



From Silos to Synergy: Collaborative Laboratories and the Transformation of Knowledge Production

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Abstract

The increasing societal importance of cutting-edge science and technology calls for a closer examination of public policies' influence on the evolving dynamics of knowledge production and transfer. This focus is especially pertinent in peripheral economies such as Portugal, where persistent structural challenges include the limited integration of highly qualified human resources within the economy. The purpose of this research is to investigate how the knowledge coproduction and transfer dynamics of 'Collaborative Laboratories' (CoLABs), a new form of intermediary organization in Portugal, differ from those of more traditional science-industry interface set-ups, in the Portuguese context. This research employed a deductive, quantitative, multiple-case, cross-sectional design, utilizing scientific publications as collaboration indicators and applying Social Network Analysis to map and analyze the knowledge coproduction and transfer networks of CoLABs in Portugal, comparing them to Technology Centers. The results reveal that CoLABs prioritize the creation of flexible collaboration networks and the broad coproduction and dissemination of knowledge. CoLABs are found to function as value-occupying hub organizations and serve as crucial bridging entities and are characterized by high connectivity, diverse collaboration, and cohesive research and innovation communities. The need for public agencies and CoLAB governance structures to devise strategies to enhance communication and collaboration within the CoLAB network is highlighted. This is the first study to investigate CoLABs as a new form of intermediary organization in Portugal, specifically examining how their knowledge coproduction and transfer dynamics differ from more traditional science-industry interface set-ups in the Portuguese context.

Keywords:

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R&I Ecosystems;
Network Orchestration;
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1- Introduction

The strategic deployment of policy tools remains the primary mechanism through which governments can guide their policy systems and influence target behavior. Policy instruments are a crucial area of inquiry within public policy research as this is essential for enhancing our understanding of policy development and informing more effective policy design [1]. An instrument-based approach offers a valuable lens for elucidating policy dynamics, providing prescriptive insights that can empower policymakers to make more informed and effective decisions compared to solely relying on input-based approaches [2]. However, while acknowledging that the link between policy instruments and outcomes is complex and influenced by numerous factors [3], a deeper understanding of how specific instruments influence target group behavior and compliance with governmental aims remains a critical gap in the literature [4]. Despite emerging research indicating that certain instruments or instrument mixes correlate with enhanced performance [2], a comprehensive understanding of the precise relationship between instrument choices and policy outcomes remains limited. Therefore, this study adopts an output-oriented approach, drawing upon the foundational work of scholars such

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as Vedung [5] and Salamon [6] to examine the outcomes of science policymaking. Following a constructivist paradigm, we assume that the production of knowledge is a social process whereby the world of research and science and the world of policymaking meet in producing policy-relevant information.

Policymakers, funders, and scientists continue to grapple with effectively leveraging science to address emergent societal challenges. This necessitates systemic changes in how research and innovation (R&I) are funded, conducted, and disseminated to generate new knowledge, economic activity, and societal value simultaneously. In particular, understanding the roles of new ‘actors’ designed to foster collaboration between scientists, industry, government, and broader society is crucial. This article focuses on Portugal, a small, peripheral economy facing these challenges, to investigate Collaborative Laboratories (CoLABs) as a novel policy instrument for promoting knowledge co-production and translating scientific advancements into tangible societal and economic benefits.

Scientific knowledge gains problem-solving efficacy through collaborative development [7]. The increasing contextualization of scientific research has spurred the emergence of diverse organizations within international higher education and R&I sectors, aiming to facilitate knowledge co-production [8] with significant implications for R&I ecosystems [9]. Given the substantial public investment in these intermediary organizations, the dynamics between producers and consumers of research-based knowledge and skills are of growing concern [10]. This worry has driven the development of policies and strategies aimed at increasing the utilization of scientific research by industry and society, primarily by fostering stronger connections between universities, enterprises, government agencies, and the public [11]. Specifically, the co-production of knowledge among scientists, industrialists, third-sector actors, and policymakers is encouraged to translate scientific discoveries into tangible opportunities and solutions [8], making a focused discussion of knowledge production and exchange processes essential [12].

Establishing and maintaining impactful academy-industry partnerships remains a persistent challenge, particularly in peripheral economies characterized by limited R&D capacity and structural weaknesses. While various government policies aim to stimulate science-industry links, their uneven success underscores the limitations of traditional approaches and the need for innovative solutions. Traditional university-industry partnerships, such as science parks, often prioritize technology transfer over knowledge co-production. New ‘actors’, dedicated to knowledge production and transfer, encompass various forms, including facilitating networks, communities, alliances, and platforms [11]. Notably, contemporary collaborative research consortia and open innovation models significantly promote interdisciplinary research and knowledge-sharing.

Non-university R&I institutions, acting as intermediaries [12], play a vital role in bridging the gap between science and innovation by facilitating collaboration, research, and technology transfer. These institutions typically possess specific research focuses and develop deep expertise applicable to real-world challenges. They actively pursue collaborations with industry partners and often manage intellectual property, patents, and licensing agreements [13]. Furthermore, they frequently offer testing facilities and expertise to evaluate the feasibility of new ideas, accelerating the adoption and commercialization of research outcomes. These institutions may also contribute to policy discussions and influence regulations and standards.

One such organizational setup that promotes effective collaboration and the prioritization of joined-up thinking for the coproduction of knowledge and value creation [14] has emerged since 2017 in the Portuguese R&I ecosystem: the CoLABs. Established as intermediary organizations, they represent a potential alternative or complement to conventional policy tools such as Technology Centers (TCs). CoLABs correspond to infrastructures dedicated to knowledge coproduction, providing expertise and services in knowledge and technology transfer. They are dedicated to specific sectors or challenges, such as forestry or the low demographic density of mountain regions. Their focal areas are not defined at the policy-making level but through a bottom-up approach in which the interested parties create a consortium and apply for public bootstrap funding. Their formal status is also open, and they can be established as not-for-profit organizations or firms. This represents a paradigm change in the Portuguese R&I ecosystem, which is composed of over 300 R&D units supported by the National Foundation for Science and Technology (FCT) and over 30 ‘Technology and Innovation Centers’ funded by the National Innovation Agency (ANI). Notably, CoLABs are jointly supported and monitored by FCT and ANI. To fulfill their mission, CoLABs aim to create highly qualified employment with economic and social value.

Despite the increasing variety of intermediary ‘actors’, there is a significant gap in understanding how university-industry collaborations should be structured to develop and share fundamental and practical knowledge to address societal challenges [15]. This study addresses this gap, and the limited understanding of the relationship between specific policy instruments and outcomes [4], by focusing on CoLABs as a case study in a peripheral economy. It addresses this new type of actor's opportunities, potentialities, and limits. In particular, this study seeks to answer the following research question: “How do the knowledge coproduction and transfer dynamics of Collaborative Laboratories differ from those of more conventional science-industry interface set-ups, in the Portuguese context?” To the best of our knowledge, this is the first study to investigate this new form of intermediary organization in Portugal.

