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Knowledge brokers for Circular Bioeconomy: evidence from European regions

Discussion paper n. 43/2025

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Keywords: recombinant knowledge; collaborative research; innovation network; circular bioeconomy

JEL codes: R11, R15, O52, O33

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Knowledge brokers for Circular Bioeconomy: evidence from European regions

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Abstract

The transition to a Circular Bioeconomy (CBE) requires effective knowledge recombination across scientific and technological domains. This study examines how universities, Research and Technology Organisations (RTOs), and firms contribute to regional knowledge recombination in the CBE domain through their brokerage roles in collaboration networks. Using a unique dataset on CBE-related Horizon 2020 projects (2015–2019) and regional patenting activity, we exploit the structural and geographical dimensions of entities within the CBE research network and employ econometric models to assess the role of inter-organizational partnerships in fostering knowledge recombination. Our findings highlight that universities and RTOs are more effective in facilitating knowledge recombination when acting as brokers in cross-regional collaborations, whereas firms have a stronger impact when brokering connections within their own region. These results provide novel insights into the geography of innovation, emphasizing the importance of brokerage roles in shaping regional technological capabilities. By advancing our understanding of collaborative knowledge spillovers, this study also offers valuable implications for policymakers seeking to strengthen CBE innovation ecosystems.

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1 Introduction

The transition towards a Circular Economy (CE) is increasingly considered crucial for achieving sustainability goals, challenging the linear "take-make-dispose" model (Murray et al., 2017). The European Commission defines CE as an economy that aims to maintain the value of products, materials and resources for as long as possible while minimizing waste generation (European Commission, 2015). This aligns with the principles of the Bioeconomy, which emphasizes the sustainable use of biological resources in the production of goods, promoting waste reduction and recycling (European Commission, 2018).

Recognizing the urgent need for sustainable economic models and the significant use of biological resources, European institutions have emphasized the incorporation of Bioeconomy strategies into CE policies (European Commission, 2012, 2018, 2019). The simultaneous pursuit of CE and Bioeconomy objectives is fundamental for a successful transition towards a sustainable economic system. Shifting to a Circular Bioeconomy (CBE) is challenging because it requires major changes in how materials and products are designed, produced, used, and managed. Success depends on innovation at all levels, from individuals and businesses to industries and institutions. Key obstacles include a lack of scalable technologies, fluctuations in natural resources, and the need for strong collaboration across sectors (Molden et al., 2025). To overcome these challenges, it is crucial to understand local innovation processes and build effective long-term collaborative partnerships.

Previous studies have shown that knowledge does not spread freely among co-located organizations, but it moves selectively through networks linking specific actors (Breschi and Lenzi, 2015; Fleming et al., 2007). These links often go beyond regional borders, as actors work with partners both within and outside their region at the same time (Bathelt et al., 2004). In this context, collaboration between academic institutions, Research and Technology Organisations (RTOs) and companies plays a key role in knowledge transfer, helping to bridge capability gaps in knowledge recombination processes (Fleming, 2001; Weitzman, 1998). The innovation literature on network brokerage offers an interesting perspective to look at these issues, as it shows that the so-called *brokers* connect otherwise unlinked or weakly connected actors, enabling the exchange of knowledge, resources and information (Allen, 1977; Burt, 1992). The foundational work on this topic suggests that actors take on different brokerage roles depending on the network in which they operate (Gould and Fernandez, 1989; Marsden, 1982). Specifically, according to the Gould and Fernandez (1989)'s taxonomy, they act as *coordinators* within internal networks, while they serve as *gatekeepers* or *liaisons* in external networks.

Existing research has only marginally examined how collaboration dynamics influence innovation at the intersection of the CE and Bioeconomy, contributing to the description and classification of the European regional CE-Bioeconomy network, but has not yet disentangled the innovation dynamics within it (Ciffolilli et al., 2025). This study aims at addressing this research gap by exploring how partnerships between European companies, academic institutions and RTOs drive regional technological innovation, particularly through the recombination of CBE-related knowledge. To explore these issues, we exploit the network brokerage approach and analyze how those actors contribute to regional knowledge recombination in CBE, depending on their specific brokerage roles (i.e., coordinator, gatekeeper, or liaison) within the regional innovation network. Specifically, we expect different types of actors to play distinct brokerage roles, as their motivations for sharing knowledge and collaborating – largely shaped by whether they are public or private organizations – affect how knowledge is transferred and recombined within the regional innovation system.

The analysis relies on a unique dataset covering detailed information on CBE-related EU collaborative projects financed by the Horizon 2020 program between 2015 and 2019 and regional patenting activity. By exploiting advanced network analysis instruments, we measure the structural and geographical dimensions of the resulting CBE research network and employ econometric techniques to investigate the role of inter-organizational partnerships for knowledge recombination in the CBE-related domain.

Our findings show that when regional actors take part to scientific collaborations, they help their region combining knowledge in the CBE field. Their impact on this process depends on their role within local or cross-regional collaboration networks. Universities, due to their wide research focus and emphasis on knowledge sharing, and RTOs, which bridge research and industry, are more effective for knowledge recombination when they connect with partners from outside the region. In contrast, firms play a crucial role in knowledge recombination when they act as brokers within their own region, connecting with local partners.

This work contributes to the academic literature in several ways. First, it fills a gap in the geography of innovation literature by examining how different actors facilitate knowledge recombination through specific brokerage roles, moving beyond the traditional focus on gatekeepers, which dominates existing studies. This provides a deeper understanding of how various types of brokerage role affect knowledge recombination in collaboration networks. Second, it contributes to research on regional knowledge spillovers by emphasizing the importance for knowledge recombination of collaborative spillovers, intended as those that occur through formal partnerships, rather than assuming spillovers happen simply because actors are located in the same geographic area. Third, while many studies have explored innovation networks, few have looked at how brokerage roles shape the CBE domain. This is crucial because CBE is at the forefront of sustainable and resilient economic growth. To unlock its full potential, we need to understand how to establish fruitful and long-term collaborations across different actors and sectors.

The remainder of the paper is organized as follows. Section 2 reviews the relevant literature and sets up the conceptual framework. Section 3 describes the data, variables and methods employed in the empirical analysis. Section 4 presents and discusses our findings. Finally, Section 5 concludes.

2 Literature and conceptual framework

2.1 Circular Bioeconomy, eco-innovation and recombinant knowledge

The shift to a CE requires industrial and technological transformation, driven by regional innovation to develop cleaner technologies, new business models, and stronger institutions.

In this process, environmental innovation plays a key role in achieving CE goals (de Jesus et al., 2018). Understanding this transition benefits from insights from innovation studies, particularly the eco-innovation framework (de Jesus and Mendonça, 2018; Fusillo et al., 2025). Building on this perspective, our study adopts the recombinant knowledge approach (Weitzman, 1998) as a framework to explore what drives the recombination of CBE-related knowledge.

