokerage roles negatively associating with novel innovation but causing positive effect on new collaboration. Since actors get more benefit from a dense collaboration network, the result on novel innovation highlights that more structural holes hamper innovation output (Ahuja, 2000a; Coleman, 1988; Jiang et al., 2019; Seo, 2019). On the other hand, more brokerage role is beneficial to new collaborations, which is in line with the point of view of Burt's theory (Burt, 1992; 1997) that emphasizes the potential of brokers for enriching the new network with which they have not interacted before. Secondly, external collaboration has a positive impact on both novel innovation and new collaboration. As we will argue, even if some regions may already have sufficient resources necessary for innovation, it is still beneficial for local inventors to collaborate with inventors from outside the region in order to increase the probability of accomplishing novel innovation and new collaboration. Finally, collaboration intensity positively moderates on the relationship between brokerage roles and novel innovation. This highlights the importance of external collaboration for regions to achieve novel innovation, via their brokerage positions.

The paper is organized as follows. In section 2 we present a brief review of the existing literatures on brokerage role and collaboration intensity at the regional level. In the third section, we describe the data, variables and the empirical strategy. Section 4 presents descriptive overview of our main variable of interest. The fifth section presents findings from the econometric analysis. The sixth section offers discussion and conclusion.

2. Literature review

2.1 Regional collaboration intensity

Collaboration is an effective method for innovation, which enables knowledge diffusion or access to new knowledge (Teece, 1986) and sharing of risks and costs between collaborators (Cassiman & Veugelers, 2002). In fact, collaboration aiming for technology development has been adopted to enhance productivity and competitiveness at various levels including national, regional, and organization. Innovation accomplished through collaboration can be investigated through a network perspective, where individual actors with different knowledge interacts in order to create new invention.

In a regional context, a region is a geographical unit of knowledge dimension conducting collaboration with other regions. Economic geography literature shows that geographic proximity, in the sense of lower geographical distance, contributes to greater knowledge exchange (Boschma, 2005). Furthermore, social proximity and cognitive proximity of region are also important for creating new invention (Feldman et al., 2015).

In this light, regions with strong collaboration network are expected to benefit from greater knowledge spill-over effects with respect to regions with weaker collaboration ties, as the former regions have easier access than the latter to diverse and complementary knowledge sources. An example of this is the study carried out by Fritsch (2004) in which he shows that regions which benefit from a more dense collaboration intensity exhibits higher innovation performance than similar region characterized by lower collaboration. The literature has explored the complementarity between regional and inter-regional collaboration, finding that in order to achieve a better innovation performance, both types of collaborations are necessary (Bathelt et al., 2004b; Broekel, 2012; Camagni, 1991).

Besides highlighting the advantages for innovation coming from agglomeration and spatial proximity (Boschma, 2005; Feldman & Kogler, 2010), the literature has also emphasized the limits arising from and excessive regional collaboration.

Indeed, excessive collaboration between regions can also worsen the innovative performance of companies. If collaboration is repeated within a local network, firms or individuals within that network have a tendency to over-rely on prior knowledge and expertise (Camagni, 1991; Fleming, 2001; Stuart & Podolny, 1996). In this case, the danger is to autonomously create a cage whose walls are composed of the redundancy of knowledge and technologies used in local research (Rosenkopf & Nerkar, 2001; Uzzi & Spiro, 2005; Rychen & Zimmermann, 2008; Giuliani, 2011).

On the other hand, if many studies have shown that the regional innovative performance is favored by the intensity of intra-regional collaboration (Saxenian & Societies, 1996; Asheim & Isaksen, 2002; Cainelli et al., 2007), the former may also be hindered by poor inter-regional connections (Camagni, 1991). A similar reasoning can be applied to the case of low intra-regional collaboration and high inter-regional collaboration. As shown by Storper and Venables (2004), in fact, the regions that find themselves in this situation may have a low innovative performance due to the fact that the excessive inter-regional collaboration can give rise to a segmentation of regional organizations that are no longer able to integrate the local buzz.

Several studies in the field of collaboration networks have underlined how broker positions exert a structural influence on knowledge networks (Boschma, 2005; Boschma & Frenken, 2006; Breschi & Lissoni, 2001; De Prato & Nepelski, 2014; Glückler, 2007). A node in the position of broker connects different sources of knowledge, controlling the flow to and from its network, thus supporting its viability (Sapsed et al., 2007).

2.2 Brokerage role

Research on brokerage dates back to the early 1920s with the foundational work of Simmel, later reprised by Merton in the late 1960s and by research on social networks as early as the 1980s. As brokerage roles have been studied for decades, the literature provides several definitions. Ryall and

Sorenson (2007) define a broker as an individual who is able to profit from the intermediation among parties. Shi, Markoczy and Dess (2009), more precisely, point out that a broker is an actor who mediates between two other actors who are unconnected to each other. Diani and McAdam (2003) better define the ability of brokers to connect actors who do not communicate, underlining how this can be caused by a specific social or political barrier.

In all of these definitions, brokers' main characteristic is the capacity to form a bridge between two disconnected nodes in order to compensate for structural holes connectivity weaknesses. None of these general concepts, however, is suitable to highlight the specific impact of different types of brokerage role which can arise. For this reason, we draw upon the original definitions as put forward by Fernandez and Gould (Gould & Fernandez, 1989; Fernandez & Gould, 1994) who distinguish several types of brokerage positions: i) *coordinator* brokers link individuals who are unconnected but belong to the same group, such that the information flows through the broker remaining inside the group; ii) *consultant* (or *itinerant*) brokers connect individuals co-located in the same external group; iii) representative brokers transfer externally information which is internal to their group, and are able to negotiate on behalf of it; similarly, but with opposite direction, iv) *gatekeeper* brokers transfer external information inside their group; finally v) *liaison* brokers mediates between individuals belonging to different groups and it is positioned outside both of them.

A node in a broker position is able to combine information internal and external to the network, together with existing knowledge between non-connected nodes, and diffuse them generating a competitive advantage for the network itself (Graf & Krüger, 2011). Therefore, it influences the nodes inside and outside the network, producing higher innovative outputs (Burt, 2005). So far the literature has paid very little attention to the impact of broker positions on the inventive performance of the cluster as a whole.

