COLLABORATIVE NETWORKS OF FIRMS AND INNOVATIVE CLUSTERS IN THE DIGITAL ECONOMY: A BIBLIOMETRIC ANALYSIS

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Abstract: *This study examines the development of research on inter-firm collaborative networks and innovation clusters in the digital economy through a bibliometric analysis of scientific literature. Its main objective is to identify key research trends, analyze the evolution of publications over time, and explore collaboration patterns among authors, institutions, and countries. The study also investigates emerging topics related to digital innovation ecosystems. As digital transformation continues to reshape economies and societies, collaboration between firms, universities, and research organizations has become increasingly important for innovation, knowledge sharing, and regional development. Drawing on cluster theory, innovation networks, and open innovation perspectives, this study provides an overview of how these concepts have evolved within the context of the digital economy. The analysis follows the PRISMA 2020 framework and is based on peer-reviewed articles and review papers indexed in the Web of Science Core Collection between 2000 and early 2026. Bibliometric techniques and network visualizations were applied using Bibliometrix to examine co-authorship relationships, co-citation networks, keyword co-occurrence patterns, and thematic structures. The findings show a significant increase in scholarly interest in collaborative networks and innovation clusters, particularly in recent years, as digital technologies and Industry 4.0 applications have become more widespread. The analysis highlights the most influential countries, institutions, and research collaborations in the field, while identifying major themes such as knowledge spillovers, university–industry cooperation, digital ecosystems, and regional innovation policies. By bringing together a fragmented body of literature, this study offers a comprehensive overview of the field and identifies several directions for future research. In particular, the results point to the need for more multi-level analytical approaches, greater integration of artificial intelligence in network analysis, and more longitudinal studies comparing the evolution of digital innovation ecosystems across different regions. These findings may support both future academic research and evidence-based regional development policies.*

Keywords: *Bibliometric analysis; Web of Science; Digital innovation ecosystems; Open innovation; PRISMA protocol; Industry 4.0.*

JEL Classification: *L14; O31; O32; O36; R11*

1. Introduction

This paper provides a systematic bibliometric analysis of research on collaborative networks of firms and innovation clusters in the digital economy. As digital technologies continue to transform economic and innovation processes, understanding how collaboration networks evolve and contribute to innovation has become increasingly important. Accordingly, the study focuses on six key aspects of the literature: the evolution of research output over time, the main thematic areas, co-authorship and institutional collaboration patterns, collaboration dynamics within innovation ecosystems, emerging research trends, and gaps that warrant further investigation.

2. Theoretical Background

Collaborative networks and innovative clusters represent key components of the digital economy and contemporary innovation ecosystems, facilitating knowledge exchange, technology transfer, open innovation, and regional competitiveness. Theoretical developments in this field have evolved through several interconnected perspectives, reflecting broader technological, economic, and industrial transformations. The main theoretical frameworks that have shaped research on collaborative networks and innovative clusters are summarized in Table 1.

Table 1: *Theoretical perspectives on collaborative networks and innovative clusters*

Theoretical perspective	Main focus	Contribution/Relevance
Cluster Theory	Geographic concentration of firms and institutions	Evolution toward digitally connected and hybrid clusters
Innovation Network Theory	Relationships, knowledge flows, and social capital	Real-time collaboration and reduced geographical constraints
Open Innovation	Knowledge exchange across organizational boundaries	Platform ecosystems and co-creation of innovation
Smart Specialization (S3)	Place-based regional innovation policies	Alignment of regional strengths with digital and green transitions
Digital Economy Frameworks	Digital infrastructure, governance, and regulation	Institutional support for data-driven innovation ecosystems

Source: Authors' own elaboration

One of the most influential perspectives is *Cluster Theory*, introduced by Porter (1998), which initially focused on the competitive advantages generated by the geographical concentration of interconnected firms and supporting institutions. While traditional clusters relied primarily on physical proximity and localized interactions, recent developments have led to the emergence of hybrid clusters in which digital platforms complement geographical concentration, enabling local firms to participate in global innovation and value networks. This evolution reflects the transition from the industrial logic of earlier production systems toward the digitally interconnected environments associated with Industry 4.0 - 5.0.