Innovation research has long emphasized that new discoveries emerge from combining existing ideas, information, or technologies in novel ways, a concept known as the recombinant knowledge framework (Fleming, 2001; Weitzman, 1998). More recently, scholars have applied this perspective to innovation capabilities, introducing the idea of recombinant capabilities. This refers to an agent's ability to access external knowledge and integrate it into new combinations (Carnabuci and Operti, 2013; Orsatti et al., 2020). This concept extends to regional innovation, where capabilities depend on how effectively local actors coordinate efforts to generate new knowledge (Cooke, 2001; Quatraro, 2009). In this context, regional recombinant capabilities refer to the ability of local actors to manage the knowledge recombination processes that drive innovation (Orsatti et al., 2024).

This concept is particularly relevant for CBE and green-related technologies (GTs) in general. As the open eco-innovation model suggests (Ghisetti et al., 2015), eco-innovative activities inherently rely more on external sources of knowledge and information, compared to other types of innovation. This includes information on new materials, compliance with environmental standards, and sustainable production inputs. This is especially important in emerging fields like CBE, where new technological developments require diverse and specialized expertise (Ciffolilli et al., 2025).

Studies based on patent data have indeed shown that GTs are often more complex than conventional technologies, and that they frequently rely on unique or rarely attempted combinations of technological components (Barbieri et al., 2020; Fusillo, 2023; Orsatti et al., 2024). Because green innovations tend to be both complex and novel, they require skills and knowledge that often go beyond the expertise of a single industry. As a result, developing these technologies demands collaboration across different fields and access to several and heterogeneous sources of knowledge (Messeni Petruzzelli et al., 2011; Ghisetti et al., 2015).

In the economics of innovation literature, local actors that facilitate knowledge recombination are broadly referred to as "innovation intermediaries". Since the seminal work of Howells (2006), research on innovation intermediaries has expanded significantly, leading to a proliferation of definitions and categorizations, such as brokers, gatekeepers and boundary spanners (Caloffi et al., 2023). Building on recent research on regional innovation (Operti and Kumar, 2023; Sigler et al., 2023; Kim et al., 2024), we refer to these actors as brokers, specifically adopting the taxonomy developed by Gould and Fernandez, 1989 (henceforth GF).

Hargadon and Sutton (1997) highlight that brokering goes beyond merely linking actors; it also transforms the ideas and knowledge being transferred. In their study, they describe brokers not only as facilitators of connections but also as knowledge repositories that leverage cumulated expertise to create novel combinations of existing ideas, leading to innovative solutions.

In our framework, we consider brokerage as a process that can occur both among co-located actors and across geographical boundaries. Furthermore, we will examine the advantages and disadvantages of internal brokerage and external boundary-spanning, focusing on the type of actor (private firms, universities, or RTOs) occupying these network positions and investigating whether each performs distinct functional activities.

2.2 Regional brokers

Extensive empirical research explores how brokerage supports regional innovation by bridging otherwise unconnected entities. Studies in this domain identify two main types of brokers: local brokers, who foster innovation by linking disconnected agents or organizations within a region, and external boundary-spanners, who facilitate knowledge exchange by connecting agents located in different regions (Sigler et al., 2023).

Previous research has shown that brokers operating within regions play a key role in fostering innovation (Fleming et al., 2007; Operti and Kumar, 2023). GF's taxonomy refers to these brokers as *coordinators* and their role is to connect local actors who have not collaborated before. By building ties between separate groups or organizations within the same region, they help integrating and recombining local knowledge, making new ideas and innovations possible.

The second category of brokers refers to those that operate across regions, linking geographically distant actors. Many studies highlight the importance of these interregional connections in spreading knowledge (Bathelt et al., 2004; Miguelez and Moreno, 2018). GF's taxonomy describes these brokers as *gatekeepers* because they channel external knowledge into a region and adapt it for local use. This role helps local communities in accessing and applying ideas from other locations.

Finally, the third type of interregional broker is one that GF calls *liaison*, which links actors across different regions, enabling the flow of diverse knowledge across geographical boundaries. Liaisons access heterogeneous knowledge sources and introduce new perspectives, increasing a region's ability to absorb and recombine external ideas. In relation to this, Giuliani and Bell (2005) and Graf (2011) highlight the importance of regional brokers' absorptive capacity, which reduces the risk of technological lock-in and fosters long-term innovation (Lazaric et al., 2008). The positive impact that these brokers have on regional innovation systems is highlighted by numerous empirical studies. For instance, Breschi and Lenzi (2015) found that cities with stronger external linkages tend to renew and expand their knowledge base more effectively. In addition, Le Gallo and Plunket (2020a) showed that brokers with direct access to external knowledge improved team creativity and had positive spillover effects on the broader regional innovation system.

We expect different types of actors to play distinct roles in the regional innovation CBE network. In particular, public and private actors are likely to have different incentives to share knowledge and collaborate, which directly influences the diffusion of external knowledge.

As institutions committed to open science, universities are generally more inclined to share knowledge (Dasgupta and David, 1987, 1994). Their emphasis on disseminating and applying scientific findings makes knowledge originating from universities more accessible than that from private organizations (Owen-Smith and Powell, 2004). This openness enables universities to serve as bridges between heterogeneous actors and across different domains. The key advantage of universities is their large stock of R&D personnel and access to globally dispersed knowledge, as the scientific community is highly interconnected internationally (Kauffeld-Monz and Fritsch, 2013), which enhances their absorptive capacity (Cohen and Levinthal, 1990). Their experience in teaching and research dissemination further reinforces their ability to connect actors and transfer knowledge effectively (Owen-Smith and Powell, 2004). Furthermore, universities typically have a knowledge transfer mission and operate within an open science culture, making them well-suited for performing brokerage roles (Kauffeld-Monz and Fritsch, 2013). As a consequence, we expect universities to play primarily a crucial role in brokerage, specifically in relation to GF *liaison* role, by fulfilling two key functions: the "transcoding function", which allows them to translate and simplify complex knowledge for others, and the capacity to integrate knowledge from distinct, previously unconnected groups (Boari and Riboldazzi, 2014).

In contrast, RTOs operate at the intersection of public and private research, with a strong focus on applied research and industry needs. Within national and regional innovation ecosystems, they act as key intermediaries between scientific research and market innovation (Van Lente et al., 2003). Their potential role as regional boundary-spanners arises from their inherent ability to bridge academic research and industrial applications. However, RTOs represent a highly heterogeneous category of innovation intermediaries (De Silva et al., 2018). Rather than following a single universal model, each RTO adapts to the specific needs of its regional environment (Miller, 2014). Consequently, their role in knowledge and technology diffusion is inherently place-specific. Therefore, we expect RTOs to act as GF *gatekeepers*, predominately enhancing the innovation capabilities of regional actors by linking them with external stakeholders relevant to their local context (Ciapetti and Perulli, 2018).

Firms, on the other hand, often face greater challenges in managing networking interactions effectively (De Silva et al., 2022). This is partly due to their operating environment, as they face strong market pressures, the liabilities of newness and obsolescence, and greater instability than public entities, given their risk of exiting the market due to failure or mergers (Owen-Smith and Powell, 2004). Additionally, their incentive structures differ, leading to distinct approaches to the use and dissemination of scientific knowledge compared to public entities (Owen-Smith, 2003).