Network Orchestration Theory [16, 17] is used to analyze how CoLABs act as 'hub organizations' within a network of diverse actors. In particular, the study examines how CoLABs orchestrate knowledge production and transfer across the network. It provides a robust theoretical lens for analyzing their function and impact. This theory is crucial for understanding how a central organization, or an 'orchestrator,' intentionally manages and guides a network to generate value. In this study, CoLABs are conceptualized as 'hub organizations' that orchestrate knowledge production and transfer across a diverse network of actors, including universities, firms, and other entities. The theory helps to elucidate the processes through which CoLABs construct and manage these cross-organizational networks to achieve collective goals. The application of Network Orchestration Theory allows the study to highlight how CoLABs act as value-occupying orchestrators, leading value creation and promoting collaboration within their networks, and how they bridge the gap between research and the market. This theoretical approach ultimately helps to illuminate the potential of emerging and alternative configurations within the Triple/Quadruple Helix model for university-industry interactions in peripheral economies. Social Network Analysis (SNA) [18, 19] is used to map collaboration patterns between CoLABs, universities, firms, and other actors. Scientific publications are used as a proxy for knowledge coproduction. Data are compared between CoLABs and first-generation intermediary organizations in Portugal (the TCs).

Ultimately, by examining the organizational role played by CoLABs in the current stage of Portugal's national R&I ecosystem development, this research aims to contribute to the understanding of how intermediary infrastructures can shift from a mere scientific and technological service to a collaborative knowledge development process, thereby fostering more diverse and effective policy-science-industry interactions. This study is particularly relevant given Portugal's decade-long efforts to encourage science-industry links and the unique challenges it faces as a peripheral economy striving to enhance its innovation capacity. It offers valuable insights into the design and implementation of effective policies aimed at bridging the gap between science, industry, and society.

The article proceeds by first detailing the theoretical framework that underpins this study. Following this, the methodology is outlined, explaining the use of SNA to map collaboration patterns among CoLABs, universities, firms, and other key actors, with scientific publications serving as a proxy for knowledge co-production. The article then presents and discusses the results of the comparative analysis, where data collected from CoLABs are contrasted with those of TCs. Finally, the conclusions summarize the study's contributions and implications for policymakers and practitioners.

2- Background

The collaboration between academia and industry is increasingly recognized as a crucial driver of innovation [20]. Governments worldwide implement policies to foster this collaboration, aiming to address scientific and technological challenges. However, the success of these policies hinges on effective implementation at the local level, leveraging existing infrastructure and resources to translate policy objectives into tangible advancements [21]. While numerous programs and policies aim to bridge the science-industry divide, their effectiveness varies significantly across countries due to diverse cultural, cognitive, organizational, and human capital factors influencing innovation [22].

Previous research emphasizes the influence of state involvement and established production specialization profiles on the relevance and diversity of intermediation processes and organizations within science-industry innovation networks. Mazzucato [23] compellingly demonstrates the state's entrepreneurial role, even in ostensibly liberal economies like the United States, highlighting how state investment in the early, high-risk stages of innovation has been crucial for fostering emerging technologies. This aligns with broader analyses of varieties of capitalism, which demonstrate how national state approaches to development influence the propensity of specific productive, scientific, and technological structures to engage in radical innovation [24]. Critically, previous policy instruments have often overlooked the heterogeneity of socio-politico-economic contexts and the potential of variations in organizational set-ups, hindering their overall effectiveness [25]. This study addresses these limitations by focusing on the specific role of CoLABs within the Portuguese context.

Existing research has extensively explored the intermediation role of university organizations and specialized intermediaries, such as science parks, business incubators, and technology transfer offices (TTOs). However, a significant gap exists in the literature regarding CoLABs, a relatively new type of intermediary. This article addresses this gap by examining the organizational role of CoLABs within the national R&I ecosystem and their impact on knowledge co-creation between actors. Specifically, we investigate how CoLABs contribute to evolving policy paradigms. Our research contributes to policy process literature by framing CoLABs as a tool that can shift the understanding of publicly-funded intermediary infrastructures from mere scientific and technological services providers to a collaborative knowledge development process, thereby fostering more diverse policy-science-industry interactions.

2-1- Challenges in Peripheral Economies

Peripheral economies, characterized by a focus on capability-building and transition, are heavily reliant on external politico-economic environments. Specific knowledge generation and diffusion contexts in these economies can create unique barriers to technology transfer that conventional policy approaches often fail to address, as observed in Central

and Eastern European countries [26]. Portugal, as a small and peripheral economy with limited research and development (R&D) capacity, faces challenges in fostering independent technological innovation [27]. Importantly, contrary to the belief that there are too many PhDs, there is actually a shortage of doctorate holders in many sectors in Portugal. This shortage is expected to worsen in the coming decades, highlighting the need for public policies to attract and retain PhDs and involve them in the modernization of the economy [28]. The dual nature of the labor market, where both high and low levels of education and skills can generate employability, the preference for public sector employment, and the slow adoption of advanced technologies in the industry contribute to the low employment rate of PhDs in the private sector. Also, the Portuguese socio-economic context, particularly during periods of crisis, further impacts innovation development, with firms in less favorable circumstances experiencing compromised innovation and reduced future confidence [29]. Moreover, in Portugal, EU structural funds are a primary source for R&I policy. However, the focus on maximizing fund absorption (e.g., in the context of smart specialization strategies) as led to a short-term orientation in the R&I institutional climate, potentially hindering strategic long-term impact. This reinforces the core-periphery dynamic within the Portuguese context, necessitating targeted state intervention to address persistent structural issues.

The local context, encompassing national and regional environments, significantly influences sectoral patterns of innovation and development [30]. Key challenges for peripheral economies include their basic R&I capabilities and the nature of existing institutional structures and networks [30, 31]. These economies are typically in a 'catching-up' phase regarding technological advancements [32], characterized by a reliance on foreign technologies, associated learning dynamics, and relatively limited local R&I efforts [33]. Consequently, R&I policies and public investments in these countries are crucial not only for advancing basic research but also for facilitating the local adaptation and diffusion of existing technologies [32]. While technology transfer policies in core European economies such as France and Germany often emphasize developing intermediary institutions and direct, formal economic benefits [34], peripheral contexts face different challenges. The most significant barriers to technology transfer and innovation in these contexts are linked to the aforementioned availability and quality of human resources and knowledge, coupled with a general reluctance among firms to collaborate with universities [35]. This highlights the need for tailored policy interventions that address these specific constraints.