A complementary perspective is provided by *Innovation Network Theory*, which examines the relational structures, social capital, and collaborative ties that facilitate collective learning and innovation. Earlier forms of collaboration were often based

on relatively stable and contractual relationships among organizations. However, the widespread adoption of digital technologies has transformed innovation networks from static, contract-based alliances into dynamic and data-driven ecosystems characterized by real-time communication, continuous knowledge exchange, and reduced geographical constraints.

The development of *Open Innovation frameworks* further expanded the understanding of collaborative innovation processes. In contrast to traditional closed innovation models, where research and development activities were conducted primarily within organizational boundaries, open innovation emphasizes the strategic value of knowledge flows across firms, universities, research institutes, and other stakeholders. The increasing technological complexity of digital transformation (Industry 4.0) has reinforced the importance of these collaborative arrangements, particularly through platform-based ecosystems that support co-creation and distributed innovation.

At the policy level, *Smart Specialization Strategies* (S3) have emerged as a prominent framework for regional innovation development, particularly within the European Union. Based on a place-based approach, S3 seeks to align regional strengths and capabilities with strategic innovation priorities, while supporting both digitalization and sustainability objectives. As a result, these strategies have become important instruments for advancing the twin (digital and green) transition across European regions.

More recently, *Digital Economy frameworks* have provided a broader institutional and regulatory perspective on innovation and collaboration. Developed by international organizations such as the European Union and OECD initiatives these frameworks establish strategic priorities, measurement indicators, and governance principles related to digital infrastructure, data governance, cross-border digital trade, digital skills, and the ethical deployment of artificial intelligence.

Although collaborative networks and innovative clusters have attracted increasing scholarly attention, a comprehensive understanding of the field's intellectual structure and development trajectory remains limited. Examining how research has evolved over time, which topics have received the greatest attention, and where important gaps persist is therefore of both theoretical and practical relevance. In response to these challenges, the present study applies a standardized bibliometric methodology to investigate the evolution of research on collaborative networks and innovative clusters in the context of the digital economy.

3. Methodology

3.1. Research Design – PRISMA 2020

To address the stated objectives and ensure a transparent and replicable analytical process, this study follows the PRISMA 2020 guidelines to conduct a systematic literature review. This internationally recognized framework provides clear guidelines for identifying, screening, and selecting relevant studies, thereby enhancing the methodological rigor and consistency of the review process.

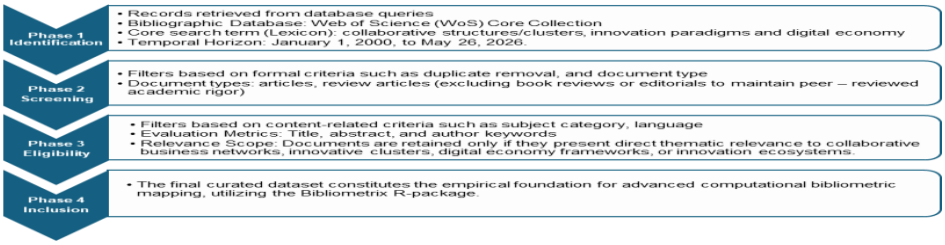

Figure 1: PRISMA 2020 literature selection process
Source: Authors' own elaboration

As illustrated in Figure 1, the literature selection process followed the four sequential phases recommended by the PRISMA 2020 framework: identification, screening, eligibility assessment, and inclusion. This structured approach ensured a transparent and systematic selection of publications relevant to the research objectives.