Previous research has also highlighted cultural, strategic, and institutional differences between universities, RTOs, and firms (Cummings and Teng, 2003; Hilkenmeier et al., 2021). Unlike universities, firms typically share knowledge with a selected group of close partners (Morrison, 2008). Such "closure", i.e. the intensive exchange of information within a tightly connected group, is essential for fully capturing the value generated through brokerage activities (Burt, 2005). Consequently, companies often form alliances with the explicit goal of co-developing opportunities within their existing network (Kirkels and Duysters, 2010). Therefore, we expect firms to act as GF *coordinators*, integrating connections within their networks and fostering new interactions among existing partners (Winch and Courtney, 2007).

Against this background, we spell out our main research hypothesis as follows: the role of brokerage for CBE knowledge recombination differs across type of actor (firms, RTOs, universities) and their brokerage role (*coordinator*, *gatekeeper* or *liaison*, respectively). This is because each type of organization has different motivations for collaborating and sharing knowledge, which in turn influences how knowledge is transferred and recombined within the regional innovation system.

3 Data, variables and methodology

3.1 Data and variables

We develop an econometric model in which the dependent variable measures the extent of CBE knowledge circulation within a region. This represents a proxy of regions' ability to recombine CBE-related knowledge. Considering the purpose of our analysis and the relatively limited number of CBE patents by region, the dependent variable is worked out as the region-level count of patents that cite at least one CBE patent within its backward citations.

Patent data are collected through the OECD-REGPAT Database (March 2024). Each patent is typically associated with at least one technological class indicating the subject to which the invention relates. We exploit the Cooperative Patent Classification (CPC) technological classification (at the four-digit level) to identify patents related to the CBE field. To the best of our knowledge, a classification of CBE technologies has yet to be developed. Therefore, we combine the validated classification proposed by Frietsch et al. (2016), which provides a methodology to identify bioeconomy-related technologies, with the widely accepted classification developed by the European Commission to identify patents related to the CE. Thus, we define as CBE-related patents those that are simultaneously classified as circular and bioeconomy-related.

Our key explanatory variables measure the brokerage role played by universities, RTOs and firms in the European network of CBE projects. Their construction consists of a number of steps. We first collected data on EU H2020 collaborative research projects from 2015 to 2019, extracted from the CORDIS (Community Research and Development Information Service) database.[1] The database provides detailed information on projects' content, name and type of partner organizations, their geographical location, sector of application, and budget. To identify collaborative projects related to the CBE field, we followed the methodology used by Ciffolilli et al. (2025), hence exploiting the information on the textual content of the financed projects. Specifically, the set of CBE projects is obtained by intersecting the Bioeconomy projects, identified through their research sector of application, with the CE projects, classified through keyword search on projects' titles, objectives and descriptions (see Ciffolilli et al., 2025, for additional detail). The resulting final sample consists of 338 CBE collaborative research projects, involving 3987 partners. Table 1 presents the annual distribution of these projects, including the total number of partners, the number of distinct European NUTS2 regions involved, and the types of partners, i.e., firms (ENTR), universities (UNIV), Research and Technology Organizations (RTO), others (OTH). Over time, the number of CBE projects

[1]The 2015-2019 time span refers to the announced starting year of the collaborative projects financed under the EU H2020 programme.

shows a growing trend, with the number of partners in 2019 nearly doubled compared to 2015 and the number of involved regions increasing over time. They feature a large presence of companies as project participants, representing approximately 51% of all partners, followed by RTOs and universities. A visualization of the most frequently mentioned words in the topic program of the identified CBE projects is presented in Figure 1, indicating that CBE projects cover several key thematic areas, such as "materials", "resources", "bio-based", and "energy" efficiency, together with solutions and "valorisation" for products, waste, food, water and raw materials, and "systemic" and "large-scale" innovative approaches (Ciffolilli et al., 2025).

Table 1: EU H2020-Funded CBE Projects

Year	# Projects	# Partners	# NUTS2	ENTR	UNIV	RTO	OTH
2015	55	522	162	298	100	124	76
2016	59	800	197	335	242	226	140
2017	63	736	190	405	174	174	137
2018	75	905	217	450	205	235	202
2019	86	1,024	208	545	267	304	174

Source: Adapted from Ciffolilli et al. (2025).

By exploiting the participation of partner entities in projects, we are able to build a network of collaboration based on CBE project co-participation. The CBE collaboration network is thus treated as a one-mode projection of a two-mode network based on joint project participation. In such a network, nodes are represented by partner entities, and a link exists between two entities (nodes) if they participate in the same CBE research and innovation project. A weight is also attached to links, indicating the number of co-participated projects between entities.

The second step consists of identifying the projects' brokerage roles. As discussed in Section 2, we adopt the taxonomy proposed by Gould and Fernandez (1989) (GF), which is the most widely used classification in the literature and provides greater insights into brokerage behavior (Kirkels and Duysters, 2010; Le Gallo and Plunket, 2020a). GF typology define brokerage roles as facilitating information flows and argues that actors' heterogeneous

Figure 1: Word cloud of key terms in EU H2020-Funded CBE Projects

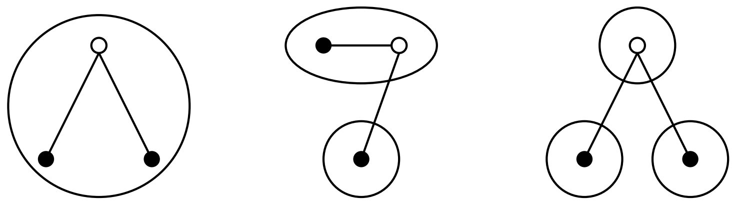
Source: Ciffolilli et al. (2025).

interests influence how they seize brokerage opportunities. In the GF approach, a node k act as a broker between i and j (solid points in Figure 2) if k is directly connected to both i and j, but i and j are not directly connected. Based on group membership, GF identify several types of brokerage relations, and a node in a network can take on multiple roles. We focus on three GF brokerage positions, illustrated in Figure 2 a), b), and c), respectively: a *coordinator* facilitates interaction among members of its own group; a *gatekeeper* mediates knowledge between in-group and out-group members; a *liaison* enhances interactions between members of different groups to which it does not belong.[2]

According to this classification, brokers in the CBE network are thus entities who act as "bridges" between actors belonging to their region or to different ones with unique and non-redundant collaboration opportunities within the CBE field. Building on existing research

[2]It is worth noting that GF identifies two additional types of brokerage role, i.e., *representative broker* and *itinerant broker*. We exclude from the analysis the *representative broker* since, by construction, it is equivalent to the gatekeeper position in non-directed networks, such as the CBE research network. The *itinerant broker*, mediating interactions between two out-group members, is also excluded due to its redundancy in our regional setting with the other brokerage positions.

Figure 2: GF brokerage roles



a) Coordinator b) Gatekeeper c) Liaison

Notes: Adapted from Gould and Fernandez (1989). White points represent the brokers. Ellipses correspond to subgroup (regional) boundaries.

on regional innovation, we calculate the brokerage score for each entity based on its brokerage role in the CBE network. We do this annually from 2015 to 2019 and consider as a broker any entity with a positive brokerage score, as in previous literature (Le Gallo and Plunket, 2020b; Lissoni, 2010).