Breschi and Lenzi (2015) focus on how the regional knowledge base can be renewed and expanded thanks to the gatekeeping position of individual inventors within networks of co-inventors. Graf and Krüger (2011) consider four regions in Germany and investigate whether patent applicants benefit from their gatekeeping position in terms of innovative production, finding inconclusive results. More recently, Le Gallo and Plunket (2020) analyse the inventor network of firms, showing how they benefit from their inventors' regional gatekeeping position in terms of inventive performance.

As seen, previous studies have mainly focused on two types of brokerage positions, namely gatekeeper brokers and representative brokers, which have been studied in innovation research at the organization level and at the geographic cluster level (Haas, 2015). In general, most of the regional economics literature focuses on specific clusters and on the impact that gatekeepers exert on the supply and dissemination of knowledge within the same clusters (Biggiero, 2002; Giuliani & Bell, 2005; Morrison, 2008; Morrison et al., 2013).

This study extends the brokerage typology of Gould and Fernandez to the network across regions. We apply the notion of brokerage, which commonly indicates the idea that nodes are protagonists in the transfer of external knowledge in the group to which they connect, to the regional framework, thus considering a region in a brokerage position as a broker node in the collaboration network among regions. We expect a brokerage region to be pivotal in the production and connection of external knowledge within an innovation system. In particular we will focus on three of the five original brokerage positions proposed by Gould and Fernandez, those which do not take into account the directionality of the links between nodes, namely: coordinator, consultant and liaison. As far as we know, no study empirically addresses the contribution of specific broker roles of a region taking into account both on innovation performance and the evolution of a regional network.

3. Data & Method

3.1 Data

For empirical analysis, the European Patent Office (EPO)'s PATSTAT database and European Regional Database (ERD)[1] is used. From each data set, we extracted all patent and economic indicators including NUTS-3 regions between 1986 and 2015. For knowledge space analysis, the subclass cooperative patent classification (CPC) is used with a window of 5 years. Knowledge capital depreciates, and it loses its economic value within 5 years (Griliches, 1979, 1984). In this regard, a 5 year-window has been regarded as an appropriate timeframe for analysing technological impact of prior inventions (Ahuja, 2000b; Gilsing et al., 2008; Henderson & Cockburn, 1996; Podolny & Stuart, 1995; Stuart & Podolny, 1996). To geo-locate the patents, inventor's address and NUTS-3 classification have been used. The NUTS-3 regions are converted into Metropolitan and Non-metropolitan regions by the concordance table provided by Eurostat based on 2013 NUTS version[2]. As a result, total 274 metropolitan (hereafter metro) regions and 859 non-metropolitan (hereafter NUTS-3) regions are included. From ERD, regional level economic variables to control the regional difference are collected.

[1] European Regional Database (ERD) is a service provided by Cambridge Econometrics that contains information on Regional employment, level of output and population.
[2] https://ec.europa.eu/eurostat/web/metropolitan-regions/background

3.2 Regional collaboration network

The regional collaboration network uses the aggregated co-inventor network transformed into the regional level. In co-inventor network, the linkage between inventors can be measured either by the number of collaboration between inventors or the share of inventors. The share of inventors (hereafter inventor-share) is the proportion of the inventor participating for the patent application. For instance, if there were five inventors participated for developing a certain patent, the prior assumes the value 1 for total 10 co-inventor linkages while the latter gives the value of 1/10 for each linkage[3]. The problem occurs when number of regions are less than number of inventors, in which some regions have more inventors than others. Under this mechanism, the greater values are assigned to the patent with greater number of inventors, which gives benefits to the region with many inventors participating on the same patents. For the aggregation to the reginal level with inventor's address, therefore, the share of inventors is used to control the inventor size effects. Except this difference, either using the number of collaboration or sum of inventor-share for co-inventor network does not show big difference because both assumes the equal weight and their values increase equally.

At regional level where considering collaboration between regions by aggregating the co-inventor collaboration, however, these two options make big difference. From the same example, let us assume that three inventors (A, B, C) resides in the same region (region 1) while the fourth inventor (D) and the fifth inventor (E) live in other regions (region 2 and 3, respectively). If the number of collaboration links were used, given the equal value of 1 for each co-inventor linkage, region 1 has 6 linkages (A-D, B-D, C-D, A-E, B-E, C-E), region 2 has 4 linkages (D-A, D-B, D-C, D-E) and region 3 has 4 linkages (E-A, E-B, E-C, E-D). From this, total 14 linkages have made from a single patent, which is greater than the number of linkages obtained from co-inventor collaboration. Once again, this can create biased results for patents with greater number of inventors, and it can broaden the gap between the regions with greater number of inventors and with the less one.

Regarding this, a weighted regional collaboration is used, which is measured by the following procedures. First, we differentiate patents into solely developed patents and collaboratively developed patents. The solely developed patent is assigned to the region of its inventor with the full weight of 1, and collaborated patent uses inventor-share. Using inventor's geo-location code, the regional-share table is calculated by summing up the inventor-share by the region for each patent. Based on the

[3] Given five inventors, the total number of possible collaboration is calculated by ${}_5C_2 = 10$.

regional-share table, the regional collaboration table is made. Since each region has different values of regional-share, the sum of regional-share between two regions is firstly measured. Once the co-inventor collaboration is aggregated at a regional level, each region no longer shares the equal weight. Then, for each patent, the sum of regional-shares is divided by the total sum of regional-share to obtain the proportion of the combination between two regions used for the patent creation. Through this process, the collaboration between regions with different regional-share can be easily obtained. At the end, this regional collaboration table is used to obtain regional collaboration network. Figure 1 illustrates the sample of region-share table and regional collaboration table.