*Phase 1: Identification***.** To retrieve the relevant literature, a Boolean search query was developed and applied to the WoS Core Collection database. The search was conducted using the Topic Search (TS) field, which examines titles, abstracts, author keywords, and Keywords Plus. The analysis covered publications indexed between 2000 and 2026, providing a longitudinal perspective on the evolution of research in the field. To capture the complexity of the research domain, the search strategy combined three interrelated dimensions: collaborative networks and clusters, innovation-related concepts, and the digital economy context. The following search string was used: TS=(("*collaborative networks*" OR "*firm networks*") AND ("*innovation clusters*" OR "*industrial clusters*") AND ("*digital economy*" OR "*innovation ecosystems*" OR "*open innovation*" OR "*regional innovation systems*" OR "*digital transformation*")).

Phase 2: Screening. Following the initial data extraction, the retrieved records were subjected to a screening process aimed at ensuring the quality and consistency of the dataset. Duplicate records were identified and removed, while the inclusion criteria were restricted to peer-reviewed journal articles published in English. Editorials, book reviews, conference abstracts, and other non-peer-reviewed publications were excluded, together with records published in languages other than English.

Phase 3: Eligibility. The records remaining after the screening stage were evaluated against the predefined eligibility criteria through a review of titles, abstracts, and author keywords. Only studies providing direct theoretical or empirical insights into collaborative networks, innovation clusters, and digital economy-related processes were retained. Publications with limited relevance to the research scope were excluded from further analysis.

Phase 4: Inclusion. Following the screening and eligibility assessment, the remaining records were included in the final dataset. The selected publications were exported and standardized for bibliometric analysis using the Bibliometrix R-package. This dataset constituted the basis for the subsequent analyses, including co-authorship networks, co-citation analysis, and thematic mapping.

3.2. Research Matrix and Analytical Mapping

To ensure methodological consistency, the research objectives were aligned with specific bibliometric techniques implemented in the Bibliometrix and Biblioshiny (R-

package) environment. This alignment is summarized in the matrix below, which links each objective to the corresponding analytical approach and empirical indicators.

Table 2: Research Matrix: Objectives, Bibliometric Methods, Empirical Indicators

#	Research Objective	Bibliometric Method / Tool	Core Metrics & Empirical Indicators	Location in Paper
I	Temporal Evolution	Descriptive Bibliometrics & Longitudinal Mapping	Annual Scientific Production, Annual Growth Rate, Document Average Age, Trend Topics Trajectories	*Section 4.1 & 4.4*
II	Core Thematic Domains	Conceptual Structure Network Analysis	Keyword Co-occurrence Mapping, Callon's Centrality & Density Quadrants, Factorial MCA Space	*Section 4.4 & 4.5*
III	Co-authorship & Affiliations	Social Structure Mapping & Geographic Metrics	Most Productive Authors, Relevant Affiliations, Corresponding Author's Countries (SCP/MCP), Country Citations	*Section 4.2 & 4.3*
IV	Innovation Ecosystem Dynamics	Intellectual Structure & Citation Topology	Author and Document Co-citation Networks, Reference Metrics, Average Citations per Document, Density View	*Section 4.5 & Chapter 6*
V	Emerging Frontiers	Chronological Lexical Inferences	Trend Topics Mapping (2019–2026), Frontier Keyword Intensity Tracking (AI, Digital Infrastructures)	*Section 4.1, 4.4 & 7*
VI	Literature Gaps	Multi-Network Intersection Analysis	Structural Fragmentations (Social vs. Conceptual), Thematic Map Quadrant Intersections (Emerging vs. Niche)	*Section 4.6 & 7*

Source: Authors' own elaboration

3.3. Data Sources and Collection Strategy

The empirical data for this science mapping study were retrieved from the Web of Science (WoS) Core Collection, including the Science Citation Index Expanded (SCIE), Social Sciences Citation Index (SSCI), and Conference Proceedings Citation Index (CPCI). This database was selected due to its extensive coverage of peer-reviewed literature in economics, management, and related fields, as well as its robust citation indexing system.