Exploiting the regional location of these entities, our main independent variables are the yearly count of broker entities in each region. We analyze both the total number of brokers across all roles (coordinator, gatekeeper and liaison) and each role separately. Importantly, to clarify the role of different types of institutions, we categorize entities based on the CORDIS database as universities (Univ.), firms (Entr.), and Research and Technology Organizations (RTOs). Accordingly, we divide our independent variables into three regressors, counting the yearly number of broker universities, firms, and RTOs in each region.

In addition to our focal variables, we include two regressors to account for the role of centrality in the collaborative research network for the regional ability to recombine CBE knowledge. To do so, we re-build the network by exploiting the participation of regions to projects based on their entities' co-participation in CBE research projects. In such a network, nodes are represented by regions, and a link exists between two regions (nodes) if their entities participate in the same CBE research and innovation project. A weight is also attached to links, indicating the number of co-participated projects between regions. In this way, we are able to measure the importance (centrality) of nodes (regions) in the

CBE network by exploiting two well-known centrality measures, i.e., degree centrality and betweenness centrality. Degree centrality simply counts the number of links incident upon a node. In a weighted network, as in our case, degree centrality measures the sum of the weights of the links incident upon a node (accounting for repeated collaborations).[3] Thus, a high degree centrality indicates that the region is highly relevant in the network since it is involved in a high number of projects. Betweenness centrality measures the number of times a node lies on the shortest path between any two nodes, giving an indication of the "amount" of CBE research exchanges that pass through the region. In line with existing studies on the role of collaboration network centrality and embeddedness for innovative outcomes, we expect both the degree (*Net. Degree*) and betweenness (*Net. Betweenness*) centrality of regions in the CBE collaborative research network to be positively associated with the ability to manage and exploit CBE knowledge for successful recombinations.

Furthermore, we include a number of additional control variables. Firstly, we control for the stock of regional patents to account for the pre-existing knowledge base of regions. This variable is calculated by applying the PIM (Permanent Inventory Method) to the number of patents of inventors located in the regions, with a 15% depreciation rate (as most commonly employed in the patent literature). In order to alleviate endogeneity concerns, CBE patents are excluded from the set of regional patents, hence are not considered in the calculation of the variable. We also account for the economic size of the region by including the Gross Value Added of the region, and for the level of economic development as proxied by regional total employment. Regional data on GVA and employment are extracted from the Annual Regional Database of the European Commission's Directorate General for Regional and Urban Policy (ARDECO), maintained by the Joint Research Centre of the European Commission.

3.2 Methodology

To investigate the role of regional gatekeepers on CBE recombinant ability, we estimate a model in the following form:

[3] In network studies, weighted degree centrality is often referred to as strength centrality (Barrat et al., 2004).

$$CBE\ recomb_{r,t} = \alpha + \beta_1 Brokerage_{r,t-1} + \theta \boldsymbol{N}'_{r,t-1} + \psi \boldsymbol{X}'_{r,t-1} + \delta_r + \gamma_t + \epsilon_{r,t} \quad (1)$$

where $CBE\ recomb_{r,t}$ is the dependent variable and is calculated as the (log) number of patents in region r at time t that cites at least one CBE patent. $Brokerage_{r,t-1}$ is one of our main independent variables measured in region r at time $t-1$: i) the (log) total number of broker entities (*All Brokerage*); ii) the (log) number of broker universities (*Univ. Brokerage*); iii) the (log) number of broker RTOs (*RTO Brokerage*); iv) the (log) number of broker firms (*Entr. Brokerage*). We further explore the distinct impact of the three specific brokerage positions (represented by the variables *All Liaison*, *All GK*, and *All Coordinator*) and examine the specific roles of universities, firms, and RTOs within each of them. In addition to our main independent variables, we include in all models a vector of network variables ($\boldsymbol{N}'_{r,t-1}$), that includes the (log) degree and betweenness centrality in the CBE network of region r at time $t-1$ (*Net Degree* and *Net Betweenness*). $\boldsymbol{X}'_{r,t-1}$ is the vector of one-year lagged control variables that account for regional characteristics. The set includes the knowledge base of the regions measured by the (log) regional stock of patents, excluding CBE patents (*Knowledge base*); the (log) GVA (*GVA*); the (log) level of total employment (*Employment*). Lastly, we include regional (NUTS-2) fixed-effects to control for region-specific time-invariant unobservable factors (δ_r), and year fixed-effects to account for common shocks in the period of analysis (γ_t). Finally, $\epsilon_{r,t}$ is an idiosyncratic error term. All models are estimated through OLS panel fixed effects estimators, with heteroskedastic-robust standard errors clustered at the region (NUTS2) level.

Table 2 reports the descriptive statistics of the variables included in the empirical analysis. The correlation matrix is provided in Table A1 in the Appendix 5.

Table 2: Descriptive statistics

Statistic	N	Mean	St. Dev.	Min	Max
CBE recomb	1,875	2.587	4.735	0	57
All Brokerage	1,875	0.158	0.544	0	6
Univ. Brokerage	1,875	0.051	0.237	0	2
RTO Brokerage	1,875	0.060	0.297	0	4
Entr. Brokerage	1,875	0.036	0.216	0	4
All Liaison	1,875	0.124	0.444	0	5
Univ. Liaison	1,875	0.041	0.210	0	2
RTO Liaison	1,875	0.051	0.264	0	3
Entr. Liaison	1,875	0.024	0.170	0	2
All GK	1,875	0.130	0.533	0	7
Univ. GK	1,875	0.041	0.216	0	2
RTO GK	1,875	0.051	0.274	0	3
Entr. GK	1,875	0.029	0.222	0	5
All Coordinator	1,875	0.048	0.297	0	5
Univ. Coordinator	1,875	0.016	0.130	0	2
RTO Coordinator	1,875	0.022	0.179	0	3
Entr. Coordinator	1,875	0.007	0.098	0	2
Knowledge base	1,875	1,998.646	3,356.323	2.572	26,149.210
Net. Degree	1,875	19.628	30.931	0	153
Net. Betwenness	1,875	0.003	0.007	0.000	0.095
GVA	1,875	53,074.260	64,063.860	1,162.704	679,392.900
Employment	1,875	889.519	765.331	18.474	6,624.818

4 Empirical results

4.1 Baseline results

Table 3 presents the baseline results of our empirical analysis. Column 1 considers all brokerage roles and institutions together. Columns 2 to 4 break down the brokerage effect by institution type (universities, RTOs, and firms), while column 5 examines all distinct brokerage entities together.

Regarding the control variables, the direction of effects is mostly in line with our expectations. *Net. Degree* is consistently positive and significant across all specifications, suggesting that a higher number of network connections enhances knowledge recombination. Similarly, *Net. Betweenness* is positive and significant, suggesting that regions in central network positions benefit from their role in facilitating knowledge flows across the network. The positive and significant coefficient for the regional stock of patents (*Knowledge base*) indicates that regions with strong knowledge and absorptive capacity are better placed for knowledge recombination. We do not estimate statistically significant coefficients for *GVA* and *Employment*.