Regional-share table

Period	Patent	Region	Regional-share
1996-2000	Patent 1	Region 1	0.3334
		Region 2	0.1667
		Region 3	0.1667
		Region 4	0.1667
		Region 5	0.1667
Sum			1

Weighted regional collaboration table

Period	Patent	Region 1	Region 2	Region-share 1	Region-share 2	$\sum share_1 + share_2$	$\sum share_1 + share_2 / \sum(\sum share_1 + share_2)$
1996-2000	Patent 1	Region 1	Region 2	0.333	0.167	0.500	0.125
		Region 1	Region 3	0.333	0.167	0.500	0.125
		Region 1	Region 4	0.333	0.167	0.500	0.125
		Region 1	Region 5	0.333	0.167	0.500	0.125
		Region 2	Region 3	0.167	0.167	0.333	0.083
		Region 2	Region 4	0.167	0.167	0.333	0.083
		Region 2	Region 5	0.167	0.167	0.333	0.083
		Region 3	Region 4	0.167	0.167	0.333	0.083
		Region 3	Region 5	0.167	0.167	0.333	0.083
		Region 4	Region 5	0.167	0.167	0.333	0.083
					$\sum(\sum share_1 + share_2)$	3.998	1

Figure 1: Parts of regional-share and weighted regional collaboration table

3.3 Dependent variables

This study uses two dependent variable: novel innovation (*Nov.INN*) and new collaboration (*New.COL*). New innovation, also known as explorative patents, is measured by the number of patents containing new CPC classes that were not existed in the previous period (Gilsing et al., 2008; Guan & Liu, 2016). To measure this variable, technological profiles of all regions are compared between the two consecutive periods to obtain the number of patents containing subclass CPCs that had not been used before. Our second dependent variable, new collaboration, is measured by the number of regions that were not collaborated before. For this measure, collaboration profiles of all regions are compared to find out which regions are joined as a new collaborator in the following period.

3.4 Independent variables & Moderator

With the increased interest on the network theory, various measures have been introduced to capture the different aspects of network values of the node or the network. Among various network indicators capturing the level of bridging, the formal typology of the brokerage roles proposed by Gould & Fernandez (1989) has been used. These measures originally is designed upon the directed network, which considers from whom the resource flows to. In the regional collaboration, however, the direction of collaboration is ignored as it focuses on the aggregated co-inventor collaboration. In this sense, this study uses the three brokerage roles that the direction of flows do not changes the original meaning: *Coordinator*, *Consultant* and *Liaison*. As shown in Figure 2, three brokerage roles are measured by counting the frequency of specific roles in collaboration. A *Coordinator* role indicates when a region connects the nodes within the same region. The greater number of coordinator implies that a region has greater knowledge flow remaining inside the region. A *Consultant* role is when a region is placed in a position with inventors from other regions living in the same region. For this case, this region transmits the knowledge between the inventors that are living in the same region. For instance, if a region has engaged in more consultant role, we may assume that it plays important role as an information channel for another region. A *Liaison* role is when a region connects the two different regions. Similarly, a region with greater liaison role can be regarded as an important channel across the regions.

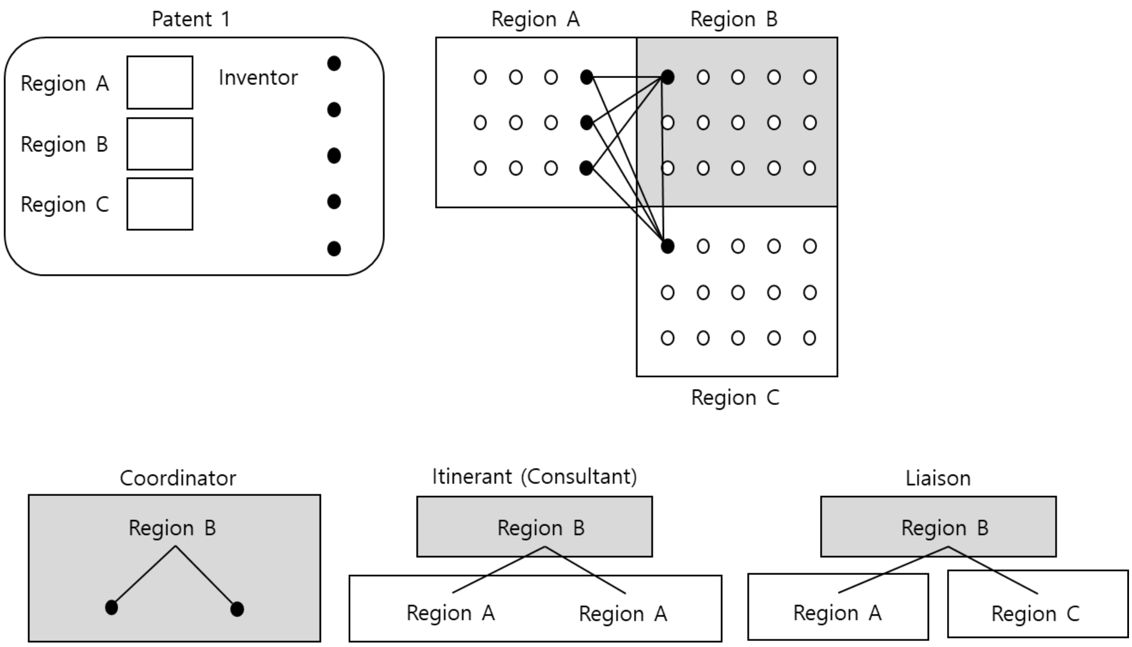

Figure 2: Concepts of brokerage role of regions

Our moderator, *Collaboration Intensity*, indicates how intense a region's collaboration is made either within the region or across regions. Given this concept, *Collaboration Intensity* is measured by the O-I index computed based on external and internal collaboration made by each region. O-I index allows not only capturing whether the collaboration pattern is conducted either internally or externally, but also normalizing the size effect of both (Choe et al., 2016). It ranges between -1 to 1. If a region collaborates more with internally, the value is close to -1; on the other hand, a region performs more external collaboration, the value is close to 1. *Collaboration Intensity*, therefore, tell us whether a region collaborates more with other regions (greater than 0) or within region (lower than 0).

$$Collaboration\ Intensity\ (O - I\ index) = \frac{(External\ collaboration - Internal\ collaboration)}{(External\ collaboration + Internal\ collaboration)} \quad (1)$$

3.5 Control variables

To control the level of technology advancement across regions, revealed comparative advantage (*RCA*) index[4] proposed by Hidalgo et al. (2007) has been used. By definition, a technology with RCA is one that has higher share of technology in its technological portfolio than the share of the same technology in entire EU regions. Such a technology existing in each region can be found with RCA value above 1. In this regard, the number of technology with RCA is measured for each region and period. In addition, the productivity of region is controlled with *GDP per capita* (GDP) as highly productive regions may have greater opportunities to conduct innovation. *Employment per capita* (EMP) is added to control the influence of economic condition while *employment of manufacturing industry* (EMP.M) is included to the size of manufacturing industry because it is one of the largest patenting industries. To account for the effect of human resources involved in innovation activity, *number of inventors per capita* (INV) is used. On the other hand, geographical location and its neighbouring region is important factor affecting regional collaboration. Obviously, regions that are more surrounded by many regions have greater possibility for collaboration than compared to those that are isolated. In such sense, the *number of adjacent regions* (Adj.R), which counts the number of regions that are adjacent to the border, is included to control the geographical advantage in conducting collaboration with other region. Metro regions, which are the group of NUTS-3 regions representing all agglomerations of at least 250,000 inhabitants[5], have comparably more human resources and better infrastructures compared to the NUTS-3 regions not only because of their size, but also the

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[4] Equations in Appendix A.
[5] https://ec.europa.eu/eurostat/web/metropolitan-regions/background

government's focused investment on those major regions. To differentiate the effects between metro and NUTS-3 regions, *metropolitan region dummy* (Metro) is added.