2-2- Collaborative Laboratories

The Triple and Quadruple Helix models view innovation as a complex interplay of actors involving linear and nonlinear processes [36]. These collaborative networks require various intermediaries to function effectively. In Europe, example Helix organizations include the VINN Excellence Centers in Sweden, the Fraunhofer-Gesellschaft (Fraunhofer Society) in Germany, the Catapult Centers in the UK, and the CARO Centers in France. All have a public funding base and are industry-co-funded. The Fraunhofer-Gesellschaft is Europe's largest technology and innovation organization [37]. Its institutes tend to be subject-specific, focus on core and enabling technologies, and are closely linked to academia (typically, the head of a Fraunhofer Institute is an active professor at a local university). The success stories of Fraunhofer Gesellschaft include the development of the MP3 player. Led by an academic, the Swedish VINN Excellence Centers are multidisciplinary and typically involve 5–10 associates established within a research locus, usually a university. The Catapult Centers are focused on late-stage R&D on specific topics (e.g., cell and gene therapy) and are led by a CEO (not necessarily an academic). CAROs also focus on particular topics, such as new materials.

In Portugal, public funding supports R&I activities primarily conducted within R&I higher education institutions (HEIs), public research laboratories, and private (non-for-profit) organizations that are part of the 'National Science and Technology System'. Currently, there are more than 300 R&I units formally recognized by FCT, some of which further comprise 'Associated Laboratories' (45), 'Technology and Innovation Centers' (TICs, 31, including seven TCs), and CoLABs (41). Associated Laboratories are top-tier R&I centers that address critical national challenges in science, health, society, the environment, and the economy. TICs are committed to generating and sharing knowledge to create economic value. They directly contribute to pursuing public policy objectives within the national or regional specialization priority areas. In addition to TCs, TICs include Technology Transfer Centers and 'Institutes of New Technologies'. TCs collaborate closely with business associations and play a key role in promoting open innovation, knowledge transfer, and networking [38]. They offer various services: R&D, analytical facilities, inspection and certification, testbeds, business development advice and support, and training. TCs hold a distinct position as sector-specific support structures, fueling technical and technological advancements across diverse industries. Previous research has extensively explored the pivotal role of TCs in fostering innovation ecosystems [24]. Prior studies acknowledge their key functions in facilitating knowledge transfer, bridging the gap between science and commercial application, and acting as central hubs for collaborative R&D activities with technology-based firms [39].

CoLABs correspond to a new organizational form of 'intermediary entities' [12] implemented by ANI, backed by evidence that knowledge and technology coproduction is an ideal model for effective collaboration between academic researchers and industry partners [40], is key for sustainable long-term university-industry partnerships [41], and is crucial for scaling up and implementing solutions to 'grand challenges' in real-world settings [42]. CoLABs are mostly mission-oriented and focused on areas considered key to the national context (e.g., biodiversity and forest) and are

geographically spread out. They have a different formal status, organizational make-up, thematic focus, and mission than TICs such as TCs. Their primary objective is to promote the creation of highly qualified and scientific jobs (internally and externally) by executing R&I agendas designed to create economic and social value. Currently, 639 highly qualified positions (32% PhDs) have been created by existing CoLABs. The Portuguese government has financially supported them during their bootstrap period, directly (funding being provided, for example, for human resources hiring and infrastructure capacitation) and indirectly (through public, open calls for proposals for collaborative projects).

A key distinction between CoLABs and TCs lies in their operational mechanisms and governance structures, representing a paradigm shift in the Portuguese R&I ecosystem. Unlike TCs, whose focal areas may be defined at the policy-making level, CoLABs emerge from a bottom-up approach, where interested parties form a consortium and apply for public bootstrap funding. CoLABs also possess an open formal status, allowing them to be established as either not-for-profit organizations or firms, offering a flexible alternative or complement to conventional policy tools. In terms of their financing, CoLABs utilize a distinct model based on equal shares of public base funding, competitive funding, and private funding, which sets them apart from other intermediary organizations in Portugal. Operationally, CoLABs prioritize the creation of flexible collaboration networks and broad knowledge co-production and dissemination. They function as 'hub organizations' that orchestrate knowledge production and transfer across diverse networks of actors, including universities and firms, leading to highly connected and diverse collaborations. In contrast, TCs are typically sector-specific support structures focused primarily on technology development and transfer to industry, with their associate structures being more industry-focused. This allows CoLABs to act as value-occupying orchestrators, taking a hands-on approach to lead value creation and occupy a more central broker position within the value chain compared to TCs, actively promoting collaborative knowledge development processes.

In sum, the literature suggests that science-industry interfaces in Portugal arise from a nuanced synthesis of universal innovation models (such as university research laboratories, TTOs [43], science parks [44] and TCs [24]) and context-sensitive adaptations driven by regional innovation dynamics (reflected in the thematic focus of each CoLAB), institutional capacities (namely centered around HEIs [10]), or policy frameworks such as smart specialization strategies that define specific topics/areas of interest [45].

2-3- Scientific Publications as Proxies for Knowledge Co-creation

Several researchers have suggested using scientific publications to assess industry-academy interactions as a proxy for the research activities generated within R&I support infrastructures [46]. For example, Hung [47] examined the public-private co-authorship of publications and patents by firms based at Hsinchu Science Park. He observed that the collaboration between universities and industry exhibited consistent growth in terms of publications. Moreover, the trends associated with patenting activity remained stable or showed signs of decline. In another example, Minguillo et al. [48] studied whether scientific publications could prove that R&I support infrastructures in the UK (technology parks, science parks, science and innovation centers, research parks, incubators, and other parks) successfully promote scientific activity and cooperation among entities of different natures. They observed a systematic increase in R&D activity starting in the 1990s, as indicated by publications from firms within research parks and research institutions. Therefore, scientific publications were shown to be helpful as a proxy for scientific cooperation. HEIs were identified as the primary external partners for businesses in the technology park. Nevertheless, contradictory studies can be found in the literature. For example, Olmeda-Gómez et al. [49] reported that academic articles from collaborations between universities and private enterprises appeared less visible in Spain than those published by other institutions.

2-4- Network Orchestration Theory

Network Orchestration Theory describes how a central organization, or orchestrator, intentionally manages and guides a network to generate value [17]. It elucidates the processes by which an orchestrator constructs and manages a cross-organizational network to achieve a collective goal [50]. The orchestrator leverages its central position to influence and coordinate diverse resources and capabilities among network members [51].

Research on network orchestration has focused in particular on orchestration processes [52] and orchestrator roles [53]. In innovation networks, the processes and practices performed by the orchestrator have been shown to impact its position relative to other network members over time [54]. Hurmelinna-Laukkanen et al. [55] emphasize the importance of tailoring orchestration strategies to different innovation networks to maximize their impact.

