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STRUCTURAL CONSTRAINTS AMID REGIONAL ASPIRATIONS: ASSESSING CATALONIA'S COMPETITIVENESS PATHWAY WITHIN THE EUROPEAN UNION

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ABSTRACT

This study investigates the evolution of Catalonia's regional competitiveness within Spain and the European Union by applying the EU's Regional Competitiveness Index (RCI) 2.0 framework. Through a combination of longitudinal benchmarking, peer region analysis, and k-means clustering, we assess how Catalonia's competitiveness has shifted from 2016 to 2022 across eleven sub-indices grouped under the Basic, Efficiency, and Innovation pillars. The findings reveal that Catalonia, despite its strengths in infrastructure, technological readiness, and innovation capacity, remains structurally constrained by weak institutional quality, labour market inefficiencies, and underperformance in education. While it advanced to a stronger competitiveness cluster by 2022, its relative position declined compared to core Western European regions, and it was surpassed by the País Vasco region in the national competitiveness ranking. Peer group dynamics confirm a shift from the association with innovation-led Western European regions to a more heterogeneous set, including emerging Eastern regions, highlighting Catalonia's relative stagnation. These insights challenge assumptions of uniform competitiveness often cited in regional autonomy debates and emphasize the need for systemic reforms in governance and human capital development. The paper also demonstrates the analytical value of RCI 2.0 in uncovering the structural foundations of regional performance and offers policy-relevant implications for territorial cohesion and sustainable development.

1. RESEARCH BACKGROUND

Regional competitiveness has become a central focus for policymakers across the European Union (EU) and a growing subject of interest among researchers in the academic landscape. It is more often regarded as a critical foundation for achieving inclusive growth, reducing territorial disparities, and enhancing resilience amid increasing global uncertainties (Huggins et al., 2013). This has especially intensified in the aftermath of the COVID-19 pandemic, which exposed and accentuated pre-existing inequalities among and within regions across Europe (Carullo et al., 2025). As spatial disparities are more and more prominent and structural challenges, such as demographic decline, labour market fragmentation, and unequal access to innovation, persist, regional performance and competitiveness have emerged as a central concern in the debate on sustainable development (Rodríguez-Pose & Wilkie, 2017). Therefore, it is no longer assumed that national policies alone are responsible for European regions' capacity to retain productivity, foster innovation, and push for low unemployment rates. Rather, it is widely recognized that regional competitiveness is a territorially embedded process that is influenced by the infrastructure, human capital, knowledge systems, social capital, and institutional quality of a region (Bristow, 2010). This approach illustrates how well regional systems can mobilize their resources, respond to outside shocks, and successfully engage in more significant technical and economic changes.

The academic discourse on regional competitiveness has changed drastically over the last two decades, moving from widely discussed productivity and growth metrics toward a more multidimensional and territorially embedded conceptualization of regional performance. Traditionally, competitiveness was associated with economic output and market share, drawing heavily on Michael Porter's (1990) firm-centric paradigm. However, on a modern note, regional competitiveness is far from being seen as a static ranking and instead is defined as a more dynamic, context-specific process shaped by a region's institutional framework, innovation ecosystems, and adaptability (Giannakis et al., 2024; Sutton et al., 2023). Recent macro-regional assessments highlight that economic resilience and sustainable development are closely tied to how regions leverage their unique assets and adapt to external shocks. For example, analyses of post-crisis recovery across EU territories point out that regions with strong institutional coordination and diversified economic bases recover faster and perform better in the long term (Iacobucci & Perugini, 2021; Ketels & Porter, 2021). Moreover, competitiveness is increasingly viewed as interlinked with environmental protection and digitalization, particularly in the context of the green and digital transitions currently promoted by the EU cohesion strategies (Kouskoura et al., 2024).

In response to the limitations of traditional single-variable metrics, particularly their inability to capture complex interdependencies, composite indicators have gained prominence in regional analysis (Stanickova & Melecký, 2018). The Regional Competitiveness Index (RCI) remains the benchmark in Europe due to its consistent methodology (Bocci et al., 2024). RCI's strength is described by its ability to capture granular, sub-national disparities in competitiveness and to support longitudinal assessments. Scholars such as Chrobocińska (2021), Borsekova et al., (2024), and Ferrarini et al., (2024) have used RCI to analyse convergence/divergence trends, cluster regional trajectories, and evaluate the efficacy of cohesion policy.

Within the EU, several regions have sought greater political autonomy, or even full independence, with economic arguments playing a significant role alongside cultural and historical factors. The most well-known cases are Lombardy, South Tyrol, and Veneto in Italy, Flanders in Belgium, and Catalonia and the Basque Country in Spain. Lombardy and Veneto, the wealthy northern Italian regions, held non-binding referendums in 2017 that overwhelmingly backed requests for greater autonomy from Rome (Secler, 2018). The main driver behind these referendums was the desire to retain at the local level a higher share of the regions' substantial tax revenues instead of redistributing them to less developed regions within Italy (Giovannini and Vampa, 2020). The concrete result of the referendums was Rome passing legislation that ensures "differentiated autonomy", which allows regions to request higher control over specific policies and keep the associated tax revenue – the so-called Calderoli law (Bianchi and Prota, 2025). In Belgium, Flanders is often perceived as the more dynamic and economically potent region, and debates about the scale of fiscal transfers from the region to the French-speaking region of Wallonia are frequent, although Belgium already has a high level of decentralization of fiscal policy (Wong, 2023). The Basque Country region in Spain enjoys a unique and high degree of fiscal autonomy rooted in the historic "Economic Agreement" (Concierto Económico) that allows local authorities to collect most of their taxes directly and then pay a negotiated amount to the Spanish state for centrally provided services (Montes, 2018). A similar fiscal regime operates for the Navarre region, but most regions in Spain operate under a "Common Regime" that resides in receiving central transfers and shares of taxes.

Probably the EU region that has gained the most attention in both economic and political debates regarding autonomy is Catalonia. Often described as one of Spain's most dynamic regions, Catalonia is known for its strong industrial base, high export intensity, and the global profile of Barcelona (Ghemawat et al., 2010). Over the years, Catalonia has been seen as Spain's industrial heartland during the 19th and early 20th centuries, backed by strong manufacturing sectors like textiles, chemicals, and automotive (Tapiador, 2020). This early industrialization differentiated Catalonia from other regions of Spain and assessed the ground for its export-oriented economy. During the early 2000s, Catalonia proved once again its competitive advantage through the transition of Barcelona as a global city. Urban innovation ecosystems flourished, supporting the development of information and communication technology, design, biotechnology, and creative industries (Sandulli et al., 2022). Micro-geographic studies confirm that Barcelona's entrepreneurial ecosystem grew rapidly, attracting high-potential start-ups in emergent industries thanks to agglomeration economies and proximity to key innovation infrastructures (Coll-Martínez et al., 2022). At the same time, Catalonia consistently ranked above the Spanish average in innovation performance according to the European Innovation Scoreboard, although it lagged behind Northern European leaders in digital transformation and advanced technologies (European Commission. Directorate General for Research and Innovation., 2023). However, the debate on the competitiveness of Catalonia is somewhat controversial. Other studies, such as Brunet, (2022) highlight that despite recovery after the crisis in 2008 in some innovation indicators, labour market performance, business sophistication, and governance quality stagnated or declined relative to peer EU regions.

These economic strengths have fuelled political narratives advocating for greater fiscal autonomy or even independence of the region. Such narratives frequently rely on claims of Catalonia's superior economic performance compared to other Spanish regions (Escoriza Morera, 2021). Autonomy proponents also frequently cite the region's "fiscal deficit", arguing that Catalonia contributes significantly more in taxes to the Spanish central government than it receives back in public spending and investment (López-Casasnovas and Rosselló-Villalonga, 2014). They believe that greater fiscal autonomy or independence would allow Catalonia to manage its resources more effectively, potentially leading to greater prosperity (Dalle Mulle, 2017). However, these claims were rarely tested against broader, European-level comparisons using systematic data.