Table 1: Variables description

	Variable	Description	Source
Dependent variable	Nov.INN	Number of patents containing newly introduced sub-class CPC	EPO PATSTAT
	New.COL	Number of new collaboration with new regions	EPO PATSTAT
Independent variable	Coordinator	Number of a Coordinator role	EPO PATSTAT
	Consultant	Number of a Consultant role	EPO PATSTAT
	Liaison	Number of a Liaison role	EPO PATSTAT
Moderator	OI	Collaboration Intensity	EPO PATSTAT
Control variable	RCA	Number of technologies with RCA	EPO PATSTAT
	EMP.M	Employment of manufacturing industry	ERD
	GDP	GDP per capita	ERD
	EMP	Employment per capita	ERD
	INV	Number of inventors per capita	ERD
	Adj.R	Number of adjacent regions	Eurostat
	Metro	Metropolitan region dummy (1 if Metro, 0 otherwise)h	Eurostat

Source. Authors' own calculations using the 1986-2015 EPO's PATSTAT and ERD.

4. Regional collaboration network in the EU metro and NUTS-3 regions

In this section, regional collaboration network in EU metro and NUTS-3 region are presented and discussed with the empirical observation. Table 2 summarises top 5 brokering regions and their major firms for each period. The major firms are selected by the firms with the greatest number of patents. In the fourth and last column, the firm's total number of patents and its proportion of patents in the region are presented. The order of regions are sorted by the average of the three brokerage roles. Throughout the periods, metro regions are ranked as top 5 brokerage regions. The majority of them are German metro regions such as Stuttgart, Frankfurt, Ruhgrebiet, and München, and these regions are where the headquarter of global manufacturing firms are located. Except Paris, the hub of the European economy, the major firms takes the large proportion of the local inventions.

Table 2: Top 5 brokering regions and their major firms per period

Period	Region	Firm	Patents	Prop
1986-1990	München (DE)	SIEMENS	4,175	0.59
1986-1990	Paris (FR)	THALES	1,076	0.07
1986-1990	Stuttgart (DE)	BOSCH	1,643	0.38
1986-1990	Frankfurt (DE)	AVENTIS	2,012	0.39
1986-1990	Ruhrgebiet (DE)	THYSSENKRUPP	341	0.17
1991-1995	Paris (FR)	ALCATEL	897	0.05
1991-1995	München (DE)	SIEMENS	3,992	0.52
1991-1995	Frankfurt (DE)	AVENTIS	1,426	0.28
1991-1995	Stuttgart (DE)	BOSCH	1,696	0.34
1991-1995	Ruhrgebiet (DE)	DEGUSSA	262	0.14
1996-2000	Paris (FR)	ALCATEL	1,940	0.09
1996-2000	München (DE)	SIEMENS	6,618	0.42
1996-2000	Frankfurt (DE)	CLARIANT	445	0.09
1996-2000	Stuttgart (DE)	BOSCH	4,751	0.47
1996-2000	London (UK)	UNILEVER	774	0.11
2001-2005	Paris (FR)	L'OREAL	1,707	0.07
2001-2005	München (DE)	SIEMENS	6,757	0.35
2001-2005	Frankfurt (DE)	CONTINENT	436	0.10
2001-2005	Stuttgart (DE)	BOSCH	5,603	0.45
2001-2005	Basel (CH)	ROCHE	1,089	0.25
2006-2010	Paris (FR)	CEA	2,015	0.07
2006-2010	München (DE)	SIEMENS	6,330	0.31
2006-2010	Berlin (DE)	BAYERHEALTH	340	0.11
2006-2010	Basel (CH)	ABBASEA	1,445	0.34
2006-2010	Frankfurt (DE)	CONTINENT	446	0.13
2011-2015	Paris (FR)	CEA	2,105	0.10
2011-2015	München (DE)	SIEMENS	6,162	0.39
2011-2015	Basel (CH)	ABBASEA	1,455	0.41
2011-2015	Frankfurt (DE)	HERAEUSDENTAL	320	0.14
2011-2015	Stuttgart (DE)	BOSCH	3,748	0.46

* Prop indicates the proportion of patents made by firm to the total number of patents made from the region

Figure 3 shows collaboration intensity and brokerage role relation in 2011-2015.[6] To recap, O-I index close to -1 indicates that a region is more collaborating with "within-region" collaborator and O-I index close to 1 implies a greater collaboration with "inter-region" collaborators. In case of brokerage role, the average value of three brokerage roles is normalized by the maximum value to rearrange all values between 0 and 1. As illustrated, each node represents the region distinguished either by metro or non-metro regions by the shape, and the size indicates patenting per capita. Among all, top 15 regions of brokerage roles, those playing important roles in connecting different regions, are labelled. Top brokerage regions are metro regions, and this shows the strength of metro regions providing

[6] Due to the limited space and consistency in observation, only the latest result is included.

better working environment and transportation services to collaborate with other inventors living in the different regions.

In terms of collaboration intensity, however, no such a tendency is found either between metro and non-metro regions or large patenting and less patenting regions. For instance, Paris, London, and Milano are turned out to be "within-regional" collaborator group that greater proportion of their regional collaboration is based on within themselves. Since metro regions have greater resources and inventors, the local inventors in those regions are less in need of searching collaboration opportunity from outside. On the other hand, Frankfurt, Ruhrgebiet, and Manheim are "inter-regional" group whose regional collaboration is more focused on external collaboration. This also can be explained as metro regions play as a hub for transportation and network, which makes them more feasible for collaboration. In a similar sense, collaboration intensity also varies by the level of patenting for each region. This tells us that collaboration intensity of region varies regardless of its size or possessed resources.