From column 1, we can see that the coefficient for the overall brokerage variable is positive and significant, indicating that brokers in the regional innovation network contribute to CBE knowledge recombination. However, when we separate brokerage by institution type, it is possible to see that this positive effect is mostly driven by universities (column 2), while it is only marginally statistically significant for RTOs (at 10% level) and non-statistically significant for firms (columns 3 and 4, respectively). When estimating simultaneously the role of all institution types, we find similar results, with a positive and strongly significant estimated coefficient only for university brokers (column 5).

These findings align with our expectations. Universities play a central role in regional knowledge networks due to their broad research portfolios, emphasis on knowledge dissemination and ability to bridge structural holes. By facilitating interdisciplinary collaboration and cross-sectoral knowledge transfer, in fact, universities accelerate innovation and connect otherwise isolated actors in the regional innovation system.

In fact, as discussed in section 2, universities benefit from a large stock of R&D personnel and access to globally dispersed knowledge, as the scientific community is highly interconnected internationally, which enhances their absorptive capacity. Their experience in teaching and research dissemination further strengthens their ability to connect diverse actors and facilitate effective knowledge transfer (Owen-Smith and Powell, 2004). Moreover, universities have a clear knowledge transfer mission and operate within an "open science" culture, making them well-suited to occupy brokerage roles (Kauffeld-Monz and Fritsch, 2013).

This "open science" nature of universities facilitates the diffusion of new knowledge, making it more readily available than knowledge originating from firms (Dasgupta and David, 1994; Jaffe et al., 1993). In contrast, private firms and RTOs tend to share knowledge only with a select group of close partners, limiting their overall impact on knowledge diffusion (Morrison, 2008). This explains why their brokerage coefficients are not statistically significant.

In Table 4, we break down the brokerage effect by examining each brokerage position (gatekeeper, liaison, and coordinator) separately for universities, firms, and RTOs. The results show that both boundary-spanning roles, liaison and gatekeeper (columns 1 and 3, respectively), and inter-regional brokerage, i.e. coordinators (column 5), positively and significantly contribute to regional CBE knowledge recombination. However, once we analyze such effects by institution, the estimates reveal interesting heterogeneity.

In columns 2 and 4, we find that universities primarily drive the boundary-spanning effect. For liaison roles, universities are the only institutions with a statistically significant coefficient. For gatekeeping positions, while coefficients for RTOs and firms are weakly significant, universities have the strongest and most significant effect. These findings reinforce our baseline results, confirming that universities are key actors in regional knowledge recombination. Their unique characteristics allow them to leverage their boundary-spanning roles effectively, sourcing external knowledge, preventing regional lock-in, and enhancing the region's ability to recombine knowledge in the CBE domain.

A different pattern emerges when estimating the coordinator role by institution (column

Table 3: CBE recombination and Brokerage

	CBE recomb				
	(1)	(2)	(3)	(4)	(5)
All Brokerage	0.1650**				
	(0.0639)				
Univ. Brokerage		0.2909***			0.2925***
		(0.0788)			(0.0787)
RTO Brokerage			0.1424*		0.1435*
			(0.0860)		(0.0858)
Entr. Brokerage				0.0324	0.0321
				(0.1078)	(0.1058)
Knowledge base	0.7119***	0.7044***	0.7117***	0.7087***	0.7079***
	(0.1603)	(0.1606)	(0.1604)	(0.1604)	(0.1606)
Net. Degree	0.0544***	0.0552***	0.0575***	0.0583***	0.0540***
	(0.0129)	(0.0129)	(0.0130)	(0.0130)	(0.0129)
Net. Betwenness	0.1219*	0.1455**	0.1566**	0.1757***	0.1198*
	(0.0687)	(0.0651)	(0.0679)	(0.0647)	(0.0669)
GVA	0.3949	0.4126	0.4011	0.4121	0.4008
	(0.4531)	(0.4527)	(0.4525)	(0.4520)	(0.4538)
Employment	-0.6368	-0.6074	-0.6061	-0.5919	-0.6286
	(0.4389)	(0.4379)	(0.4379)	(0.4381)	(0.4388)
Region FE	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓
Observations	1,875	1,875	1,875	1,875	1,875
R^2	0.69861	0.69908	0.69779	0.69736	0.69956
Within R^2	0.05009	0.05158	0.04750	0.04616	0.05308

Dep var: number of patents citing at least one CBE patent. *Brokerage* independent variables measure, respectively, the total number of broker entities, the number of broker universities, the number of broker RTOs and the number of broker firms within the region. All variables are log-transformed ($log(x) + 1$), and explanatory variables are lagged by one year. Models are estimated using OLS panel fixed-effects estimators. Heteroskedastic-robust standard errors, reported in parentheses, are clustered at the NUTS2 level. *p<0.1; **p<0.05; ***p<0.01

Table 4: CBE recombination and Brokerage

	CBE recomb					
	(1)	(2)	(3)	(4)	(5)	(6)
All Liaison	0.1320*					
	(0.0698)					
Univ. Liaison		0.2474***				
		(0.0903)				
RTO Liaison		0.1477				
		(0.0976)				
Entr. Liaison		0.0171				
		(0.1047)				
All GK			0.2077***			
			(0.0612)			
Univ. GK				0.2319**		
				(0.0954)		
RTO GK				0.1694*		
				(0.0966)		
Entr. GK				0.1724*		
				(0.0999)		
All Coordinator					0.2306***	
					(0.0854)	
Univ. Coordinator						0.2516*
						(0.1387)
RTO Coordinator						0.0621
						(0.1586)
Entr. Coordinator						0.3902***
						(0.1485)
Knowledge base	0.7138***	0.7135***	0.7199***	0.7193***	0.7133***	0.7129***
	(0.1607)	(0.1610)	(0.1607)	(0.1608)	(0.1604)	(0.1607)
Net. Degree	0.0560***	0.0550***	0.0523***	0.0522***	0.0554***	0.0556***
	(0.0129)	(0.0128)	(0.0129)	(0.0129)	(0.0130)	(0.0131)
Net. Betwenness	0.1407**	0.1398**	0.1504**	0.1533**	0.1707**	0.1756***
	(0.0686)	(0.0681)	(0.0659)	(0.0659)	(0.0661)	(0.0669)
GVA	0.3950	0.3977	0.3871	0.3903	0.4137	0.4164
	(0.4519)	(0.4520)	(0.4509)	(0.4515)	(0.4513)	(0.4522)
Employment	-0.6156	-0.6067	-0.5890	-0.5887	-0.5846	-0.5867
	(0.4391)	(0.4399)	(0.4411)	(0.4410)	(0.4389)	(0.4396)
Region FE	✓	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓	✓
Observations	1,875	1,875	1,875	1,875	1,875	1,875
R^2	0.69802	0.69875	0.69924	0.69945	0.69850	0.69857
Within R^2	0.04824	0.05053	0.05209	0.05275	0.04974	0.04997