The 2017 Catalan independence referendum introduced a prolonged period of political uncertainty, negatively affecting investment, business confidence, and the overall competitiveness climate. Rodríguez-Teruel and Barrio (2021) demonstrate that political polarization asymmetrically increased support for independence while simultaneously weakening institutional stability, a critical foundation for competitiveness. Catalan political leaders have employed two contrasting narratives to advocate for further autonomy. Pro-independence parties (e.g., Junts per Catalunya, Candidatura d'Unitat Popular) consistently assert that authentic "democracy" means letting citizens decide their future via a legally binding referendum. Also, they characterize Madrid's refusal as indicative of a democratic deficit and depict Spanish institutions as corrupt and unresponsive to Catalonia's requirements (Remiro Brotóns & Torroja, 2024). In contrast, unionist parties in Barcelona (e.g., Socialists' Party of Catalonia, Ciudadanos) and Madrid (e.g., Partido Popular, Partido Socialista Obrero Español) argue that democracy persists only if the constitutional order rules the country, implying that any vote outside Spain's legal framework is invalid and jeopardizes economic and social stability (Ubillos, 2024). In parliamentary discussions preceding and following 1 October 2017, Catalan legislators asserted the "right to decide" as a sovereign mandate, while lawmakers associated with Madrid cautioned against the legal and financial repercussions of separation. Adam et al. (2025) and Vampa (2024) quantify that the prospect of regional fragmentation imposes measurable economic costs, with higher risks of trade disruption, loss of scale economies, and decreased attractiveness for foreign investment. Although Catalonia retains advantages in innovation ecosystems and metropolitan dynamism, its political situation has introduced friction that top-performing European regions increasingly avoid.

To address the existing gap in the literature, a comparative and longitudinal analysis of Catalonia's competitiveness using Regional Competitiveness Index data from 2016, 2019, and 2022 is performed. Furthermore, the study employs unsupervised machine learning approaches to group Catalonia with other EU regions that share comparable features across the RCI's 11 pillars. This model allows us to examine not only Catalonia's performance but also its evolution relative to its European peer regions and the other Spanish regions over time. In addition, we identify which specific RCI pillars, such as innovation capacity, labour market efficiency, or institutional quality, serve as drivers or barriers to Catalonia's competitive standing.

Regional Competitiveness Index 2.0, as the key to our analytical framework, was designed by the European Commission and updated for 2016, 2019, and 2022. It consists of 68 standardized indicators categorized into 11 pillars and three analytically separate dimensions: Basic, Efficiency, and Innovation (Dijkstra et al., 2023). The Basic component (Institutions; Macroeconomic Stability; Infrastructures; Health; Basic education) encompasses the public-good resources and governance quality that reflect a region's fiscal flexibility and administrative capability, both essential to discussions on autonomy. The Efficiency dimension (Higher education and lifelong learning; Labour-market efficiency; Market size) assesses the effectiveness with which regions transform their resources into productivity and engage with national and EU-wide markets. The Innovation component (Technological readiness, Business sophistication; Innovation) assesses a region's capacity to develop, absorb, and disseminate innovation, which is essential for maintaining long-term competitive advantage and mitigating external shocks like political crises. Treating each of these pillars as an operational proxy for fundamental political-economy constructs (governance capacity, resource conversion, and innovation resilience) establishes a clear conceptual connection where regions with greater institutional autonomy should achieve higher scores on the Basic pillars, thereby facilitating more efficient market integration and, ultimately, fostering more resilient innovation ecosystems. Methodologically, and in line with the recommendations of Bocci et al., (2024) and Vo and Tran, (2023), this study applies k-means clustering on the RCI 2.0 set of each of 11 components to present how Catalonia is ranked among its European peers and how it has evolved in terms of competitiveness over the last years.

This study makes three major contributions to the literature on regional performance and competitiveness. First, it makes a significant methodological contribution by combining longitudinal RCI data with unsupervised machine learning techniques to create dynamic cluster profiles of EU regions. Unlike traditional static analyses that rank regions or track individual trajectories, this unique approach reveals how regions naturally group together based on similar competitive characteristics and how these groups evolve over time. Therefore, we offer a more nuanced understanding of the multidimensional nature of regional competitiveness that identifies meaningful competitive peer groups and their structural challenges. Second, this research provides a valuable contextualized analysis of Catalonia's competitive position within the EU, situating the region within naturally formed clusters of comparable EU regions instead of evaluating its performance and competitiveness against arbitrary benchmarks or national averages. Using this approach, this study agrees with Fantechi and Fratesi (2024) that competitiveness is relatively defined through comparison with regions sharing similar structural characteristics. Moreover, by tracking Catalonia's movement between clusters over time, the study explores how the region's competitive position is evolving relative to its peer regions and groups. This contextual setting provides policymakers with more relevant comparisons and insights than traditional rankings or national-level analyses. The third major contribution lies in identifying the specific RCI pillars that are drivers or barriers to Catalonia's competitive evolution. The disaggregation of the analysis to examine how individual competitive pillars influence Catalonia's positioning within the EU, the research provides novel granularity in understanding regional competitiveness dynamics. This detailed understanding of competitiveness dimensions, enabled by the RCI analytical framework, enables more targeted and effective policy interventions than would be possible with composite indices alone, contributing a valuable analytical structure for regional development strategies. The findings offer important insights not only for regional policymaking in Spain but also for the European Union's wider efforts to reduce territorial disparities and to support dynamic regions as engines of sustainable growth.

The remainder of the paper is organized as follows. In the next section, we present the data and research methodology employed. Afterwards, the main results are introduced and discussed. The last section concludes and highlights the implications of our findings, while also acknowledging limitations and suggesting avenues for future research.

2. DATA AND RESEARCH DESIGN

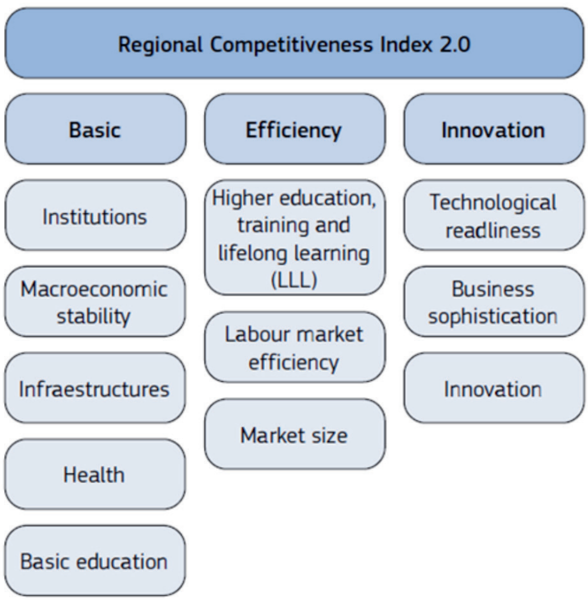
In this section, we present the data collection and cleaning process, as well as the methodological approach followed in the research, in relation to the research objective.

2.1. Data

The study employs data from Eurostat and the EU Regional Competitiveness Index (RCI) for the years 2016, 2019, and 2022, which were collected from the dedicated web page of the European Commission on EU Regional Competitiveness (European Commission, 2023). RCI is based on a comprehensive methodology that measures the main drivers of competitiveness in all NUTS-2 level regions within the EU borders and aims at assessing the ability of regions to provide an environment that is attractive for both companies to operate and residents to live and work, for short and long-term (Dijkstra et al., 2011). RCI was released for the first time in 2010 and is published every three years. Although for comparative purposes a longer period of time would have been more appropriate for our analysis of Catalonia's performance against regional peers and EU regions, the methodology behind the calculation of RCI and its pillars suffered changes from one edition to the other, which makes the values of indicators difficult to directly compare. However, the 2022 edition of RCI used an updated methodology (it is referred to as RCI 2.0) and, more importantly, the indicators for the previous two editions (2019 and 2016) were recalculated according to this new methodology (Dijkstra et al., 2023). Therefore, there is now full comparability of the RCI indicators for the most recent three editions of the index, which supports our goal of positioning Catalonia's competitiveness within the NUTS-2 EU regions over a fairly long period of time spanning around ten years.

RCI is structured around three sub-indices and eleven pillars, designed to capture the various facets of regional competitiveness (see Figure 1). The pillars are measured using 68 indicators, 48 of which are at the regional level and the remaining at the macroeconomic level in each country. The three main pillars and their sub-indices are: (1) Basic pillar – it captures the fundamental developmental factors for an economy, focusing on the essential drivers of regional competitiveness, including five sub-indices: Institutions (INST), Macroeconomic stability (MACRO), Infrastructure (INFR), Health (HLTH), and Basic education (BASED); (2) Efficiency pillar - it relates to factors that contribute to a more skilled labour force and more efficient labour market as a regional economy progresses, and includes the sub-indices of Higher education, training and lifelong learning (HE), Labour market efficiency (LBMEFF), and Market size (MKS); (3) Innovation pillar - it encompasses the drivers of improvement at the most advanced stages of economic development, including three sub-indices on Technological readiness (TECHR), Business sophistication (BUSS), and Innovation (INNOV). The values for RCI, the three main pillars, and the sub-indices are benchmarked against the EU average (100); hence, all values above 100 indicate a better performance of a given region compared to the EU average, and all values below 100 indicate a worse performance of a region than the EU average.