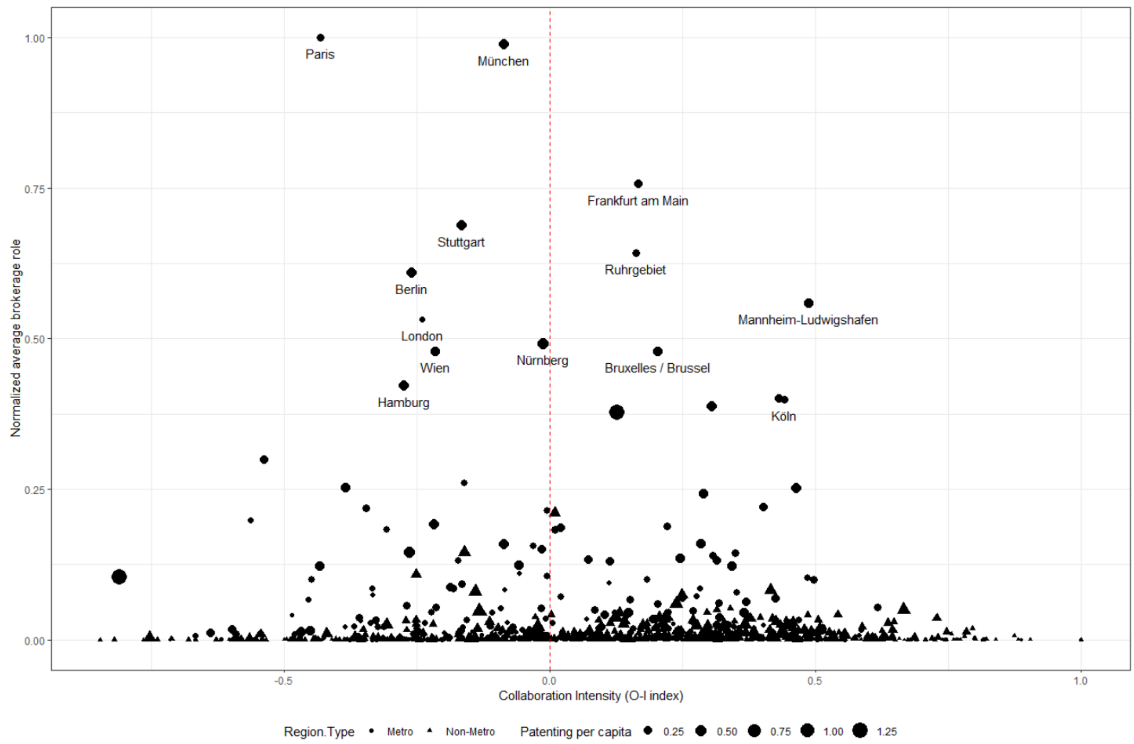

Figure 3: Collaboration intensity –brokerage role graph in 2011-2015

Figure 4 presents the map of European regions showing the level of brokerage role in 2011-2015. For better visualization, all values are log-transformed and darker colour indicates the greater value. As already discussed, metro regions shows greater brokerage roles compared to the NUTS-3 regions. Especially, metro regions that are geographically centre-located ones shows comparably larger values, which obviously implies that their advantage in transportation and advanced infrastructure eases linking inventors from far-distance regions.