Research suggests that network orchestrators play a pivotal role in driving innovation. They initiate projects, select network members, and manage the innovation process [56]. While knowledge sharing and network coordination are common orchestrator roles, their responsibilities can vary over time and context [53]. In addition to these core functions, orchestrators contribute to network stability, protect innovation investments, and facilitate knowledge exchange [57]. Additionally, they actively reshape the network to adapt to changing environments [58]. Prabowo [59] identified four orchestrator roles in innovation networks: promoting entrepreneurship, knowledge activation, innovation intermediation, and network leadership. Stahl et al. [60] reported that facilitating access to external resources and stimulating interactions among innovation ecosystem participants are crucial roles of network orchestrators. Moradlou et al. [61] applied network

orchestration theory to understand how innovation networks can bridge the gap between research and the market. Their findings suggest that orchestrators are crucial in transforming intellectual property into a public asset that benefits businesses. Xie et al. [17] explored how not-for-profit organizations can facilitate value creation in global innovation networks. They identified three key orchestrator roles: network design, relationship management, and leadership. Moreover, they found that successful orchestration in this context relies on trust, resource optimization, and adaptable strategies. The network roles depend on the orchestrator type (e.g., ‘players’ vs. ‘nonplayers’, ‘facilitators’ vs. ‘sponsors’) [16]. For instance, a value-occupying orchestrator takes a hands-on approach, leading the network in value creation. On the other hand, a value-independent orchestrator adopts a more supportive role, helping network members identify innovation opportunities independently [53].

2-5- Social Network Analysis of Research and Innovation Networks

Social networks have been a focus of social science research for decades, but their application to understanding research collaborations is a relatively recent development [62]. Nevertheless, it has proven to be a valuable tool when analyzing the dynamics of R&I ecosystems [63].

SNA has been used to map actors and technologies within innovation ecosystems [18]. When applied to research collaborations, SNA helps researchers understand network structure, actor roles, and knowledge flow [19]. Research has shown that central actors are more likely to be innovative [64] and that network density and structural holes can positively impact innovation [65]. SNA can help identify key actors within the network who act as ‘brokers’ by facilitating communication and knowledge exchange between different groups. This can be particularly insightful in understanding how collaborative R&I practices influence knowledge dissemination patterns. In addition to their role in social networks, gatekeeper organizations within R&D ecosystems play crucial roles in information flow and performance evaluation [66]. Research has also explored how network structure influences innovation, with studies examining the impact of small-world networks on industry and university-industry collaboration [67]. Moreover, SNA has been applied to analyze the role of technological districts in regional innovation [68] and the dynamic nature of innovation networks in high-tech clusters [69].

3- Methods

The methodology process is represented schematically in Figure 1.

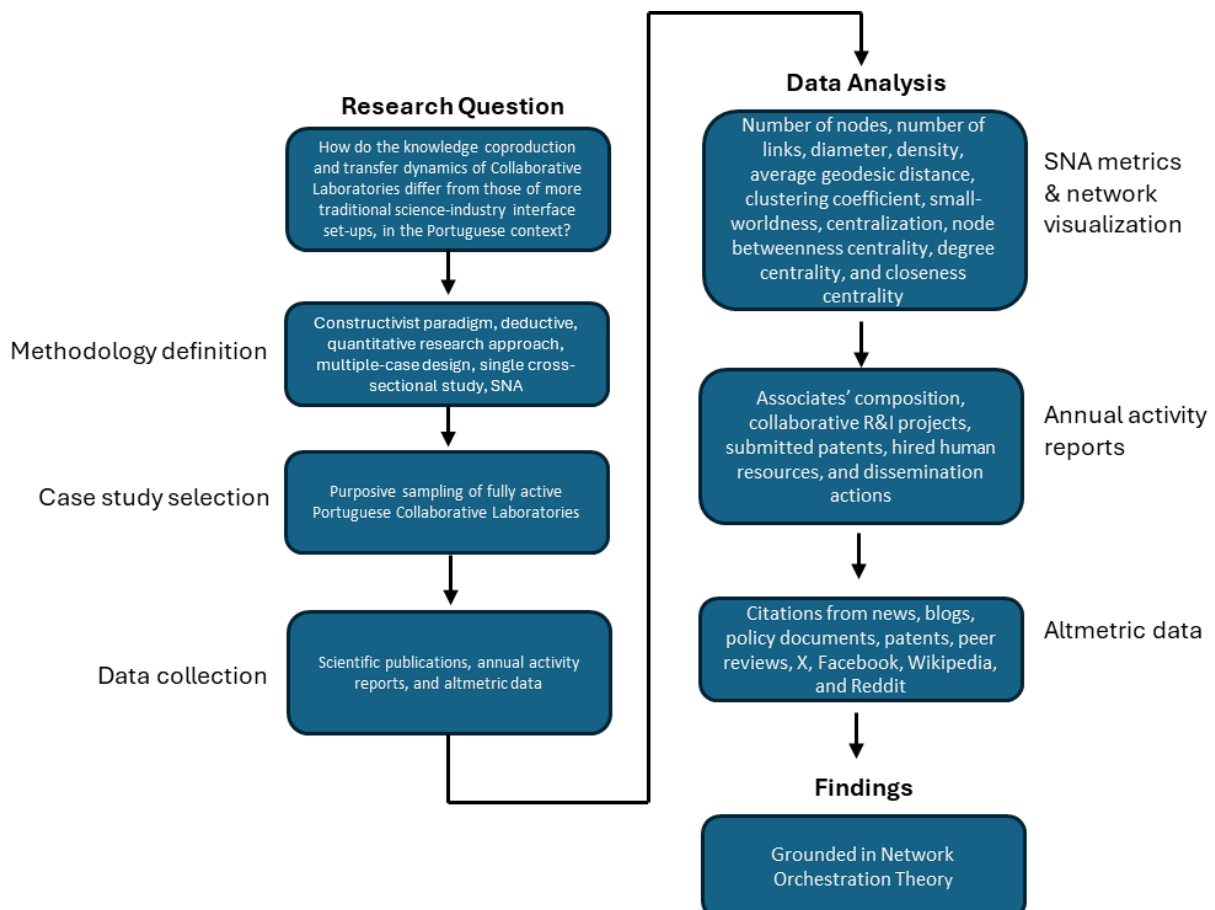


Figure 1. Methodology workflow

A deductive, quantitative research approach was used to determine the cause-and-effect link grounded upon assumptions of determination [22]. A multiple-case design was used within a single cross-sectional study, which implies replication logic [70], where a case is treated as an idiosyncratic expression of the phenomenon under study. SNA takes relationships among actors as the unit of analysis [71]. Purposive sampling was used to select CoLABs fully active for at least three years and operating under ‘stable’ conditions (i.e. after an initial induction period of two years to build or consolidate their infrastructure and to hire a core team of highly qualified human resources). This sampling method enables the intentional selection of study cases that can offer valuable insights or distinct perspectives relevant to the research problem [72].