Dep var: number of patents citing at least one CBE patent. *Brokerage* independent variables measure, for each brokerage type (*Liaison*, *GK* and *Coordinator*), the total number of broker entities, the number of broker universities, the number of broker RTOs and the number of broker firms within the region. All variables are log-transformed ($log(x) + 1$), and explanatory variables are lagged by one year. Models are estimated using OLS panel fixed-effects estimators. Heteroskedastic-robust standard errors, reported in parentheses, are clustered at the region (NUTS2) level. *p<0.1; **p<0.05; ***p<0.01

6). We find that firms drive the effect, showing the largest and most significant coefficient, while the coefficient for universities is only weakly significant (estimated coefficient for coordinators RTOs is not statistically significant). Firms, in fact, arguably benefit from university knowledge spillovers and contribute to regional knowledge recombination when they act as coordinators within the regional collaboration network. While sourcing external knowledge is essential to avoid regional lock-in, knowledge transfer and recombination require more than just geographical proximity. Social connectedness between actors is also crucial (Boschma and ter Wal, 2007; Breschi and Lissoni, 2009). Firms are particularly well-suited for this role. Unlike universities and RTOs, private firms tend to share knowledge within a closely connected group of partners (Morrison, 2008), making them more effective as coordinators in regional networks. By bridging structural holes, coordinator firms enhance the depth and richness of knowledge exchange, strengthening regional innovation.

4.2 Robustness checks

We carry out a robustness analysis using an alternative approach to operationalizing our key independent variables of brokerage roles. Instead of counting the total number of brokerage roles, we use a dichotomous variable indicating the presence or absence of at least one brokerage position in the region. Our baseline results, both for all brokerage positions combined and for individual roles, remain robust and consistent with those reported in Tables 3 and 4, in line with our expectations. In particular, the findings confirm the central role of universities as overall brokers, while a clearer distinction emerges for RTOs and firms. The latter entity now shows significance only when acting as *coordinator*. As discussed, firms and RTOs operate under different incentives regarding knowledge dissemination; in addition to this, RTOs tend to be more stable than firms, which may exit the market due to failure or mergers (Owen-Smith and Powell, 2004). This stability may explain why RTOs show significance not only as *gatekeepers* but also as *liaisons* (albeit at the 10% level).

In additional analyses (reported in the paper Appendix 5), we examined the impact of regional broker shares in the inter-regional network, taking into account different brokerage

Table 5: CBE recombination and Brokerage

	CBE recomb				
	(1)	(2)	(3)	(4)	(5)
All Brokerage d	0.1147**				
	(0.0563)				
Univ. Brokerage d		0.1990***			0.1994***
		(0.0572)			(0.0574)
RTO Brokerage d			0.1129		0.1130
			(0.0722)		(0.0725)
Entr. Brokerage d				0.0001	0.0054
				(0.0759)	(0.0764)
Knowledge base	0.7088***	0.7036***	0.7106***	0.7084***	0.7058***
	(0.1603)	(0.1605)	(0.1603)	(0.1605)	(0.1605)
Net. Degree	0.0550***	0.0555***	0.0577***	0.0585***	0.0546***
	(0.0130)	(0.0129)	(0.0130)	(0.0130)	(0.0129)
Net. Betwenness	0.1329**	0.1464**	0.1548**	0.1788***	0.1214*
	(0.0672)	(0.0648)	(0.0678)	(0.0647)	(0.0667)
GVA	0.3987	0.4126	0.4008	0.4124	0.4010
	(0.4522)	(0.4527)	(0.4525)	(0.4519)	(0.4536)
Employment	-0.6236	-0.6090	-0.6049	-0.5885	-0.6262
	(0.4384)	(0.4376)	(0.4377)	(0.4379)	(0.4381)
Region FE	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓
Observations	1,875	1,875	1,875	1,875	1,875
R^2	0.69813	0.69889	0.69778	0.69734	0.69933
Within R^2	0.04859	0.05098	0.04747	0.04610	0.05237

Dep var: number of patents citing at least one CBE patent. *Brokerage* independent variables are expressed as dummy variables equal to 1 if there is, respectively, at least one broker entity, one broker university, one broker RTO, and one broker firm within the region. The dependent variable and the control variables are log-transformed ($log(x)+1$). All explanatory variables are lagged by one year. Models are estimated using OLS panel fixed-effects estimators. Heteroskedastic-robust standard errors, reported in parentheses, are clustered at the NUTS2 level. *p<0.1; **p<0.05; ***p<0.01

Table 6: CBE recombination and Brokerage

	CBE recomb					
	(1)	(2)	(3)	(4)	(5)	(6)
All Liaison d	0.1052*					
	(0.0590)					
Univ. Liaison d		0.1627**				
		(0.0676)				
RTO Liaison d		0.1364*				
		(0.0759)				
Entr. Liaison d		0.0062				
		(0.0828)				
All GK d			0.1639***			
			(0.0592)			
Univ. GK d				0.1513**		
				(0.0741)		
RTO GK d				0.1505**		
				(0.0756)		
Entr. GK d				0.1238		
				(0.0853)		
All Coordinator d					0.1542*	
					(0.0816)	
Univ. Coordinator d						0.1901**
						(0.0949)
RTO Coordinator d						0.0426
						(0.1283)
Entr. Coordinator d						0.3284***
						(0.1041)
Knowledge base	0.7113***	0.7129***	0.7168***	0.7164***	0.7113***	0.7121***
	(0.1606)	(0.1609)	(0.1606)	(0.1605)	(0.1604)	(0.1607)
Net. Degree	0.0558***	0.0551***	0.0531***	0.0526***	0.0563***	0.0555***
	(0.0130)	(0.0129)	(0.0130)	(0.0130)	(0.0130)	(0.0131)
Net. Betwenness	0.1442**	0.1379**	0.1536**	0.1503**	0.1696**	0.1757***
	(0.0668)	(0.0673)	(0.0660)	(0.0660)	(0.0662)	(0.0671)
GVA	0.3958	0.3953	0.3881	0.3927	0.4136	0.4178
	(0.4515)	(0.4519)	(0.4502)	(0.4513)	(0.4511)	(0.4522)
Employment	-0.6109	-0.6080	-0.5811	-0.5883	-0.5857	-0.5869
	(0.4389)	(0.4397)	(0.4400)	(0.4402)	(0.4383)	(0.4394)
Region FE	✓	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓	✓
Observations	1,875	1,875	1,875	1,875	1,875	1,875
R^2	0.69796	0.69875	0.69867	0.69926	0.69803	0.69871
Within R^2	0.04804	0.05054	0.05029	0.05214	0.04828	0.05043

Dep var: number of patents citing at least one CBE patent. *Brokerage* independent variables are expressed as dummy variables equal to 1 if there is, for each brokerage type (*Liaison*, *GK* and *Coordinator*), at least one broker entity, one broker university, one broker RTO, and one broker firm within the region. The dependent variable and the control variables are log-transformed ($log(x) + 1$). All explanatory variables are lagged by one year. Models are estimated using OLS panel fixed-effects estimators. Heteroskedastic-robust standard errors, reported in parentheses, are clustered at the NUTS2 level. *p<0.1; **p<0.05; ***p<0.01

positions and entity types. Hence, beyond the total number of broker entities, we explored their regional distribution to assess whether broker concentration influences CBE knowledge recombination. In order to do that, we measured (i) the share of universities, firms, and RTOs among all broker entities located in a region (Table A2) and (ii) the share of each entity type in specific brokerage positions (Table A3). The results align with our main findings.