Figure 1. Regional Competitiveness Index pillars and main indicators (RCI 2.0)



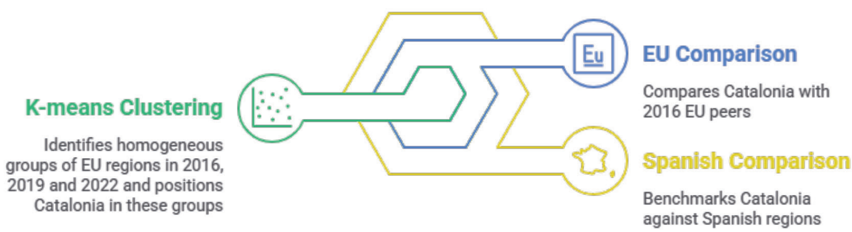
Source: Dijkstra et al., 2023

Although RCI 2.0 offers data on 234 NUTS-2 regions, in the research we have used data on only 224 regions. The reason for the exclusion of 10 regions is related to territorial reorganizations in several EU countries, which made the regions not present in the calculations for 2016 (Latvia, Ireland, Poland, Croatia, and France). The 224 regions are, therefore, part of 24 EU countries (all EU members, except for Latvia, Ireland, and Croatia). While RCI 2.0 provides extensive insights into NUTS-2 competitiveness, it possesses certain limitations. Approximately 30% of its 68 indicators, specifically within the institutions, macroeconomic stability, basic education, and technological readiness pillars, are derived from national-level governance and fiscal data, thereby hiding significant intra-country regional disparities (Moirangthem & Nag, 2023).

2.2. Research design

Our methodology is based on three main stages, illustrated in Figure 2. In stage 1 we benchmark Catalonia (ES51 as code in NUTS-2 regions) against the other 17 Spanish regions over the timeframe covered by RCI 2016, 2019 and 2022, to uncover the leads and lags in its competitive framework, but also to highlight the most important areas of progress or regression against the closest regions in terms of development. In stage 2, we contrast Catalonia's evolution against its EU peers from 2016, as evidenced in the RCI 2016 report (Annoni et al., 2016). In the third stage of the investigation, we use an advanced K-means clustering methodology based on unsupervised machine-learning to identify homogeneous groups of EU NUTS-2 regions. The objective of this clustering is to create groups that are as dissimilar as possible from each other, while maximizing the similarity of entities within the same group. Therefore, we identify groups of EU regions that are most similar based on RCI indicators but most dissimilar with the EU regions included in the other clusters. This clustering is performed for each year with RCI data - 2016, 2019 and 2022 – with the aim of studying the relative competitive dynamic of Catalonia against its peer regions.

Figure 2. Research design



Source: Authors' work

The clustering approach in the study is based on the classic k-means algorithm advanced by Hartigan (Hartigan, 1975; Hartigan, 2001), but it uses Lloyd's expected maximization (EM) method to identify the clusters in Tibco Statistica – see Lloyd (1982). This method extends the basic k-means approach in three significant ways: (i) the EM clustering algorithm computes probabilities of cluster membership founded on one or more probability distributions with the goal of maximizing the overall probability or likelihood of a case to belong to the final cluster; (ii) the algorithm can be applied to both continuous and categorical variables; (iii) a v-fold cross-validation scheme is used to determine the optimal number of clusters instead of the a-priori specification of the number of clusters – this means that instead of indicating the number of clusters before implementing the algorithm (as is the case in traditional k-means clustering), this method self-determines the optimal number of clusters given input data.

The most important advantages of EM-enhanced k-means algorithm stem from its ability to handle the multidimensionality of RCI indicators while maintaining the interpretability of the results, as well as from treating the uncertainty in assigning cases (regions, in this research) to clusters. Moreover, this clustering method is suitable for the analysis of cases transitions in clusters for different moments in time, which is of interest for this study.

Clusters were formed using the Euclidean distance (the geometric distance in a multidimensional space), which measures the dissimilarity between cases (regions, in our research) as follows:

$$ED(x, y) = \left(\sum_i^n (x_i - y_i)^2\right)^{1/2} \tag{1}$$

where ED is the Euclidean distance between x and y vectors (cases), and x_i and y_i represent the individual components (coordinates) of the vectors x and y – in our case, the RCI indicators that are used for clustering. In general, a higher ED indicates a higher similarity between cases, while a lower ED signals more similarity between them. ED is one of the most used types of distances and is suitable for our data, given that RCI indicators that were used for clustering show no differences in scale – all values are benchmarked against the EU average (100). This particularity of the data also makes standardization unnecessary.

The k-means algorithm groups regions in clusters using the Ward method. This method minimizes the variance within clusters and begins with each case as its own cluster, then the clusters are merged in subsequent iterations so that the smallest increase in within-cluster sum of squares is obtained (Murtagh and Legendre, 2014). There are several advantages of this amalgamation method, among which the most important are the minimization of the within-cluster variance, robustness to noise and outliers than other clustering methods, and the high compatibility with Euclidean distances.

In our study the clusters were formed using all 11 sub-indices for each of the three years with RCI data: 2016, 2019, and 2022. After the clusters were formed, the positions of Catalonia, of the other Spanish regions and of Catalonia's EU NUTS-2 peers were analysed, along with their evolution over time. ANOVA methodology was also used to test the statistical significance of the sub-indices in the formation of the clusters and to help in understanding the contribution of each variable to the clustering result.

3. RESULTS

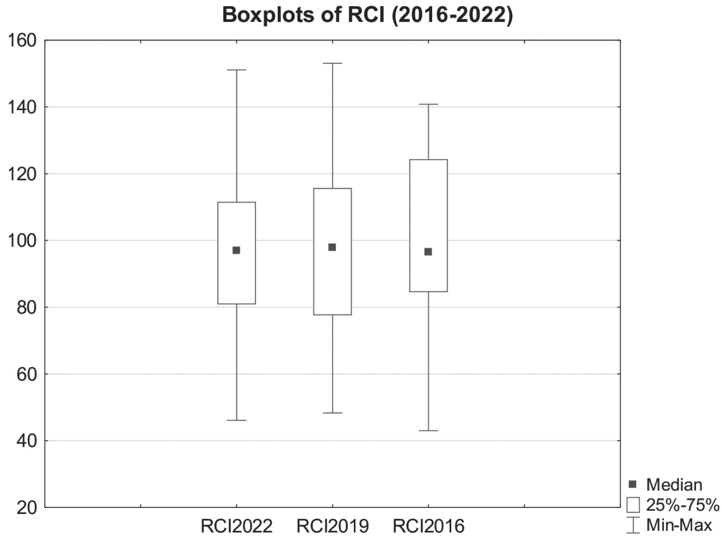
3.1. Preliminary findings

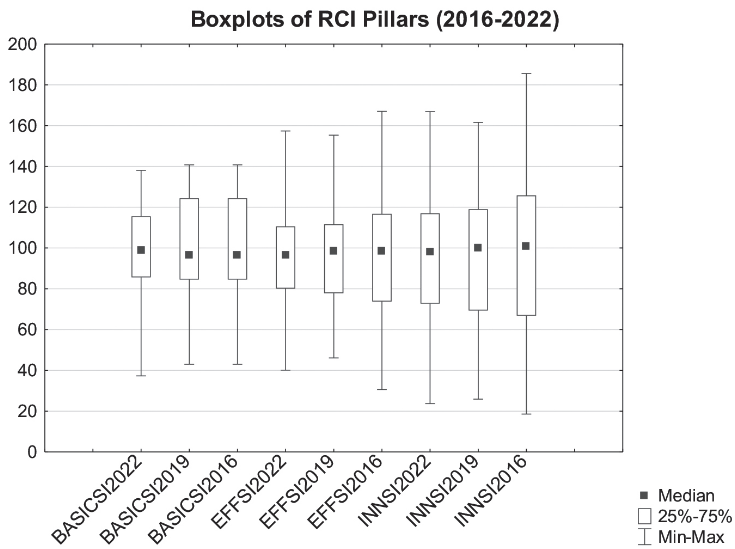
Before presenting the main results, a proper understanding of the data is needed. Figure 3 shows the boxplots with median, first and third quartiles, and range for RCI (left) and RCI pillars (right) for all regions included in the analysis. In the case of RCI, median values appear relatively consistent across all three time periods, with a very small increase in 2022 and 2019 compared to 2016. In 2016, RCI showed the widest interquartile range, suggesting more variability across EU regions in terms of competitiveness, but this was subsequently reduced in 2019 and 2022, which indicates an increased homogeneity of EU regions. The whiskers indicate a similar overall range of values across all three periods, although somewhat higher in 2019 and 2022, and all distributions span from around 40 (43 in 2016, 48 in 2019 and 46 in 2022) to 150 (140 in 2016, 153 in 2019 and 151 in 2022) on the RCI scale.