Data on scientific publications were retrieved from Elsevier’s Scopus database (as of December 2022). We limited our queries to encompass journals, book series, and conference proceedings, excluding editorials, errata, letters, and notes. A parallel search strategy was employed in the Web of Science database (Clarivate) but it yielded fewer records, all overlapping with the Scopus search results. Not all the authors mention their affiliation in the same way. Although this was thoroughly considered, this search approach may not consider all the relevant publications. Research conducted by individual departments, subunits, or corporate divisions was attributed to the parent organization. Research centers affiliated with HEIs were treated separately to yield more detailed outcomes. When possible, name variations were also considered in the case of firms.

The analysis of co-authored publications was complemented by data from the annual activity reports of the CoLABs and TCs (associates’ composition, collaborative R&I projects, submitted patents, hired human resources, and dissemination actions). Altmetric data gathered citation information from alternative sources, searching for links and references to published research (news, blogs, policy documents, patents, peer reviews, X, Facebook, Wikipedia, and Reddit).

SNA was used to analyze the structure and dynamics of the knowledge creation and transfer networks driven by the CoLABs and explore how knowledge flows between different actors. VOSviewer version 1.6 was used for network visualization, and Gephi v0.10 and UCINET v6 were used to collect SNA metrics, namely, the number of nodes, number of links, diameter, density, average geodesic distance, clustering coefficient, small-worldness, centralization, node betweenness centrality, degree centrality, and closeness centrality.

Table 1 summarizes the thematic focus of the case studies. It can be observed that CoLABs have a diverse focus, while TCs are centered around key industrial sectors.

Table 1. The thematic focus of the case studies

Case study	Thematic focus*
	Collaborative Laboratories
+Atlantic	Climate, space, and ocean (sustainable use of resources)
DTx	Digital and communication systems (cyber-physical systems)
ForestWISE	Biodiversity and forest (integrated forest and fire management)
GreenCoLab	Climate, space, and ocean (macro- and microalgae)
Vines&Wines	Agrifood (wine)
MORE	Biodiversity and forest (mountain regions)
Technological Centers	
CATIM (1986)	Advanced manufacturing and sustainable production (metalworking industry)
CENTIMFE (1989)	Advanced manufacturing and sustainable production (tooling, plastics)
CITEVE (1989)	Materials processing (textiles)
CTCOR (2003)	Agrifood, biodiversity and forest (cork)
CTCP (1986)	Materials processing (footwear)
CTCV (1987)	Materials processing (ceramics)
CTIC (1994)	Materials processing (leather)

* According to the ANI thematic areas classification (www.ani.pt)

With regard to the structure of associates, CoLABs have diverse associate structures with significant representations of HEIs, R&I organizations (e.g., R&D Labs, Interface Centers), and firms. In contrast, TCs are more industry-focused (in addition to firms, sectoral associations, and public administration). CoLABs are geographically distributed and play key roles in regional dynamics, whereas TCs are located near industrial hubs. HEIs that are geographically or thematically close are shared as CoLABs associates. Shared associates among TCs are essentially firms.

4- Results

4-1- Case Study Outputs

Table 2 summarizes the information on the outputs collected from the Scopus database (scientific publications) and ANI activity reports (the remaining data).

Table 2. Case study outputs from the Scopus database and ANI's annual activity reports (2022)

	HRs (nr.)	R&D HRs (% PhDs)	Papers (nr.)	Dissemination actions (nr.)
Collaborative Laboratories				
MORE	42	21	21	56
+Atlantic	49	20	22	37
forestWISE	17	53	49	73
DTx	49	29	42	7
GreenCoLab	19	37	53	61
Vines&Wines	15	27	24	305
Technological Centers				
CATIM	105	24	42	10
CENTIMFE	50	8	8	17
CITEVE	160	8	62	0
CTCOR	16	18	3	20
CTCP	60	14	27	43
CTCV	65	38	51	6
CTIC	26	14	14	18

Notes: HRs: full-time human resources; nr.: number

Considering their recent creation, CoLABs are relatively more productive in scientific publications than TCs. This shows that scientists are progressively embracing knowledge coproduction at a faster pace in the context of CoLABs. This is posited to have a contribution from 1) the representativeness of PhDs in their R&D workforce and 2) the different vocations of CoLABs and TCs. On the one hand, PhDs represent 28% and 17% of the respective R&D workforces. On the other hand, TCs are more focused on technology development and transfer to industry, which may inhibit wider knowledge production. In fact, Hottenrott & Lawson [73] reported, in a study involving a sample of UK engineering academics, that industry-led R&I (in our case, more significant in TCs than in CoLABs) diminishes the additional benefits of public funding by reducing the rate of increase in publications and citations typically associated with public grants.

The number of dissemination actions (Table 2) is significantly greater for CoLABs than for TCs. The dissemination actions of project results are expected to represent a key output, namely, as the presence of non-academic partners (e.g., companies, associations, governmental agencies, etc.) increases. In alignment with the Mertonian view of science [74] this is key to encouraging public discourse on scientific evidence with diverse audiences to facilitate broader societal change [75]. For example, research by Fujitani et al. [76] indicates that direct engagement and interaction between scientists and those who apply scientific findings are more effective for retaining knowledge and fostering the adoption of sustainable practices than merely presenting information. This finding underscores the broader importance of dissemination actions that build public confidence in research and enhances public engagement in science and innovation [77]. Thus, CoLABs successfully meet the requirements for enhanced dissemination to society at large, which clearly distinguishes these entities from other actors of the national R&I ecosystem, such as science and technology parks [78], 'Associated Laboratories' [79], and, as shown in our study, TCs.

The fraction of scientific publications with Altmetric mentions to the tracked outputs (Table 3) represented 86% and 51% for CoLABs and TCs, respectively. This suggests a potential gap between the public and the scientific content produced by TCs and signals an opportunity to augment the dissemination and accessibility of produced knowledge to the broader public. On the other hand, TCs' papers are more frequently mentioned in patents than those emanating from CoLABs. In addition to the shorter operation life of the analyzed CoLABs, this could indicate that the knowledge produced by the TCs is more relevant to patenting activity than that produced by the CoLABs. A broader analysis timeframe will be necessary to confirm this hypothesis. Papers from CoLABs have received more attention from policy documents than those from TCs. This result highlights the greater relevance of the scientific knowledge produced by CoLABs in shaping public policies than that produced by TCs.