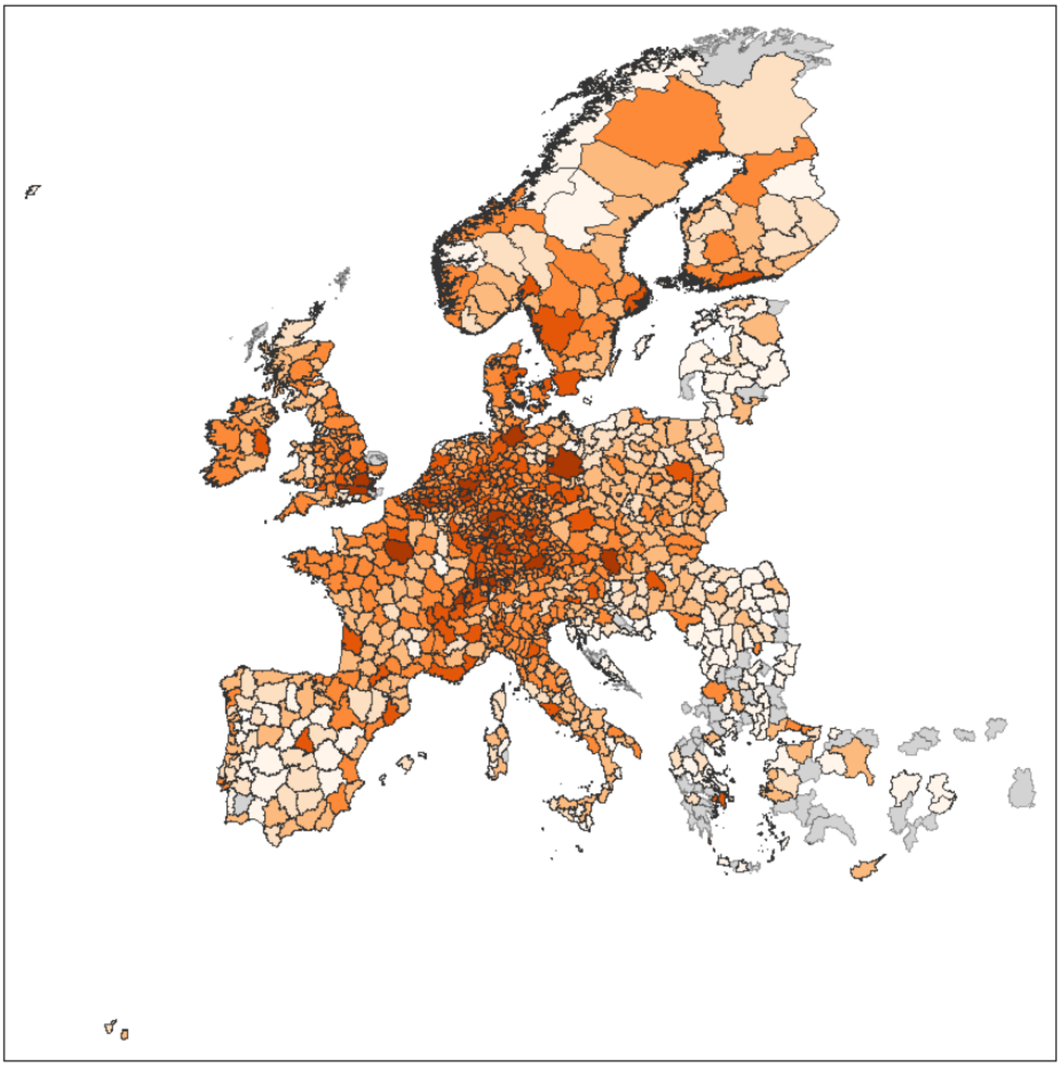

Figure 4: Brokerage map

Collaboration intensity map shows the whether the European regions rely more on external or internal collaboration. Greenish colour indicates higher tendency of the external collaboration while pinkish colour refers to the higher tendency of internal collaboration. As already discussed from Figure 3, no such a tendency that metro or bigger region show stronger external or internal collaboration. Interestingly, the majority of the Eastern European regions (Poland, Czech Republic, Slovakia, Hungary, Romania, Bulgaria, etc.) show greater external collaborations. These regions are also known as the "followers", because these regions are smaller in size of economy and innovation activity compared to the Western European regions. Thus, this could be understood as not only their weakness in developing new technology internally, but also their strategic approach to absorb the knowledge through the external collaboration. Also, most of the German regions do more external collaboration while other big European countries such as France, UK, Italy are relaying on the internal collaboration. This is quite interesting that the German inventors are actively engaging in collaboration with inventors living in other regions even though they have already enough resources in the region. Although this is not the main topic of our interest, this could be a possible explanation for the strength of German industry. On the other hand, greater internal collaboration was observed in the regions mostly in Finland, Sweden, Norway, Spain, UK, and Northern Italy. As known, those strongly internal collaborating regions in UK and Northern Italy are the wealthiest regions where the resources are concentrated. However, that does not necessarily mean that only those regions with sufficient resources do more internal collaboration. For instance, either geographical distance or technological advancement only specialized in a region can also cause the internally bounded collaboration pattern.

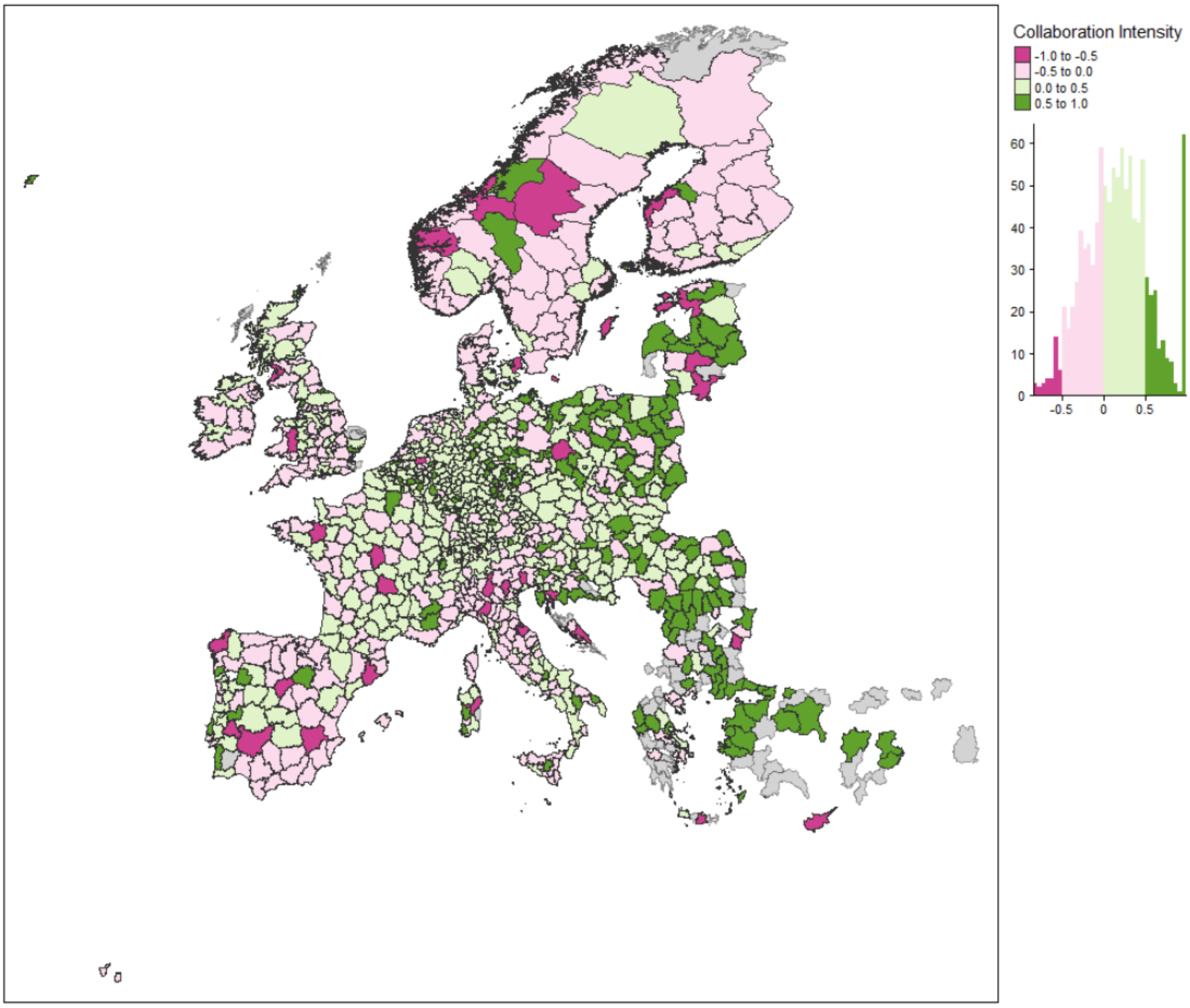

Figure 5: Collaboration intensity map

5. Results

In this section, the empirical results of all estimation models are discussed. The correlation between variables are presented in Table 1. The correlation between all variables are low except *Consultant* and *Liaison* role. To avoid the issue of multicollinearity, the estimations were made separately. Prior to the estimation, Hausman test was conducted to determine the appropriate estimation model. As a result, fixed-effects model has been used for panel regression estimation. In all models, robust standard errors are used in order to avoid heteroscedasticity (Hoechle, 2007; Szymczak, 2018).