The boxplots (see Figure 3) show relatively stable median values across all RCI pillars from 2016 to 2022 around the benchmark of 100, which is the EU mean. However, the interquartile ranges declined from 2016 to 2022, suggesting a reduced variability of sub-indices values over time across EU regions. In 2022, the most competitive regions were Utrecht and Zuid-Holland (both from the Netherlands) and Ile-de-France (France), with RCI of 151.5, 142.5, and 142, respectively. Utrecht and Ile-de-France were also first in 2019, joined by Stockholm (Sweden) in third position – with RCI values of 153.1, 143.7, and 141.4. In 2016, Utrecht, Noord-Brabant (Netherlands), Köln and Karlsruhe (Germany) occupied the first positions, with RCI values of 140.8, 139.4 and 139.2 (for the last two). At the opposite end, the Romanian Sud-Est and Nord-Est regions and the Bulgarian Severozapaden region had the worst competitive position among EU regions in 2019 and 2022, being at less than 50% of the EU average.

In 2016, Dytiki Elláda from Greece was in the second-worst place, after Nord-Est, but this region shows an important improvement until 2022, when it is situated at 59.4 of the EU average. Overall, Northern EU regions show a better competitive performance than Southern and Eastern EU regions, reflecting the benefits of agglomeration economies that result from the concentration of economic activities in urban areas, which lead to increased efficiency and productivity (Kosfeld and Mitze, 2023). Moreover, they enjoy better connectivity infrastructure that facilitates the movements of goods, services, and workforce, which fosters economic integration. Additionally, Northern EU regions have higher levels of human capital and a more educated and skilled workforce, which supports innovation and competitiveness (Boțoroga et al., 2022; Simionescu et al., 2021).

Figure 3. Boxplots of RCI and RCI pillars (2016, 2019, 2022)





Source: Authors' work in Tibco Statistica

At the same time, there are important differences in ranges between the three RCI pillars. INNO2016 displays the widest overall range (between 66 and 185). The BASIC pillar shows narrower ranges compared to EFF and INNO pillars, indicating a more comparable framework for business development across EU regions. On the other hand, regions' competitiveness drivers related to efficiency and innovation are more varied within the EU, without a clear declining trend from 2016 to 2022. The region of Utrecht (Netherlands) dominates the BASIC pillar each year, together with Hovedstaden (Denmark) and Zuid-Holland (Netherlands) in 2022, and Noord-Brabant (Netherlands) and Karlsruhe (Germany) in 2019 and 2016. Utrecht and Ile-de-France are the regions with the best performance in the EFF pillar in all three years, joined by Zuid-Holland in 2022, Düsseldorf (Germany) in 2019 and Stockholm in 2016. The top regions when the INNO pillar is considered are Hovedstaden, Stockholm, Luxembourg, and Helsinki (Finland), which dispute the first three places in all years.

Without surprise, the Southern and Eastern EU regions from Romania, Bulgaria, and Greece show the worst performance under the BASIC pillar in all three years, reflecting the generally less favourable macroeconomic conditions for competitiveness in these countries. Interestingly, two Italian regions (Sicily and Calabria), Guyane (France) and two peripherical Spanish regions (Ciudad de Ceuta and Ciudad de Melia) were the least performing regions in the EFF pillar. For the INNO pillar, though, Romanian and Bulgarian regions are the clear worst performers in all years.

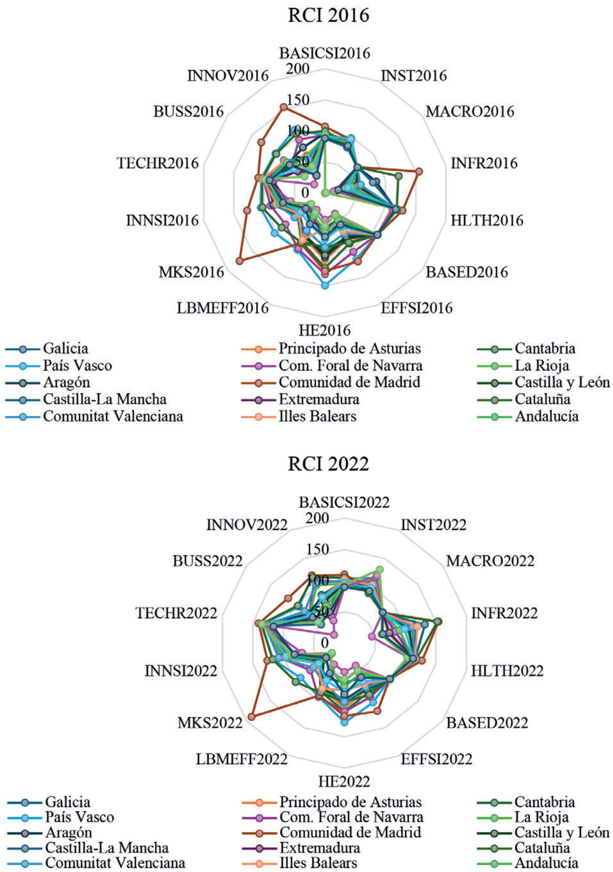
3.2. Benchmarking Catalonia's peers

3.2.1. Catalonia and Spanish regions

Figure 4 (next sheet) provides a comparative overview of Catalonia's 2016-2022 competitiveness profile relative to other Spanish regions.

In 2016, Catalonia ranked second in Spain, just behind Comunidad de Madrid and ahead of País Vasco. This position reflected its strong performance in infrastructure, innovation, and technological readiness – all three above the EU average. However, by 2022, Catalonia dropped to third place in Spain, overtaken by País Vasco, despite major improvements in infrastructure and innovation. This repositioning appears to be driven less by a decline in Catalonia's competitiveness and more by the accelerated progress of País Vasco, which improved across institutional quality, higher education, infrastructur, and labour market efficiency. Comunidad de Madrid reinforced its position as the top-ranked region in Spain (RCI of 118.6, above EU average), outperforming Catalonia in nearly all dimensions and confirming its position as the core metropolitan and administrative hub of Spain.

Figure 4. Comparative RCI sub-index: Catalonia vs Spanish regions (2016 and 2022)

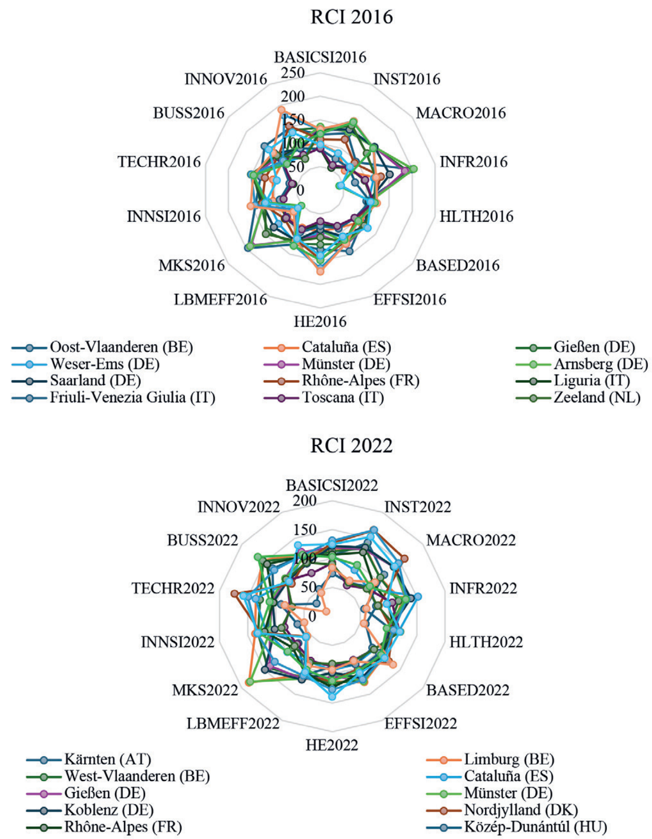


Source: Authors' work based on RCI data

3.2.2. Catalonia and European peer regions

In 2016, Catalonia was grouped in the scorecards of the RCI report (Annoni et al., 2017) with upper-middle performing EU regions such as Münster (Germany), Zeeland (Netherlands), Sydsverige (Sweden), and Rhône-Alpes (France), regions characterized by robust infrastructure, diversified economies, and above-average innovation (Figure 5). These peers shared a structural duality: strong urban-industrial bases, but moderate to weak institutional pillars. By 2022, the composition of Catalonia's peer group changed – see the scorecards of the RCI 2022 report in Dijkstra et al. (2023) -, now incorporating emerging regions from Central and Eastern Europe such as Mazowiecki (Poland) and Közép-Dunántúl (Hungary). This shift reflects stagnation in Catalonia's systemic reforms, also accompanied by increased institutional volatility after the constitutional referendum held in 2017 (Rodríguez-Teruel and Barrio, 2021).