5 Conclusions

This study examines how regional collaboration in CBE-related Horizon 2020 projects influences the recombination of technological knowledge in the CBE field. The CBE and, more broadly, the CE have gained increasing attention from governments and industries seeking to transition away from the linear economic model. However, the literature on regional innovation has largely overlooked the collaborative processes that drive the generation and recombination of circular knowledge. We address this gap by analyzing the CBE collaboration network of European NUTS-2 regions between 2015 and 2019, using patent citations as a proxy for technological knowledge recombination.

Building on the recombinant knowledge approach and on the network brokerage framework, we analyse collaboration patterns among different categories of organizations (universities, RTOs, firms) and show that regional knowledge recombination benefits from both inter-regional and intra-regional brokerage functions. Specifically, brokers who bridge regions and those who connect otherwise disconnected groups within regions play a crucial role. Universities, and to a lesser extent RTOs, are more effective in the first role, while firms primarily fulfill the second. Such results are explained by the different approaches that these institutions take toward knowledge transfer. Universities follow an open science model that enhances their ability to connect diverse actors and access various sources of knowledge. RTOs' ability to bridge scientific research and industry needs allows them to act as inter-regional intermediaries. In contrast, firms tend to collaborate within a more localised network, primarily exchanging knowledge with actors internal to the region.

The findings of this work contribute to the geography of innovation literature in several ways. First, we focus on collaborative spillovers, i.e. those that leverage on formal collaboration networks, rather than relying solely on co-location within a geographic area. In fact, while mere co-location only allows to hypothesize the presence of spillovers, actual collaboration patterns provide a direct measure of knowledge exchange between collaborating partners (D'Este et al., 2013). Second, while existing research on collaboration networks primarily examines the intensity of collaboration, often measured by degree centrality or tie strength (e.g., Coffano et al., 2017), our study emphasizes brokerage, this being a key structural property of these networks. Third, by leveraging on the GF taxonomy, we expand the research on brokerage, which has traditionally focused on a single brokerage position, typically gatekeepers (Boari and Riboldazzi, 2014). Specifically, our analysis includes both boundary-spanning brokerage positions (*gatekeeper* and *liaison*) and internal brokerage roles (*coordinator*), thus providing a more comprehensive perspective. Finally, our framework and findings highlight the role of brokerage configurations taking into account the type of organization (university, firm or RTO) in each specific brokerage role. Our analysis reveals that different organizations exhibit distinct patterns in internal versus external brokerage, hence contributing to understanding how different actors shape knowledge recombination.

Our findings also bear important policy implications, particularly given the growing role of CBE in the EU's policy agenda. The EU's commitment to fostering sustainable, circular innovation highlights the need to strengthen empirical evidence on regional knowledge recombination determinants. Our study underscores the innovation benefits of local brokerage and provides support for policies and programs that, on the one hand, encourage firms to connect groups within their local communities and, on the other hand, support universities and RTOs in bridging knowledge across regional borders.

Our study is not without limitations, which also offer avenues for future research. Firstly, our analysis focuses on regional collaboration without differentiating between national and international connections. While international ties can be a source of new knowledge to recombine, they also come with differences in specializations, knowledge endowments and institutional contexts, which we do not address in this paper. Future research could apply our framework to both domestic and cross-national regional collaborations, exploring the specificities involved. For example, researchers could explore the challenges that organizations face when they operate both as local *coordinators* within national boundaries, and as *gatekeepers* or *liaisons* in the international network. Secondly, we do not examine how differences between sectors or technologies shape network structures and regional knowledge recombination. Future research should investigate how industries and technologies interact, considering region-specific absorptive capacities and collaboration strategies in various CBE domains. This would provide deeper insights into how networks foster knowledge recombination across related and unrelated fields. Thirdly, our framework provides a static perspective on a short time-span, but future research could introduce a dynamic approach. An interesting extension to our work would be, for example, investigating how brokerage configurations evolve over time across a larger time span, offering insights into the factors driving these changes and their relationship with regional specialization and CBE-related technologies life cycles. Finally, the empirical setting does not allow to neatly ascertain causality between organizations' brokerage roles and CBE-related knowledge recombination both because of likely unobservable drivers of the knowledge generation process and because of a potentially two-way relationship between brokerage roles and knowledge recombination. Yet, the solid results of the regressions, corroborated by a set of robustness checks, certainly point towards robust associations between the variables of interest. Future research in this direction should account for organization-level drivers of brokerage roles as well as determinants of knowledge circulation in the CBE domain, such as sectoral, technological and policy-related factors.