Table 3. Mentions to Altmetric tracked scientific outputs

	Social media	News and blogs	Policy documents	Patents	Academic sources	Other sources
Collaborative Laboratories	881	46	6	3	6	5
Technological Centers	39	0	0	41	0	1

4-2- Co-authoring networks

Visualizing networks can uncover patterns and insights hidden in statistical data [80]. Figures 2 and 3 depict the CoLAB and TC co-authoring networks, respectively. Both networks have well-defined communities. Both CoLABs and TCs act as bridges between different parts of the network, facilitating knowledge exchange. HEIs and their R&D units are the entities with the most significant ‘collaboration spaces’ with both CoLABs and TCs and include (but are not limited to) their associates. This finding corroborates the findings of Minguillo et al. [48] relating to the importance of HEIs for the scientific outputs of R&I collaborations

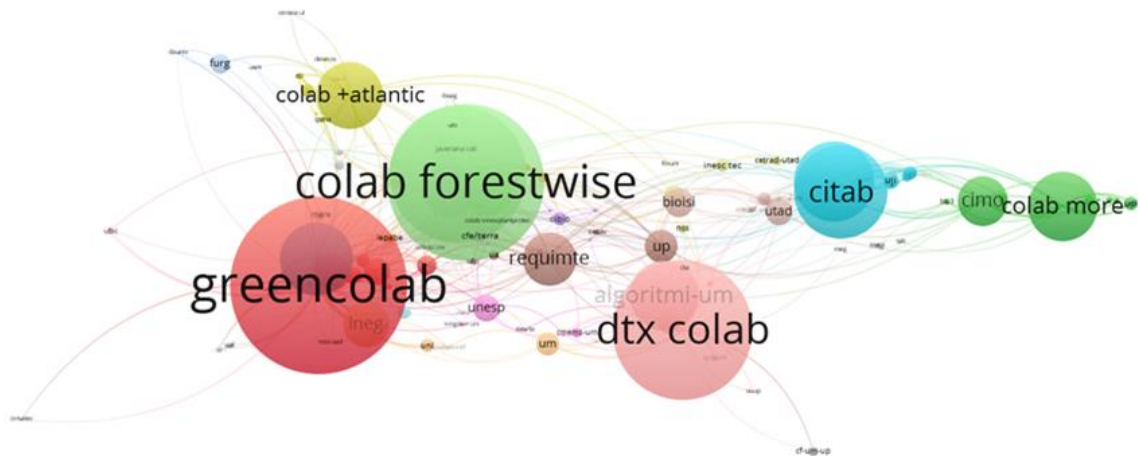


Figure 2. CoLABs co-authoring network

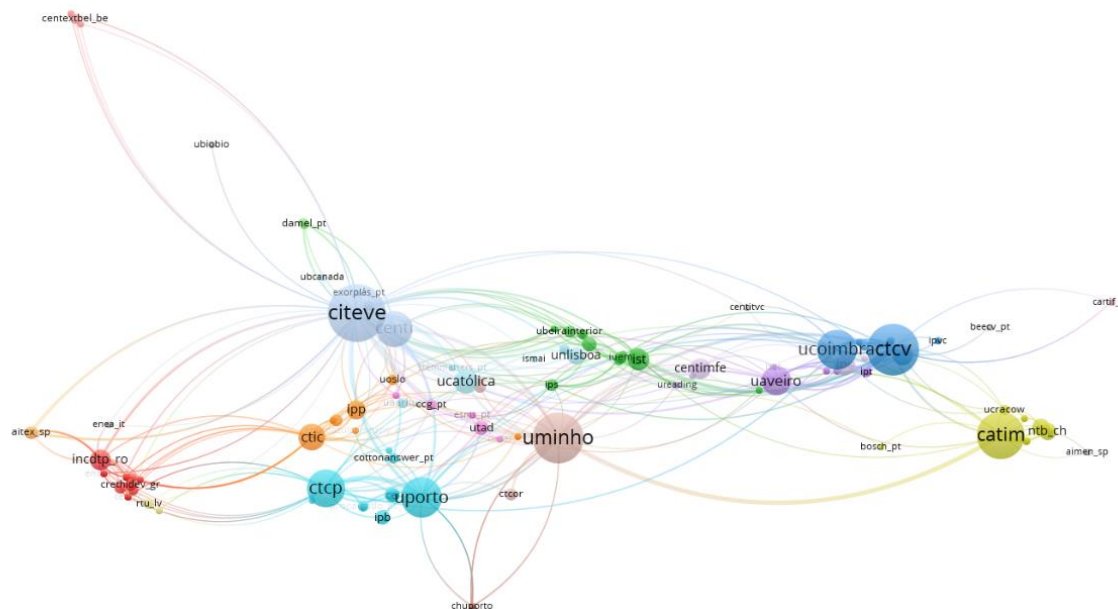


Figure 3. TCs coauthoring network

The central position of HEIs and their R&D centers in co-authoring scientific publications, particularly within Portugal's R&I networks, is believed to stem from several interconnected factors. Firstly, a significant reason is the cultural gap between academia and industry in Portugal, which is closely tied to the consistently low representation of highly qualified staff, such as PhD holders, within firms [81]. Despite the perceived abundance, Portugal actually faces a shortage of doctorate holders in many sectors, a challenge that public policies need to address to attract, retain, and integrate PhDs into the economy's modernization. This context often means that firms lack the internal scientific capacity to engage in academic-level co-authorship. Secondly, firms tend to prioritize immediate commercial viability of research

results, which may or may not be mediated by intellectual property protection mechanisms [82]. This focus means that the research outcomes generated through collaboration with firms might not always be sufficiently systematic or academically innovative to meet the rigorous publication standards of academic journals. This contrasts with the inherent goal of HEIs to produce publishable, academically recognized research [83]. Thirdly, the central position of HEIs and their R&D centers in co-authoring spaces is a common characteristic in networks involving public research organizations [19, 84]. This reflects their foundational role in generating basic and applied knowledge that is often disseminated through scientific publications.

The collaborative R&I activities generating scientific publications generally follow physical proximity. For example, the collaboration space of the Vines&Wines CoLAB overlaps with that of the CITAB R&D center, both of which are based in the same region. Additionally, CTCV has a close ‘collaboration space’ with the University of Coimbra, which is geographically close to this TC. Often, the ‘collaboration spaces’ follow thematic proximity. For example, forestWISE and GreenCoLab (geographically distant) share a focus on biotechnology. Also, the space shared between CITEVE, CTIC, and CTCP is posited to derive from the closeness of R&D topics involved in the leader, footwear, textile, and clothing industries (CTIC being geographically distant).

4-3- Social Network Analysis

The analysis of social networks was performed at two levels [85]: i) the network level, i.e., at the level of the full CoLAB and TC ecosystems (c.f. Figures 2 and 3), and ii) the node level, i.e., at the level of the individual organizational networks (to assess the relative significance of nodes within the individual CoLAB and TC networks). The ecosystem SNA metrics are shown in Table 4. The organizational SNA metrics for the CoLABs and TCs in their respective individual networks are summarized in Tables 5 and 6, respectively.