Figure 5. Comparative RCI sub-index of Catalonia vs its European peer regions (2016 and 2022)



Source: Authors' work based on RCI data

While Catalonia retained clear strengths in infrastructure and technological readiness, it scored well below average in institutional quality and business sophistication. Compared to peers like Overijssel (Netherlands) or Münster, Catalonia's profile is increasingly fragmented: high performance in urban-driven metrics, but vulnerability in education and labour adaptability. In particular, the combination of infrastructure excellence and institutional underperformance exemplifies what Rodríguez-Pose (2020) terms the "innovation paradox", where regions that generate innovation lack the institutional and human capital foundations to fully benefit from it. The peer shift also reveals that Catalonia is no longer aligned with core Western European innovation regions. Instead, its similarity with more heterogeneous peers suggests a profile that is partly advanced, and partly structurally constrained. While its innovation ecosystem remains dynamic, especially around the Barcelona metropolitan area, its institutional and educational structures lag significantly behind those of Overijssel, Münster, or Limburg (Netherlands).

3.2.3. Comparative performance: Madrid versus Catalonia

When Catalonia is compared with Madrid (Table 1), Madrid significantly outperforms both its peer group and Catalonia in efficiency (121.2), business sophistication (115.1), and innovation (126.4). In contrast, Catalonia scores below peer averages in most RCI indicators, with particular weaknesses in institutional quality, education, and labour markets. Consequently, despite Catalonia's high-tech and urban advantages, its performance remains overly reliant on sectoral dynamism without sufficient systemic support.

Table 1. Comparative performance of Catalonia and Madrid against their peer groups (2022)

Indicator RCI 2.0 (2022)	Catalonia Score	Catalonia Peer Avg.	Catalonia vs Peers	Madrid Score	Madrid Peer Avg.	Madrid vs Peers
RCI total	100.8	108.8	Below	118.6	109.1	Above
BASIC	105	111.8	Below	109.2	110.3	Below
Institution	88.5	118.5	Below	98	120.4	Below
Macroeconomic Stability	78.1	116.4	Below	78.1	122.8	Below
Infrastructure	152.4	106.6	Above	154.3	93.3	Above
Health	117.7	110.5	Above	127.2	108.1	Above
Basic Education	92.5	108.1	Below	92.5	106.5	Below
EFFICIENCY	92.4	108.3	Below	121.2	110.1	Above
Higher Education & Lifelong Learning	93.5	107.5	Below	116.7	109	Above
Labour Market Efficiency	87.9	108.6	Below	92.9	113.6	Below
Market Size	99.7	109.4	Below	189.6	104.4	Above
INNOVATION	117.7	111.7	Above	126.4	110.7	Above
Technological Readiness	136.2	114.3	Above	140.5	113.1	Above
Business Sophistication	95.9	106.3	Below	115.1	99.4	Above
Innovation	116.4	114	Above	119.7	119.6	Above

Catalonia Peers	Zahodna Slovenija, Gießen, Liguria, Rhône-Alpes, Friuli-Venezia Giulia, Sydsverige, Toscana, Zeeland, Arnsberg, Saarland, Östra Mellansverige, Mellersta Norrland, Oost-Vlaanderen, Weser-Ems, Münster
Madrid Peers	Schwaben, Sostinės regionas, Midtjylland, Unterfranken, Niederbayern, Hannover, Övre Norrland, Groningen, Vallée d'Aoste, Emilia-Romagna, Västsverige, Freiburg, Oberfranken, Provincia Autonomă di Trento, Detmold

Source: Authors' work based on RCI data

The peer groups themselves further reinforce this divide. Catalonia's peers in 2022 include Zahodna Slovenija (Slovenia), Toscana (Italy), Gießen (Germany), and Rhône-Alpes, regions with high urban capacity but varied systemic cohesion. Madrid's peers, however, consist of Schwaben (Germany), Västsverige (Sweden), Midtjylland (Denmark), and Emilia-Romagna (Italy), regions that are consistently above EU averages in institutional robustness and labour efficiency.

3.3. *K-means clustering*

The objective of this stage of our research lies in analysing the dynamic positioning of Catalonia (ES51 as NUTS-2 code) versus the other Spanish regions and EU peers' relative performance, considering the regions' relative performance in 2016, 2019 and 2022. The k-means clustering algorithm was applied for each of these three years on 11 sub-indices from the RCI pillars – Basics, Efficiency, and Innovation. This granular analysis offers significant insights into the main similarities and differences between Catalonia and its peers in an EU-wide context, while exploring their variations over time, and supports a comprehensive assessment of Catalonia's competitive advantages, as well as weaknesses at the regional level. We begin by presenting the results of the k-means clustering, and then we explore the positioning of Catalonia and its peers in clusters over time.

The k-means clustering resulted in 5 clusters for 2016 and 2022 and only 4 clusters for 2019 – see Table 2, which presents the centroids for each cluster and year by sub-indices (a centroid is the centre point representing a cluster, calculated as the average position or mean of all the data points belonging to that cluster). This points towards a more homogenous competitive performance of EU regions in 2019 compared to 2016 and 2022. These findings confirm that the Covid-19 pandemic reversed to a high extent the progress towards economic convergence within the EU, as outlined by Abrhám and Vošta (2022) and Fedajev et al. (2022). This reversion of economic convergence is explained by the uneven impact of the pandemic and the widening gaps within the EU. Southern European countries that rely heavily on tourism and contact-intensive services suffered larger GDP contractions than Northern or Central European countries. In contrast, wealthier countries experienced smaller declines or had speedier recoveries, contrasting with countries that were harder hit by the pandemic, which fell further behind.

Table 2. Centroids for k-means clustering – 2016, 2019, 2022

Cluster	INST	MACRO	INFR	HLTH	BASED	HE	LBMEFF	MKS	TECHR	BUSS	INNOV	Number of cases	Percentage (%)
							2016						
1	84.226	85.038	33.926	83.197	103.390	74.264	85.329	51.588	80.621	61.266	55.834	58	25.89
2	91.005	85.070	93.623	103.791	92.386	102.118	102.875	90.941	94.559	108.298	94.550	44	19.64
3	150.252	135.008	85.367	110.200	116.742	130.154	122.621	87.902	138.469	114.092	130.056	48	21.43
4	39.609	58.858	17.612	86.427	44.945	60.588	60.645	35.303	40.945	53.667	35.455	33	14.73
5	138.395	129.268	191.141	108.929	117.939	111.922	120.215	168.556	139.632	134.515	139.659	41	18.30
							2019						
1	74.342	75.883	77.742	100.814	92.020	75.869	85.722	70.205	81.371	82.903	76.124	59	26.34
2	53.761	73.487	45.983	72.396	46.750	82.787	90.500	35.122	50.313	45.239	59.059	46	20.54
3	131.895	118.942	90.971	103.904	132.358	117.321	106.417	83.495	122.521	107.113	107.069	77	34.38
4	141.343	134.950	141.167	108.905	133.338	112.476	116.057	167.340	133.988	139.860	125.493	42	18.75
							2022						
1	45.983	78.433	34.550	53.492	8.717	64.692	91.908	22.075	28.367	21.992	36.792	12	5.36
2	53.708	61.644	65.881	109.331	71.789	82.742	72.481	58.506	56.467	98.961	74.903	36	16.07
3	135.219	121.542	99.227	103.574	111.691	110.527	112.280	91.538	116.882	114.827	112.432	88	39.29
4	131.375	127.346	148.167	109.792	110.233	113.792	116.233	204.979	125.858	135.017	138.458	24	10.71
5	87.036	90.200	68.125	86.513	107.295	85.984	91.170	48.303	99.708	63.092	68.098	64	28.57

Source: Authors' work in Tibco Statistica

Table 3 confirms the higher homogeneity of EU regions in 2019 compared to 2016 and 2022 and the reversion of the EU regions' convergence in 2022, illustrated by the distances between clusters' centroids in the three years. In 2016, the closest clusters were 1 and 4 (distance of 97.35), and the most distanced ones were 4 and 5 (distance of 318.96). In 2019, clusters 1 and 2 were the closest (distance of 90.95), and clusters 2 and 4 were the most distanced (262.15 distance). However, in 2022, the smallest distance is between clusters 2 and 5 (85.91) and the highest between clusters 1 and 4 (324.25).