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Appendix A

Table A1: Correlation matrix

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1	CBE recomb	1	0.249	0.202	0.180	0.126	0.265	0.208	0.176	0.141	0.275	0.256	0.163	0.170	0.219	0.187	0.123	0.124	0.638	0.383	0.283	0.474	0.426
2	All Brokerage	0.249	1	0.584	0.754	0.591	0.881	0.490	0.660	0.491	0.838	0.452	0.672	0.537	0.696	0.358	0.573	0.440	0.214	0.605	0.505	0.324	0.331
3	Univ. Brokerage	0.202	0.584	1	0.146	0.120	0.528	0.847	0.129	0.129	0.451	0.719	0.140	0.144	0.344	0.581	0.087	0.053	0.117	0.461	0.334	0.189	0.181
4	RTO Brokerage	0.180	0.754	0.146	1	0.232	0.700	0.106	0.892	0.226	0.673	0.128	0.860	0.297	0.584	0.072	0.698	0.297	0.198	0.424	0.374	0.265	0.264
5	Entr. Brokerage	0.126	0.591	0.120	0.232	1	0.459	0.109	0.182	0.733	0.492	0.151	0.221	0.723	0.413	0.132	0.269	0.543	0.107	0.306	0.271	0.196	0.231
6	All Liaison	0.265	0.881	0.528	0.700	0.459	1	0.563	0.731	0.541	0.784	0.446	0.666	0.445	0.641	0.327	0.549	0.384	0.231	0.594	0.509	0.326	0.324
7	Univ. Liaison	0.208	0.490	0.847	0.106	0.109	0.563	1	0.097	0.077	0.434	0.702	0.140	0.112	0.293	0.504	0.061	0.037	0.127	0.432	0.292	0.182	0.176
8	RTO Liaison	0.176	0.660	0.129	0.892	0.182	0.731	0.097	1	0.163	0.620	0.112	0.817	0.266	0.525	0.069	0.652	0.233	0.199	0.400	0.344	0.253	0.249
9	Entr. Liaison	0.141	0.491	0.129	0.226	0.733	0.541	0.077	0.163	1	0.409	0.118	0.203	0.562	0.390	0.104	0.281	0.472	0.119	0.274	0.296	0.204	0.211
10	All GK	0.275	0.838	0.451	0.673	0.492	0.784	0.434	0.620	0.409	1	0.588	0.765	0.672	0.793	0.387	0.658	0.515	0.207	0.561	0.391	0.350	0.355
11	Univ. GK	0.256	0.452	0.719	0.128	0.151	0.446	0.702	0.112	0.118	0.588	1	0.171	0.175	0.367	0.642	0.073	0.086	0.114	0.427	0.257	0.210	0.211
12	RTO GK	0.163	0.672	0.140	0.860	0.221	0.666	0.140	0.817	0.203	0.765	0.171	1	0.309	0.644	0.082	0.781	0.304	0.177	0.417	0.312	0.268	0.273
13	Entr. GK	0.170	0.537	0.144	0.297	0.723	0.445	0.112	0.266	0.562	0.672	0.175	0.309	1	0.577	0.169	0.427	0.678	0.145	0.294	0.198	0.258	0.267
14	All Coordinator	0.219	0.696	0.344	0.584	0.413	0.641	0.293	0.525	0.390	0.793	0.367	0.644	0.577	1	0.520	0.812	0.630	0.193	0.415	0.264	0.318	0.308
15	Univ. Coordinator	0.187	0.358	0.581	0.072	0.132	0.327	0.504	0.069	0.104	0.387	0.642	0.082	0.169	0.520	1	0.077	0.075	0.066	0.322	0.165	0.160	0.151
16	RTO Coordinator	0.123	0.573	0.087	0.698	0.269	0.549	0.061	0.652	0.281	0.658	0.073	0.781	0.427	0.812	0.077	1	0.387	0.178	0.302	0.224	0.254	0.239
17	Entr. Coordinator	0.124	0.440	0.053	0.297	0.543	0.384	0.037	0.233	0.472	0.515	0.086	0.304	0.678	0.630	0.075	0.387	1	0.125	0.194	0.127	0.219	0.240
18	Knowledge base	0.638	0.214	0.117	0.198	0.107	0.231	0.127	0.199	0.119	0.207	0.114	0.177	0.145	0.193	0.066	0.178	0.125	1	0.308	0.269	0.733	0.660
19	Net. Degree	0.383	0.605	0.461	0.424	0.306	0.594	0.432	0.400	0.274	0.561	0.427	0.417	0.294	0.415	0.322	0.302	0.194	0.308	1	0.673	0.386	0.398
20	Net. Betwenness	0.283	0.505	0.334	0.374	0.271	0.509	0.292	0.344	0.296	0.391	0.257	0.312	0.198	0.264	0.165	0.224	0.127	0.269	0.673	1	0.344	0.352
21	GVA	0.474	0.324	0.189	0.265	0.196	0.326	0.182	0.253	0.204	0.350	0.210	0.268	0.258	0.318	0.160	0.254	0.219	0.733	0.386	0.344	1	0.901
22	Employment	0.426	0.331	0.181	0.264	0.231	0.324	0.176	0.249	0.211	0.355	0.211	0.273	0.267	0.308	0.151	0.239	0.240	0.660	0.398	0.352	0.901	1

Table A2: CBE recombination and Brokerage

	CBE recomb			
	(1)	(2)	(3)	(4)
Univ. Brokerage net-share	6.599**			7.320**
	(3.127)			(3.087)
RTO Brokerage net-share		4.381		5.427*
		(3.195)		(3.161)
Entr. Brokerage net-share			-1.614	-0.4130
			(3.402)	(3.662)
Knowledge base	0.7115***	0.7201***	0.7225***	0.7091***
	(0.1606)	(0.1599)	(0.1603)	(0.1604)
Net. Degree	0.0838***	0.0874***	0.0945***	0.0752***
	(0.0189)	(0.0183)	(0.0178)	(0.0194)
Net. Betwenness	0.1152*	0.1107	0.1232*	0.1044
	(0.0674)	(0.0692)	(0.0675)	(0.0678)
GVA	0.3812	0.3688	0.3716	0.3774
	(0.4489)	(0.4492)	(0.4491)	(0.4491)
Employment	-0.5822	-0.5891	-0.5901	-0.5768
	(0.4411)	(0.4422)	(0.4426)	(0.4402)
Region FE	✓	✓	✓	✓
Year FE	✓	✓	✓	✓
Observations	1,875	1,875	1,875	1,875
R^2	0.69972	0.69922	0.69887	0.70027
Within R^2	0.05358	0.05201	0.05091	0.05532

Dep var: number of patents citing at least one CBE patent. *Brokerage* independent variables measure, respectively, the share of broker universities, RTOs, and firms located in a region among all broker entities in the network. The dependent variable and the control variables are log-transformed ($log(x) + 1$). All explanatory variables are lagged by one year. Models are estimated using OLS panel fixed-effects estimators. Heteroskedastic-robust standard errors, reported in parentheses, are clustered at the NUTS2 level. *p<0.1; **p<0.05; ***p<0.01

Table A3: CBE recombination and Brokerage

	CBE recomb		
	(1)	(2)	(3)
Univ. Liaison net-share	5.453*		
	(2.854)		
RTO Liaison net-share	3.384		
	(3.029)		
Entr. Liaison net-share	-1.991		
	(2.312)		
Univ. GK net-share		4.910**	
		(2.402)	
RTO GK net-share		3.585	
		(2.384)	
Entr. GK net-share		4.626**	
		(2.290)	
Univ. Coordinator net-share			3.209**
			(1.414)
RTO Coordinator net-share			0.9253
			(1.013)
Entr. Coordinator net-share			3.552**
			(1.641)
Knowledge base	0.7169***	0.7134***	0.7194***
	(0.1607)	(0.1599)	(0.1604)
Net. Degree	0.0811***	0.0685***	0.0824***
	(0.0186)	(0.0199)	(0.0187)
Net. Betwenness	0.1165*	0.1302*	0.1238*
	(0.0692)	(0.0685)	(0.0699)
GVA	0.3715	0.3909	0.3874
	(0.4484)	(0.4502)	(0.4499)
Employment	-0.5727	-0.5570	-0.5668
	(0.4427)	(0.4417)	(0.4429)
Region FE	✓	✓	✓
Year FE	✓	✓	✓
Observations	1,875	1,875	1,875
R^2	0.69975	0.69981	0.70001
Within R^2	0.05369	0.05389	0.05452

Dep var: number of patents citing at least one CBE patent. *Brokerage* independent variables measure, for each brokerage type (*Liaison*, *GK*, and *Coordinator*), the share of broker universities, RTOs, and firms located in a region among all broker entities in the network. The dependent variable and the control variables are log-transformed ($log(x)+1$). All explanatory variables are lagged by one year. Models are estimated using OLS panel fixed-effects estimators. Heteroskedastic-robust standard errors, reported in parentheses, are clustered at the NUTS2 level. *p<0.1; **p<0.05; ***p<0.01