Table 4. SNA metrics for ecosystems

	CoLABs	TCs
No. of nodes	257	185
No. of links	2098	1326
Diameter	5	4
Density	0.03	0.04
Average geodesic distance	2.85	2.70
Clustering coefficient	0.84	0.83
Small worldness	8.99	8.65
Centralization	0.366	0.384

Table 5. Average centrality metrics for individual CoLAB networks

	MORE	Vines&Wines	DTx	GreenCoLab	forestWISE	+Atlantic	Mean
Freeman node betweenness	2769	1789	3942	11943	4612	4218	4879
Freeman degree	24	33	38	101	63	36	49
Closeness	0.368	0.399	0.406	0.547	0.471	0.421	0.435

Table 6. Average centrality metrics for individual TC networks

	CATIM	CTCV	CITEVE	CTCOR	CENTIMFE	CTIC	CTCP	Mean
Freeman node betweenness	2189	2382	7066	5	101	1600	1959	2186
Freeman degree	2	39	77	3	10	27	30	27
Closeness	0.427	0.451	0.590	0.370	0.400	0.451	0.493	0.455

Compared with TCs, CoLABs have more nodes and links, indicating a higher level of complexity, potentially greater connectivity within the ecosystem, and a wider variety of actors [19]. A greater number of nodes implies a broader range of activities and expertise within the ecosystem, which can benefit innovation by fostering cross-disciplinary collaboration and knowledge exchange. In SNA, the diameter represents the longest path between any two nodes (actors) in the network, meaning it takes more steps to connect the most distant participants. The greater diameter of the CoLAB network confirms a more diverse ecosystem with a broader range of actors and expertise [86]. A large, geographically dispersed ecosystem, such as CoLABs, might naturally have a larger diameter than a smaller, localized ecosystem (such as TCs). More links indicate more opportunities for collaboration and communication, which is crucial for successful innovation. The connections within a network, particularly those found in CoLABs, are vital for enabling the smooth and efficient circulation of knowledge, innovative ideas, and crucial resources throughout the entire ecosystem [19].

This emphasis on creating and leveraging extensive, diverse connections allows CoLABs to move beyond mere scientific and technological service provision towards a collaborative knowledge development process, fostering more dynamic and effective interactions between science, industry, and society. The similar network density observed for CoLABs and TCs suggests a comparable level of interconnectedness between the actors involved and a similar frequency of interactions and collaborations between different actors [18].

CoLABs and TCs have similar average geodesic distances, suggesting a comparable level of separation between actors within those ecosystems and a comparable efficiency in information dissemination [87]. Ideas and knowledge might travel with similar steps between actors on average and comparable ease of establishing collaborations between actors in both ecosystems. In SNA, a clustering coefficient measures the degree to which nodes (actors) in a network tend to cluster together, forming tight-knit groups or "communities". Similar network clustering coefficients suggest an equivalent level of community formation within their corresponding ecosystems [88]. The high clustering coefficients indicate strong connections and frequent community interactions, potentially fostering deep collaboration and knowledge exchange within those groups. This means that actors within both CoLAB and TC networks tend to form strong connections and engage in frequent interactions within these well-defined communities. As seen in their co-authoring networks (Figures 1 and 2), both CoLABs and TCs show clear, distinct communities. This strong within-group connectivity can foster deep collaboration and intensive knowledge exchange among members of these specific clusters.

CoLABs have greater small worldness, indicating that actors tend to form tight-knit communities where they are well-connected and where information can still travel relatively efficiently between any two actors in the network [18]. Thus, CoLABs act as bridging actors that allow knowledge and collaboration to flow across the network [66]. Combining solid communities and efficient information flow across the network can greatly benefit innovation. Ideas can be developed within communities and shared more broadly, leading to cross-pollination and the potential for breakthroughs. CoLABs have lower network centralization, indicating a more even distribution of connections [89]. Although CoLABs act as bridges, actors can potentially interact and share knowledge more directly with each other. Thus, there might be more opportunities for diverse partnerships and collaboration across different ecosystem parts.

Knowledge sharing and network location impact an organization's innovative success [90]. Central positions within an R&D network correlate with higher innovation rates [91]. Key individuals or departments can bridge different groups within the network, facilitating knowledge exchange [18]. This is more evident for CoLABs (Table 6 vs. Table 5). Additionally, CoLABs have a higher degree of centrality than TCs, i.e., they have more connections within their individual networks. More connections can indicate greater potential influence within the network [18]. Thus, CoLABs can potentially reach a larger audience and spread information or ideas more easily. Additionally, having many connections can provide CoLABs with access to a wider range of information and resources within the network. CoLABs and TCs have similar closeness centrality, suggesting they share some key characteristics in their network positions. Both are positioned relatively centrally within the network [92]. They are not isolated on the fringes but have connections that allow them to reach most other actors efficiently. Both can potentially access information from various parts of the network with similar ease.

5- Discussion

The core-periphery dynamic in Portugal creates significant obstacles that demand strategic government intervention. These obstacles, typical of peripheral economies, include established institutional frameworks and networks that hinder development [30], limited access to skilled human capital, and a lack of effective collaboration between industry and academia [35]. CoLABs are an innovative policy instrument designed to address these challenges, specifically by executing collaborative R&I agendas aimed at creating economic and social value through the promotion of highly qualified and scientific jobs.

CoLABs are effectively fulfilling their mandate by significantly enhancing knowledge co-production with a diverse array of R&I ecosystem actors, both in terms of the sheer volume of output and the variety of participants involved, and by demonstrably improving the diffusion of this knowledge through active dissemination efforts and engagement via social media. This success is largely attributable to their unique organizational structure, specifically their associates' makeup and the scientific qualifications of their workforce. The collaborative R&I activities generally follow physical proximity, which supports the regional relevance of both CoLABs and TCs, contradicting the findings of Minguillo et al. [48]. Establishing and propagating collaborative R&I centers involving science, industry, and government have demonstrated their significance as key contributors to regional innovation systems [93]. In fact, geographic proximity has been shown to be more beneficial for facilitating knowledge transfer than the size of an organization [94]. This means that how close collaborators are physically can be a more significant advantage for sharing knowledge effectively than simply how large or small the organizations involved are.

Compared to more traditional science-industry interface set-ups, the knowledge production and transfer dynamics of CoLABs present both opportunities and challenges. Analyzing this through a Network Orchestration lens highlights the need for proactive policymaking to unlock their full potential. CoLAB's network boasts many actors (diverse expertise) and a decentralized structure (encourages diverse collaborations). This fosters knowledge exchange and empowers individual actors, potentially leading to unexpected breakthroughs. However, managing such a large network effectively

requires orchestration strategies. CoLABs demonstrate efficient information flow within communities (strong clustering) and, through them, act as ‘bridging actors’ (high betweenness centrality) [95]. The presence of a strong balance between tightly-knit communities and efficient information flow throughout a network is essential for fostering both incremental and radical innovation. This means that for an ecosystem to truly thrive innovatively, it needs two key elements to work in harmony: strong communities (fostering incremental innovation), and efficient information flow (enabling radical innovation). However, the network size can hinder communication and collaboration.