Table 3. Distance between centroids of k-means clustering – 2016, 2019, 2022

2016	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
Cluster 1	0.000	103.404	167.000	97.350	250.344
Cluster 2	103.404	0.000	105.423	166.172	159.885
Cluster 3	167.000	105.423	0.000	248.817	136.817
Cluster 4	97.350	166.172	248.817	0.000	318.963
Cluster 5	250.344	159.885	136.817	318.963	0.000

2019	Cluster 1	Cluster 2	Cluster 3	Cluster 4
Cluster 1	0.000	90.945	111.974	184.170
Cluster 2	90.945	0.000	183.439	262.151
Cluster 3	111.974	183.439	0.000	107.614
Cluster 4	184.170	262.151	107.614	0.000

2022	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
Cluster 1	0.000	136.441	237.975	324.253	150.532
Cluster 2	136.441	0.000	147.399	230.403	85.902
Cluster 3	237.975	147.399	0.000	128.628	111.516
Cluster 4	324.253	230.403	128.628	0.000	216.931
Cluster 5	150.532	85.902	111.516	216.931	0.000

Source: Authors' work in Tibco Statistica

Looking at any single year, the centroids reveal distinct profiles of EU regions, which highlights that the algorithm successfully identified groups with significantly different characteristics. The ANOVA method applied to cluster formation identified all sub-indices as having discriminant power for identifying clusters for each year – see Table 4.

Table 4. ANOVA results

Sub-indices	Between	df	Within	df	F	p value
INST2016	317919.1	4	71088.3	219	244.851	0.000
MACRO2016	172600.3	4	156778.9	219	60.275	0.000
INFR2016	765484.7	4	191859.9	219	218.442	0.000
HLTH2016	30636.8	4	70380.1	219	23.833	0.000
BASED2016	129114.9	4	95070.9	219	74.355	0.000
HE2016	136740.7	4	145377.5	219	51.497	0.000

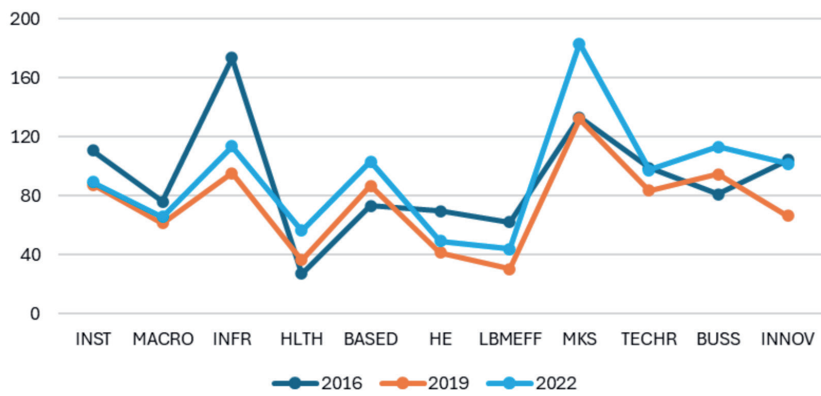
LBMEFF2016	105219.8	4	50468.5	219	114.146	0.000
MKS2016	434180.1	4	167427.8	219	141.980	0.000
TECHR2016	273487.4	4	65753.4	219	227.721	0.000
BUSS2016	211500.5	4	140885.3	219	82.192	0.000
INNOV2016	344280.5	4	142013.3	219	132.730	0.000
INST2019	285951.5	3	101253.2	220	207.102	0.000
MACRO2019	145220.9	3	111091.3	220	95.863	0.000
INFR2019	206794.2	3	121530.1	220	124.783	0.000
HLTH2019	38258.2	3	48394.5	220	57.974	0.000
BASED2019	257283.5	3	137806.7	220	136.912	0.000
HE2019	77050.6	3	81969.7	220	68.933	0.000
LBMEFF2019	30123.9	3	38907.9	220	56.777	0.000
MKS2019	412150.8	3	169134.5	220	178.700	0.000
TECHR2019	221388.5	3	59140.0	220	274.521	0.000
BUSS2019	218199.3	3	132320.5	220	120.928	0.000
INNOV2019	129327.0	3	96145.6	220	98.642	0.000
INST2022	253458.4	4	93111.5	219	149.035	0.000
MACRO2022	123110.6	4	100505.3	219	67.064	0.000
INFR2022	174806.5	4	119389.2	219	80.163	0.000
HLTH2022	42875.8	4	38969.8	219	60.238	0.000
BASED2022	145979.9	4	57206.1	219	139.712	0.000
HE2022	50480.0	4	60820.1	219	45.442	0.000
LBMEFF2022	52483.6	4	47493.2	219	60.503	0.000
MKS2022	506590.7	4	170637.0	219	162.543	0.000
TECHR2022	170420.3	4	88252.4	219	105.725	0.000
BUSS2022	202690.9	4	123581.2	219	89.798	0.000
INNOV2022	172149.0	4	115936.4	219	81.296	0.000

Source: Authors' work in Tibco Statistica

When comparing the centroids across sub-indices, several observations are noteworthy – see also Figure 6, which shows the averages of clusters' centroids in the three years. The largest differences across years are observed for INFR (Infrastructure) and MKS (Market size), while the smallest are between MACRO (Macroeconomics) and, very interestingly, TECHR (Technological readiness).

Moreover, while the ranges of clusters' centroids are close in all years – see Figure 7, except for INFR and MKS, the ranges for 2022 are higher than in 2019 for all sub-indices, but not when compared to 2016. Thus, we see a lower range of clusters' centroids in 2022 against 2016 for most sub-indices in the BASICS Pillar (INST, MACRO, INFR), HE, LBMEFF, and similar ranges for TECHR and INNOV, suggesting that in these areas the convergence process of EU regions has continued despite the pandemic setback.

Figure 6. Clusters' centroids by sub-indices – 2016, 2019, 2022



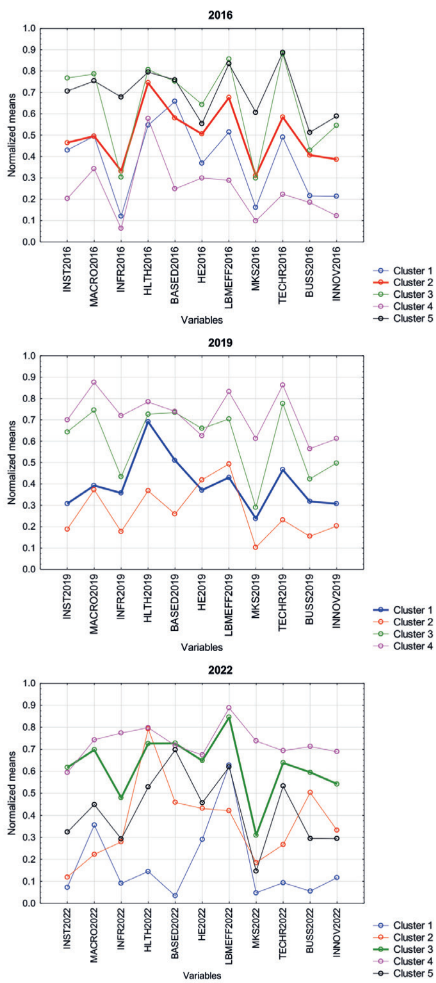
Source: Authors' work based on Tibco Statistica output

Moving on now to explore the performance of Catalonia within the EU regions, Figure 7 shows the graphs of normalized means for the three years and each sub-index. The clusters that include Catalonia are highlighted in each graph (Cluster 2 in 2016, Cluster 1 in 2019 and Cluster 3 in 2022).

Catalonia underwent significant changes in its competitive positioning within the EU regional landscape from 2016 to 2022, evidenced by its movement in different clusters in the three years. In 2016, Catalonia belonged to cluster 2 (red), characterized by a dispersed performance profile with notable peaks in HTLH (Health) and BASED (Basic education), while exposing weaknesses in INFR (Infrastructure) and MKS (Market size). These depict a region with uneven development across competitiveness dimensions, maintaining only moderate innovation performance despite being an advanced European region. By 2019, Catalonia had transitioned to cluster 1 (blue), marking a considerable shift in its competitive profile. This new cluster placement reveals lower performance in institutional and macroeconomic indicators (INST and MACRO) compared to 2016, reflecting broader economic challenges for these EU regions - the sub-indexes are constructed on country-level data. However, this period also shows a very good performance in HLTH (Health), which places cluster 1 very close to the most performing clusters 3 and 4 and suggests targeted investments in these areas in the countries whose regions are included in this cluster. At the same time, cluster 1 displays relative underperformance in HE (Higher education) and LBMEFF (Labour market efficiency) while showing more consistent performance in innovation in all three sub-indices (TECHR, BUSS, and INNO) compared to cluster 2.