Table 3: Correlation matrix

	COO	CON	LIA	OI	RCA	EMP.M	GDP	EMP	INV	Adj.R
COO										
CON	0.17									
LIA	0.49	0.82								
OI	0.01	-0.06	-0.06							
RCA	0.42	0.23	0.30	-0.20						
EMP.M	0.41	0.31	0.45	-0.20	0.38					
GDP	0.27	0.18	0.27	-0.21	0.57	0.08				
EMP	0.10	-0.03	-0.05	-0.03	0.20	0.19	0.12			
INV	0.45	0.42	0.42	-0.02	0.51	0.10	0.44	0.25		
Adj.R	0.33	0.16	0.24	0.00	0.31	0.31	-0.06	0.11	0.16	
Metro	0.31	0.20	0.26	-0.21	0.40	0.46	0.14	-0.03	0.18	0.12

* COO: Coordinator, CON: Consultant, LIA: Liaison; Due to the high correlation between Coordinator and Liaison, the estimations were made separately.

Table 4: Descriptive statistics

	Observation	Mean	Std. Dev.	min	max
Nov.INN	4,329	63.48	48.2	0	313
New.COL	4,329	13.04	18.15	0	147
Coordinator	4,329	1003.1	3,198.58	0	37,456
Consultant	4,329	73.41	440.03	0	9810
Liaison	4,329	1,050.28	4,840.31	0	1,09,202
OI	4,329	0.08	0.37	-0.92	1
RCA	4,329	73.78	46.84	1	226
EMP.M	4,329	190.27	269.94	4.22	3,624.52
GDP	4,329	0.02	0.01	0	0.08
EMP	4,329	0.09	0.04	0.01	0.33
INV	4,329	0.17	0.23	0	3.78
Adj.R	4,329	5.13	2.11	0	16
Metro	4,329	0.28	0.45	0	1

Table 5 summaries the regression result of novel innovation model. Firstly, *RCA* reports positive coefficient with statistically significant level. As expected, more a region has technologies that are above the average level in comparison with other regions, it is likely to have more possibility to make the new inventions. In a similar sense, the positive and significant coefficient of *inventor per capita* can be explained as more inventors are needed for developing the new inventions. Regional economic indicators including *employment of manufacturing*, *GDP per capita*, and *employment per capita*, however, show negative influence on novel innovation. In fact, so-called big regions with comparably greater productivity and human resources are much likely to have large number of technologies already developed by the local inventors. As these regions have already developed large number of technologies, it becomes much difficult to develop something that is not developed before compared to the regions with less number of developed technologies. Thus, these coefficients seems to provide a reasonable explanation on describing the effects on the novel innovation. *Number of adjacent regions* has positive effect on novel innovation, and this result emphasizes the importance of geographical location. Compared to either geographically isolated or partially sea-faced regions, regions surrounded by neighbouring regions have greater advantage in accessing new knowledge, human resources and collaboration. Thus, this result shows that the weakness of isolated regions in terms of utilizing necessary resources for innovation. Positive coefficient of *Metro* implies that all these effects on novel innovation are greater in metropolitan regions compared to non-metropolitan regions.

Interestingly all coefficients of brokerage roles are negative and not significant. This indicates that greater the region's brokering collaboration activities hampers the creation of new invention. From the network perspective, the regions with high brokerage role has the potential to create the new collaboration. In terms of conducting innovation, however, accessibility of resources are much more important, and these regions are weak and inefficient in this because their collaboration network is disconnected in some sense. This findings align with Coleman (1988)'s position and other empirical studies (Ahuja, 2000a; Jiang et al., 2019; Seo, 2019) that more structural holes are reducing innovation output.

On the other hand, *Collaboration Intensity* reports positive and significant coefficient throughout the models. This positive coefficient indicates that conducting more external collaboration contributes to the novel invention. As regions have sufficient external collaboration, it can overcome the shortcomings in the local knowledge base (Bathelt et al., 2004a), and successfully develop the new invention. More importantly and also interestingly, the interaction term of brokerage roles (*Coordinator*, *Consultant*, and *Liaison*) and *Collaboration Intensity* show positive and significant values. As a moderator, *Collaboration Intensity* converts the negative effect of brokerage roles into positive effect. From this buffering interaction effect, we may assume that the negative influence of brokerage role can be overcome by the external collaboration.

Table 5: Regression result of fixed-effects model: Novel innovation

	Dependent variable: Novel innovation				
	(1)	(2)	(3)	(4)	(5)
RCA	0.487***	0.494***	0.493***	0.474***	0.485***
	(0.025)	(0.024)	(0.025)	(0.026)	(0.025)
EMP.m	12.165***	12.076***	12.339***	12.967***	12.870***
	(0.965)	(0.946)	(0.947)	(0.934)	(0.946)
GDP	-2.103*	-2.197*	-2.056*	-1.692	-1.853
	(1.174)	(1.165)	(1.144)	(1.170)	(1.144)
EMP	-6.956***	-6.986***	-7.188***	-8.009***	-7.856***
	(1.239)	(1.229)	(1.173)	(1.177)	(1.166)
INV	10.992***	10.754***	10.826***	11.270***	11.028***
	(0.758)	(0.733)	(0.751)	(0.769)	(0.750)
Adj.R	0.902***	0.955***	0.853***	0.922***	0.855***
	(0.260)	(0.255)	(0.258)	(0.258)	(0.259)
Metro	7.788***	7.584***	7.438***	7.385***	7.193***
	(1.491)	(1.449)	(1.382)	(1.431)	(1.359)
Coordinator	-0.002***	-0.002***	-0.002***	-0.001**	-0.001**
	(0.0003)	(0.0003)	(0.0003)	(0.0003)	(0.0003)
Consultant	-0.005	-0.005	-0.003***		
	(0.003)	(0.003)	(0.001)		
Liaison				-0.001***	-0.0004***
				(0.0003)	(0.0001)
Collaboration Intensity	6.818***	5.861***	6.275***	6.915***	6.196***
	(1.145)	(1.081)	(1.128)	(1.139)	(1.093)
Coordinator * Collaboration Intensity		0.002**			
		(0.001)			
Consultant * Collaboration Intensity			0.018***		
			(0.004)		
Liaison * Collaboration Intensity					0.002***
					(0.0004)
Time	Included	Included	Included	Included	Included
Observation	4,201	4,201	4,201	4,201	4,201
R^2	0.759	0.760	0.762	0.761	0.763
Adj R^2	0.759	0.760	0.761	0.760	0.762
F Stat	1,320.793***	1,207.193***	1,217.627***	1,333.746***	1,225.420***
	(df=10;4186)	(df=11;4185)	(df=11;4185)	(df=10;4186)	(df=11;4185)