Network Orchestration Theory emphasizes identifying and empowering ‘bridging actors’ (orchestrators) to facilitate collaboration across diverse communities. As hub organizations, CoLABs act as catalysts for value creation and knowledge exchange within their networks. They achieve this by occupying a more central broker position than TCs within the value chain and actively leading value-generating activities based on knowledge creation and transfer [53]. CoLABs naturally foster connections at the R&I ecosystem level and can play a critical role in managing complexity by i) identifying and empowering actors with high betweenness and degree centrality to facilitate resource flow and coordination; ii) optimizing communication channels and ensuring that critical nodes are well connected; iii) promoting collaboration within communities while ensuring that they remain integrated into the broader network; and iv) encouraging distributed problem-solving and innovation while designing governance mechanisms that support decentralized decision-making and trust. By leveraging these strategies, CoLABs can enhance value creation, dynamic adaptation, and overall network resilience, ultimately fostering groundbreaking innovation.

Nimble, focused intermediary entities can play a crucial role in aligning the availability of ideas and knowledge with demand, fostering improved collaboration between science and industry. When considering establishing new collaborative entities or reorganizing existing ones, policymakers should prioritize initiatives that are driven by stakeholders, such as CoLABs. This recommendation is based on the observation that such initiatives tend to have a higher likelihood of success and increased viability [96]. Additionally, Arnott et al. [97] identified a correlation between the level of interaction between researchers and practitioners and the utilization of scientific knowledge. Stakeholder-driven initiatives can potentiate this. Nevertheless, Arnott et al. [97] reported that not all research requires intensive collaboration to be helpful, and not every collaborative research project leads to practical application.

Policymakers should also take into account certain concerns raised by academics when designing or restructuring collaborative entities such as CoLABs. The increasing focus by policymakers and funders on the direct ‘serviceability of science’. Academics are worried that this emphasis on immediate utility and practical application could potentially reduce or ‘deplete’ funding available for ‘basic’ or fundamental research [98]. This implies a tension between research driven by specific societal or economic problems and curiosity-driven inquiry that forms the bedrock of scientific knowledge, regardless of its immediate applicability. Also, the contemporary idea that science achieves a greater impact by engaging closely with non-scientists (such as industry, government, or the public) challenges a long-held belief within the academic community. Traditionally, it was believed that science delivered the most significant benefits to society when it operated with a certain degree of independence and autonomy [99]. This highlights a potential philosophical conflict between fostering broad collaborations and maintaining scientific independence. Additionally, the risk of overinvesting in new infrastructures should be considered carefully, as exemplified by the case of some science and technology parks [100] and as alerted by the Catapult centers. Another possible obstacle to the evolution of new coproduction paradigms is the substantial commitment of time and resources demanded from participants, as highlighted by Lemos et al. [101]. This challenge may be further compounded by the limited expectations and weariness experienced by non-researchers [102]. Policymakers, funders, and managers should consider all these aspects at CoLABs to optimize their impact on society.

From a theoretical point of view, our study contributes to tackling the lack of perspectives on policies to structure university-industry collaboration in peripheral economies characterized by low levels of knowledge co-creation and diffusion, and of human resources integration in the industry sector. In particular, in the light of the Network Orchestration Theory, the processes by which CoLABs, as value-occupying hub organizations, promote cross-organizational networks to achieve engaged and impactful university-industry interactions are elucidated. Thus, the potential of emerging and alternative configurations within the Triple/Quadruple Helix model is illuminated.

Studying scientific collaboration networks helps policymakers identify areas where support is needed and where new opportunities can be fostered [10]. Thus, from a practical standpoint, policymakers can use our study results to adapt public policies to further tap into the potential of highly qualified human resources to promote more productive and dynamic (regional) R&I ecosystems. The collected empirical evidence can potentially be used to consider the aggregation of existing entities and/or the creation of new entities to achieve higher efficacy and efficiency in competency transfer partnerships. Large, decentralized networks can be challenging to coordinate. Thus, the public agencies promoting these partnerships and the CoLAB governance structure should develop strategies to facilitate communication and collaboration across CoLABs ecosystem. Additionally, establishing a common vision for the ecosystem and creating incentives for collaboration can encourage actors to work together toward more engaged and impactful innovation.

As a limitation, this research might be biased towards the visibility of thematic areas with higher research and scientific publication intensity. Future studies should explore indicators for knowledge and technology co-production complementary to scientific publications and how CoLABs empower businesses and society to actively participate in co-creating science and innovation.

6- Conclusion

The nature of existing intermediary organizations and networks in peripheral economies is closely intertwined with key barriers to technology transfer and innovation. These barriers include limitations in the availability and quality of human resources and knowledge, further exacerbated by a general unwillingness of firms to collaborate with universities. Through the lens of Network Orchestration Theory, we examine the role of the Portuguese CoLABs, a newly formed type of university-industry interface organization rooted in the potential of highly qualified human resources, in fostering knowledge coproduction between HEIs, industry, and other actors and its dissemination to society at large. Our findings highlight the importance of thematically and organically flexible collaboration networks for addressing regional and national priorities. This fosters broader engagement and output than traditional approaches do. In this context, CoLABs act as ‘vectors of change’ by creating a critical mass of expertise to address complex challenges such as digital transformation and green solutions.

Thus, we observe a cultural shift toward enhanced coproduction within CoLABs, with scientists increasingly embracing this collaborative approach. The geographical spread of CoLABs highlights their regional relevance, with HEIs playing a central role in potentially shaping new regional dynamics. Compared with traditional TCs, CoLABs engage in more public dissemination, social media outreach, and policy influence, suggesting a potentially broader societal impact. Network Orchestration Theory reveals CoLABs as bridging, value-occupying orchestrators. They lead value creation and promote collaboration within their networks. However, effective strategies are crucial for managing these large, decentralized networks. CoLAB networks exhibit characteristics conducive to enhanced innovation, with high connectivity, diverse collaborations, and strong communities. This allows for both incremental and radical innovation. Thus, CoLABs offer significant potential but require strategies to enhance communication and coordination across their networks. Policymakers and CoLAB governance structures can use this evidence to optimize the CoLAB ecosystem by leveraging the identified opportunities and mitigating potential challenges. In particular, establishing a shared vision for the ecosystem, developing strategies to improve communication and collaboration within the CoLAB network, and creating incentives encouraging actors to collaborate on impactful innovations.

7- Declarations

7-1- Author Contributions

Conceptualization, J.S.; methodology, J.S.; validation, J.S. and A.B.; formal analysis, J.S. and A.B.; investigation, J.S. and A.B.; resources, J.S.; data curation, J.S. and A.B.; writing—original draft preparation, J.S.; writing—review and editing, J.S. and A.B.; supervision, J.S.; project administration, J.S. All authors have read and agreed to the published version of the manuscript.

7-2- Data Availability Statement

The data presented in this study are available on request from the corresponding author.

7-3- Funding

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7-5- Institutional Review Board Statement

Not applicable.

7-6- Informed Consent Statement

Not applicable.

7-7- Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

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