The graph from 2022 places Catalonia in Cluster 3 (green line), representing another significant repositioning compared to previous years. This second-best performing cluster shows good performance on most sub-indices, although HLTH (Health) and MKS (Market size) place this cluster closer to the least performing clusters. The transition from 2016 to 2022 reveals Catalonia as a region experiencing significant economic restructuring, with shifting strengths and vulnerabilities across the competitiveness spectrum, rather than following a linear improvement trajectory across all sub-indices. However, its placement in one of the two most performing clusters in 2022 indicates that the region has progressed significantly within the EU, but also when assessed against its EU peers and the other Spanish regions.

Figure 7. Normalized means for clusters – 2016, 2019, 2022



Source: Authors' work in Tibco Statistica

Table 5 presents the cluster placement of all Spanish regions, including Catalonia, in the three years. In 2016, three other regions – Pais Vasco, Aragón, and Comunidad Foral de Navarra – were included in the same cluster as Catalonia, while all the others – except the capital city region, Comunidad de Madrid – are placed in lower-performing clusters.

Table 5. Placement of Spanish regions in clusters

Region code	Region name	2016	2019	2022
ES11	Galicia	1	1	5
ES12	Principado de Asturias	1	1	5
ES13	Cantabria	1	1	5
ES21	País Vasco	2	3	3
ES22	Com. Foral de Navarra	2	1	5
ES23	La Rioja	1	1	5
ES24	Aragón	2	1	5
ES30	Comunidad de Madrid	5	4	4
ES41	Castilla y León	1	1	5
ES42	Castilla-La Mancha	1	1	5
ES43	Extremadura	1	1	5
ES51	Cataluña	2	1	3
ES52	Comunitat Valenciana	1	1	5
ES53	Illes Balears	1	1	5
ES61	Andalucía	1	1	5
ES62	Región de Murcia	1	1	5
ES63	Ciudad de Ceuta	4	1	5
ES64	Ciudad de Melilla	4	1	5
ES70	Canarias	1	1	5

Source: Authors' work based on Tibco Statistica output

Actually, Comunidad de Madrid is encountered in the second-best cluster in 2016 and in the best cluster in 2019 and 2022, reflecting the economic and competitive advancement of the country's capital city region. In 2019, all Spanish regions except Comunidad de Madrid and Pais Vasco are included in the same cluster, signalling a more homogeneous competitive performance (País Vasco is placed in a less performing cluster compared to Catalonia). The results for 2022, though, highlight the economic and competitive distance between Catalonia and Comunidad de Madrid when contrasted against the other Spanish regions: Comunidad de Madrid is placed in cluster 4 and Catalonia is placed in cluster 2, the most performing clusters, while all the other regions belong to cluster 5, a less performing one.

When looking at Catalonia's peers from 2016, our clustering methodology places only four of them in the same cluster 2 as Catalonia in 2016 (Liguria, Friuli-Venezia Giulia, and Toscana from Italy, and Zahodna Slovenija from Slovenia), while the other 11 belong to clusters 3 and 5 that show a relative better performance than cluster 2 – see Table 6.

Table 6. Placement in clusters of Catalonia's EU peers from 2016

Region code	Region name	Country	2016	2019	2022
BE23	Oost-Vlaanderen	Belgium	5	4	4
DE72	Gießen	Germany	5	4	3
DE94	Weser-Ems	Germany	3	3	3
DEA3	Münster	Germany	5	4	4
DEA5	Arnsberg	Germany	5	4	4
DEC0	Saarland	Germany	5	3	3
FRK2	Rhône-Alpes	France	3	3	3
ITC3	Liguria	Italy	2	1	2
ITH4	Friuli-Venezia Giulia	Italy	2	1	2
ITI1	Toscana	Italy	2	1	2
NL34	Zeeland	Netherlands	3	4	3
SE12	Östra Mellansverige	Sweden	3	3	3
SE22	Sydsverige	Sweden	3	3	3
SE32	Mellersta Norrland	Sweden	3	3	3
SI04	Zahodna Slovenija	Slovenia	2	3	3

Source: Authors' work based on Tibco Statistica output

This landscape is largely maintained in 2019: the three Italian regions (Liguria, Friuli-Venezia Giulia, and Toscana) are in the same cluster as Catalonia, but the Slovenian region of Zahodna Slovenija has moved in cluster 3, which is more performing than cluster 1. Also, as in 2016, the remaining peer regions are included in clusters 4 and 3, which are better placed in competitiveness terms than cluster 2. However, the clustering algorithm applied to the 2022 data shows a different situation. Catalonia, as discussed above, is part of the second-best cluster (3) and is joined by 9 other peers from 2016 – 3 regions from Germany and Sweden each, and one from France, Netherlands, and Slovenia each. At the same time, 3 Italian regions (Liguria, Friuli-Venezia Giulia, and Toscana) are now included in the less performing cluster compared to 2019 and 2016, indicating a lapse compared the previous periods, while

Őost-Vlaanderen (Belgium), and Münster and Arnsberg (Germany) are included in a more performing cluster than Catalonia.

4. DISCUSSIONS

The patterns captured by the movement of Catalonia in clusters between 2016 and 2022 reflect strong structural and conjunctural factors that have shaped the region's performance. These factors are of various nature, from political and institutional to economic and external, jointly explaining the non-linear competitiveness trajectory of the region and its relative positioning among Spanish regions, on the one hand, and the peer and other regions within the European Union.

Political and institutional factors that disrupted the region's governance were significant drivers of Catalonia's competitiveness volatility over the studied period. The constitutional crisis that surrounded the region's independence referendum held in 2017 and its aftermath, linked to the application of Article 155 of the Spanish Constitution that suspended the autonomy of Catalonia for five months (Payero-Lopez, 2020), raised uncertainty that impacted the competitiveness dimensions considered by RCI (mostly Institution and Macroeconomic Stability). Therefore, this institutional disturbance explains well the weakening of Catalonia's institutional quality indicators and its inclusion to Cluster 1 in 2019. It is noteworthy mentioning that during this period that foreign direct investment flows to Catalonia, highly dependent on the external sector, declined by 59% compared to 2016 (DataInvex, 2025). This led to a significant drop in the region's share of inward FDIs in Spain from 30.7% in 2016 (second after Comunidad de Madrid with 44.7%) to only 9.4%. Moreover, as Rodriguez (2022) point out, there has been an exodus of firms from Catalonia to other Spanish regions – besides Madrid, other regions that largely benefited from this leave were Aragon, Valencia and the Balearic Islands.

The institutional crisis also exposed several structural constraints within the country's quasi-federal system that limit the development of competitive strategies at Catalonia's level (Harguindéguy and Cole, 2017). Unlike the regions that enjoy higher fiscal autonomy, such as the Basque Country, Catalonia functions under the "common fiscal regime" that largely coerces its ability to adjust tax policies and support investments to enhance competitiveness (Kölling et al., 2023). Under this framework centered on fiscal redistribution within Spain, the region has a significant fiscal deficit estimated at 8-10% of Catalonia's annual GDP (Gracia, 2024), which may limit investments in infrastructure and development of human capital. Furthermore, several scholars considered that the centralized control of the Spanish government over immigration policy, in addition to infrastructure planning and taxation, prevents the implementation of coherent regional development strategies observed in other autonomous EU regions such as Bavaria or South Tyrol (The European Network, 2017). This institutional asymmetry is a good explaining factor of the outperformance of

Catalonia by Pais Vasco in institutional quality and labor market efficiency, a Spanish region with historical fiscal privileges (Aparicio-Pérez et al., 2025). However, the recent agreement signed between Catalonia and Spain's government that marks a paradigm shift whereby Catalonia is allowed to collect taxes directly starting in 2026, a significant step in the direction of revenue-driven fiscal autonomy, is expected to positively impact both tax efficiency and investment opportunities in the future, uplifting Catalonia's competitiveness (Foster, 2025).