Notes: All time-varying covariates are lagged one period; Robust standard errors in parenthesis; * p < 0.10, ** p < 0.05, *** p < 0.01

In Table 6, regression result of new collaboration model is presented. The results of control variables are positive and significant except *EMP.m* and *EMP*. While employment condition and share of manufacturing employment matters for novel innovation, it turned out the they are not significantly influencing the new collaboration. This could be understood as the regions with strong manufacturing industry already have sufficient collaboration networks, thus have less need for searching the new collaboration.

Table 6: Regression result of fixed-effects model: New collaboration

	Dependent variable: New collaboration				
	(1)	(2)	(3)	(4)	(5)
RCA	0.063***	0.064***	0.065***	0.059***	0.063***
	(0.017)	(0.017)	(0.017)	(0.018)	(0.018)
EMP.m	0.388	0.375	0.429	0.723	0.689 (0.719)
	(0.749)	(0.743)	(0.761)	(0.729)	
GDP	-2.220***	-2.241***	-2.210***	-2.355**	-2.424***
	(0.853)	(0.852)	(0.849)	(0.939)	(0.929)
EMP	0.318	0.309	0.264	-0.098 (0.878)	-0.045 (0.851)
	(0.954)	(0.950)	(0.965)		
INV	2.610***	2.575***	2.578***	3.018***	2.936***
	(0.529)	(0.522)	(0.520)	(0.573)	(0.542)
Adj.R	0.457**	0.467**	0.447**	0.545**	0.520**
	(0.219)	(0.216)	(0.218)	(0.222)	(0.220)
Metro	9.214***	9.178***	9.136***	9.578***	9.506***
	(1.002)	(0.996)	(1.002)	(1.105)	(1.074)
Coordinator	0.003***	0.003***	0.003***	0.002***	0.002***
	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)
Consultant	0.008***	0.008***	0.008***		
	(0.0002)	(0.0002)	(0.0002)		
Liaison				0.0004*	0.001**
				(0.0002)	(0.0003)
Collaboration Intensity	3.061*** (0.770)	2.882*** (0.758)	2.933*** (0.742)	3.116*** (0.794)	2.830*** (0.733)
Coordinator * Collaboration Intensity		0.0003 (0.0004)			
Consultant * Collaboration Intensity			0.004 (0.005)		
Liaison * Collaboration Intensity					0.001 (0.0004)
Time	Included	Included	Included	Included	Included
Observation	4,091	4,091	4,091	4,091	4,091
R^2	0.672	0.672	0.673	0.650	0.652
Adj R^2	0.671	0.671	0.672	0.649	0.651
F Stat	834.779***	759.404***	761.574***	757.152***	693.727***
	(df=10;4076)	(df=11;4075)	(df=11;4075)	(df=10;4076)	(df=11;4075)

Notes: All time-varying covariates are lagged one period; Robust standard errors in parenthesis; * p < 0.10, ** p < 0.05, *** p < 0.01

For new collaboration, the coefficients of all brokerage roles show all positive and significant effects. As structural hole theory argues (Burt, 1992; 1997), brokerage roles leads to the new network, which in our case is the collaboration with the new regions. *Collaboration Intensity* reports positive and significant coefficients. Once again, more external collaboration helps the region to extend its collaboration pool. The interaction terms of brokerage role and *Collaboration Intensity* are not significant for all brokerage roles. This tells us that new collaboration can be achieved by enhancing the region's brokerage role regardless of collaboration intensity.

6. Conclusions

The evidence we present contribute to the extant literature in following ways. First, we argue that local inventor's brokerage role in collaboration is not always beneficial as it either can open the opportunity for the new collaboration or hamper the creation of new invention. This clarifies the brokerage role in collaboration that it only positively associates with the creation of new collaboration network, but cause negative impact on the outcome of collaboration network, the novel innovation. Second, external collaboration drives both novel innovation and new collaboration. From an inventor's perspective, collaboration with far distant inventors are more inefficient in terms of communication and managing the workload. Although it may not be preferred in terms of efficiency, our finding provides the evidence that external collaboration is worthwhile in developing new innovation and extending the collaboration network. This allows us to extend the understanding about the brokerage role in collaboration highlighting the fact that the collaboration intensity matters for realizing in pursuing the novel innovation.

The paper has important implications for policymakers. Among all, providing better environment for local inventors to conduct external collaboration is needed for regional innovation. Even for the case where the region is isolated or far located from other regions, the geographical disadvantage can be overcome by the investment to assets improving better communication and collaboration, such as transportation, telecommunication technology, etc. In addition, this tells us that the innovation can be enhanced by local inventors' capability or their inter-regional collaboration network. Often, attracting investment or firm is regarded as one of the most effective ways of boosting regional development because it directly contributes to the knowledge spillover. From the perspective of regional innovation activity, local inventor's external collaboration can also play as the means for knowledge spillover.

As the value of external collaboration is proven through our study, seeking and making investment on what promotes better collaboration should be investigated. This can be also implied to the managers that supporting the inventors to collaborate more with other inventors, especially those who are apart from them is important. Although all inventors seek the new invention, only the few are succeed in developing literally the new invention because of the basic nature of knowledge or preferential attachment effect (Barabási & Albert, 1999; Sun & Liu, 2016). In this sense, external collaboration can be considered as a requirement for taking advantage of brokerage role to develop the new invention.

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Appendix A.

$$\frac{patents_{r,t}\ (i)/\Sigma_i\ patents_{r,t}\ (i)}{\Sigma_c\ patents_{r,t}\ (i)/\Sigma_c\ \Sigma_i\ patents_{r,t}\ (i)} > 1$$

where c is country, r is region, t is time, i is technology class.