While political and institutional factors are fundamental in understanding Catalonia's regulations and policies, the changes in the region's competitiveness revealed in our research are also a consequence of significant economic evolutions. Catalonia experienced considerable deindustrialization after 2005, reflected in the decline of the manufacturing sector's share in regional GDP from 22.7% in 2000 to 15.3% in 2021, accompanied by a corresponding expansion of services (Statistical Institute of Catalonia, 2025). This economic restructuring explains partially the region's improvement in innovation accompanied by technological readiness and business sophistication that drove Catalonia's inclusion in Cluster 3 by 2022 – the indicators associated to these areas show the region's increased specialization in knowledge-intensive and innovative activities such as advanced manufacturing, biotechnology, and digital services (European Commission, 2024). The progress in innovation was strongly supported by investments in research and development from public and private sources of national and international origin. According to the Statistical Institute of Catalonia (2025), R&D expenses increased by 64% from 2017 to 2023 overall – 55.32% from national public sources and 62% from companies -, while the R&D funds received from the rest of the world went up by 191.2% (they include the programs of the EU and other international funds).

At the same time, this structural transformation of Catalonia's economy has led to imbalances that impact other dimensions of the regional competitiveness. Garcia-Lopez et al (2020) argue that the concentration of high-value activities in the metropolitan area around Barcelona, the capital city of Catalonia, had amplified territorial disparities within the region, increasing labor market inefficiencies and mismatches in skills in areas that are peripheral to the capital. This is further reflected in a higher than EU average unemployment rate in Catalonia over the period under analysis (29.4% versus 17.2%), although lower than Spain's average rate (36.1%) – these values explain the persistent underperformance in Catalonia's labor efficiency indicators, particularly in the 2019 clustering.

As for all EU regions, the Covid-19 pandemic represented a critical period for Catalonia that exposed the region's high dependence on tourism and international trade (Duro et al., 2019). The pandemic disruptions on national and international travel heavily impacted the region's number of tourists and revenues from tourism – in 2020 and 2021, the expenditures made by all tourists in Catalonia dropped by 76.8% and further by 64.1% compared to the previous year, and it was much more marked in non-residents compared to residents (Vayá et al., 2024).

However, the pandemic also stimulated innovation and digitalization that improved the regions' related competitiveness dimensions, as evidenced by the 2022 clustering. Significantly affected by the health crisis and a huge number of patients caused by the Covid-19 virus, the region turned to digital health solutions and implemented a remote work infrastructure, as many other Spanish regions (Sust et al., 2020; Rubino et al., 2024). Moreover, the funding allocation of €3.2 billion for Catalonia from the EU Recovery and Resilience Plan has been strategically directed toward projects that support technological advancement, digital transition and green economy development (Generalitat de Catalunya, 2021), which also explains the advancement of the region is the second most innovative cluster on innovation in 2022.

An important finding of our analysis portends to Madrid's consistent outperformance over Catalonia in all competitiveness dimensions. This reflects Madrid's position as the capital region, including increased investments in infrastructure (high-speed rail, airport capacity, telecommunications) that are disproportionately financed from public sources (Nogués et al., 2021). Additionally, the competitive advantages of Madrid's region extend to the presence of multinational enterprises, financial institutions and various public institutions that create agglomeration effects in productivity and innovation Pontarollo and Serpieri, 2020).

Last but not least, the changing composition of Catalonia's regional peers from 2016 to 2022 reflects the convergence dynamics within the EU. The presence of several regions from Central and Eastern Europe in the peer group in 2022 witnesses their rapid development supported by considerable funds received through the EU Cohesion Policy implementation, as well as foreign direct investments (Navracsics and Taraczközi, 2024; Gál and Lux, 2022; Horobet et al., 2021). In this framework, regions like Lower Silesia in Poland or Zahodna Slovenija in Slovenia reached important competitiveness levels through their specialization in automotive and electronics manufacturing, strongly challenging the Western EU regions' leading positions. The convergence of these and other regions in EU explains why Catalonia's peers are very different in 2022 compared to 2016.

5. CONCLUSIONS

This study aimed to evaluate how Catalonia's regional competitiveness has changed over time and how it compares to other regions in Spain and across the European Union. Using the updated RCI 2.0 framework, we tracked Catalonia's performance across key competitiveness dimensions and assessed how its relative position evolved from 2016 to 2022. The analysis combined three approaches: longitudinal benchmarking, peer group comparison, and k-means clustering, to provide a comprehensive and structured view of Catalonia's standing within the EU's regional competitiveness landscape. This paper helps improve our understanding of regional competitiveness by (i) using unsupervised clustering on long-term RCI 2.0 data to analyze peer groups regions over time, (ii) comparing Catalonia to similar EU regions instead of just looking at national averages, and (iii) breaking down individual RCI pillars to identify the main factors that help or hinder its competitiveness.

The results reveal that Catalonia's competitiveness trajectory has been nonlinear and structurally unbalanced. Despite consistently strong performance in infrastructure, innovation, and technological readiness, the region underperforms in institutional quality, higher education, and labour market efficiency.

Between 2016 and 2022, Catalonia shifted between three different clusters of European regions, reflecting changing strengths and vulnerabilities. In 2016, Catalonia belonged to a mid-performing cluster (Cluster 2), strong in health and education, but weak in infrastructure and market size. However, in 2019 the region moved to Cluster 1, a slightly weaker group, amid stagnation in macroeconomic indicators and institutional volatility after the referendum. However, in 2022, Catalonia had ascended into Cluster 3, the second-best group EU-wide, driven largely by improvement in innovation-related metrics.

The comparison with other Spanish NUTS-2 regions reinforces this point. País Vasco overtook Catalonia in 2022 due to better institutional and labour market performance, while Comunidad de Madrid consistently outperformed all regions, reflecting a more balanced and systemic competitiveness profile; however, this is typically the case of most capital regions in the EU. At the same time, cluster analysis confirms that, by 2022, only Madrid and Catalonia remain in the top two performing clusters, while most other Spanish regions have stagnated or declined. This shows that while Catalonia maintains a leadership position within Spain, it lags behind Madrid's more cohesive, innovation- and efficiency-led growth model.

At the European level, Catalonia's peer group evolved significantly. In 2016, it was associated with advanced Western European regions like Münster, Zeeland, and Sydsverige. By 2022, it shared cluster space with a more diverse set of peers, including regions from Poland, Hungary, and Slovenia, reflecting Catalonia's relative stagnation and rapid convergence by others.

These empirical findings have important implications for the political discourse surrounding Catalonia's autonomy. The region's strong innovation and export capacity are frequently cited as evidence that greater fiscal independence would lead to improved outcomes. However, the data show that Catalonia's competitiveness is not uniformly high; it suffers from institutional and structural weaknesses that constrain its performance relative to EU leaders.

Therefore, the argument for economic self-sufficiency must be qualified. While Catalonia may have the industrial and innovation base to support greater autonomy, its comparative underperformance in institutional and human capital pillars suggests that full convergence with top EU regions would require significant reform beyond fiscal autonomy. In summary, Catalonia remains a competitive but structurally imbalanced region, whose progress is driven by sectoral strengths but limited by institutional and educational weaknesses. Its position within Europe has improved since 2019, but not sufficiently to place it among the EU's top-tier regions. The study reinforces the idea that competitiveness is a relative, dynamic process, and that policy must address both performance and convergence dimensions simultaneously. Catalonia may utilize its innovation ecosystem to achieve more resilient and inclusive growth by making improvements in three strategic directions. First, creating a single district digital portal for its businesses and citizens so they would find all the permits and documents they need on this modern platform. To implement this, the Catalan government could adopt a system that funds the performance of the districts. For example, districts that cut average permit-processing times receive funding in time with a bonus. Second, the region should develop sector-focused apprenticeships in fast-growing fields, partnering leading firms with universities, to ensure graduates' skills match employers' needs. Finally, Catalan universities and industry must jointly fund applied research hubs offering subsidized learning vouchers in data science and cleantech, along with paid internships, so that new talent is trained in the region's key areas of digitalization and sustainability. Only through this structural alignment can the region sustainably leverage its autonomy aspirations and remain a core actor in the European competitiveness landscape.

The research has several limitations that open interesting directions for future investigations. While the RCI 2.0 framework offers a comprehensive assessment and benchmarking tool, the study is inherently constrained by the reliance on predefined indicators that may not entirely capture region-specific contextual factors that influence competitiveness. A number of 20 out of the 68 RCI 2.0 indicators are reported at the national level, restraining and hiding important information about regional discrepancies within the country. Future research may complement the RCI framework by including data related to region-specific governance and fiscal metrics, such as local administrative surveys and detailed regional budgets, to accurately reflect intra-country differences. Additionally, the time frame (2016-2022) coincides with significant shocks, including Brexit, the COVID-19 pandemic, and supply chain disruptions, with a clear potential to confound the shifts in competitiveness with structural versus conjunctural factors. Hence, further studies would benefit from extending the analysis to unravel these factors, including an examination of sub-regional disparities within Catalonia.

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