The data extraction was conducted in May 2026 using a Boolean search strategy applied to the Topic field, which includes titles, abstracts, and author keywords. To ensure a comprehensive coverage of the research field, the analysis period was defined from 2000 to May 2026, capturing the full evolution of studies related to the digital economy and innovation ecosystems.

The retrieved records, including full bibliographic information and cited references, were exported from WoS in plain text (.txt, tab-delimited) and BibTeX (.bib) formats. These datasets were subsequently used as input for bibliometric analysis and visualization in the Bibliometrix environment.

To ensure a homogeneous and high-quality dataset, clear inclusion and exclusion criteria were applied during the screening stage of the PRISMA 2020 protocol.

• Document type: Only peer-reviewed journal articles were included in the analysis. book reviews, conference abstracts without full methodological details, and letters to the editor were excluded to ensure the reliability and comparability of the dataset.
• Language: The search was limited to publications written in English to ensure consistency in analysis and comparability of results across studies.
• Subject areas: The selection was restricted to journals indexed in relevant fields, including Business, Economics, Management, Industrial Engineering, Operations Research, and Social Sciences. Studies focused exclusively on technical or engineering aspects without explicit analysis of collaborative networks or innovation clusters were excluded.
Studies were identified using the WoS Core Collection database.

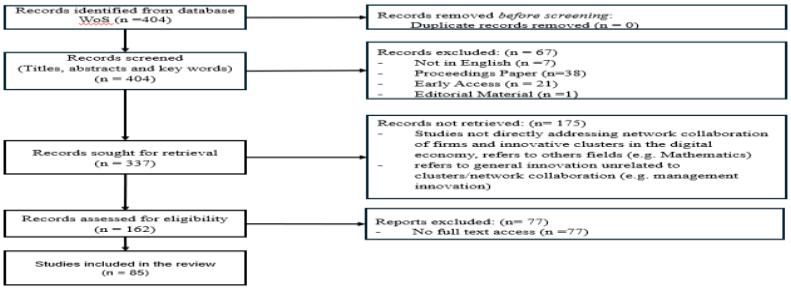

Figure 2: PRISMA 2020 flow diagram of the study selection process
Source: Authors' own elaboration

3.4. Bibliometric Analysis Tools and Analytical Framework

The bibliometric analysis of the 85 selected documents was conducted using Bibliometrix and Biblioshiny (R package, version 4.1). These tools were employed to support the full science mapping process, including data processing, descriptive analysis, and network visualization. The software was used to calculate key bibliometric indicators such as annual scientific production, growth rates, and Trend Topics analysis. It also enabled the construction of co-authorship networks, keyword co-occurrence networks, and co-citation networks at both author and document levels. In addition, Biblioshiny was applied to perform Multiple Correspondence Analysis (MCA), allowing the identification of latent thematic structures and the visualization of conceptual clusters within the dataset.
The final dataset was analyzed using a multi-level bibliometric approach covering temporal, social, intellectual, conceptual, and multivariate dimensions of the field. • Temporal analysis: Annual publication trends were examined to identify the evolution and growth of research on the digital economy over time. • Social structure analysis: Co-authorship networks were analyzed at author, institutional, and country levels. International collaboration was assessed using SCP and MCP indicators. • Intellectual structure analysis: Co-citation and bibliographic coupling analyses were conducted to identify the main intellectual foundations of the field based on 6,407 references. • Conceptual structure analysis: Keyword co-occurrence analysis and Callon's strategic diagram were used to classify themes into motor, basic, niche, and emerging clusters based on centrality and density. • Thematic and multivariate analysis: Multiple Correspondence Analysis (MCA) was applied to identify latent thematic structures and relationships between research clusters.

4. Results

The empirical outputs derived from the bibliometric mapping are structured systematically below, decoding the domain's intellectual, geographic, social, and latent conceptual topographies.

4.1. Evolution of Publications and Research Trajectory

The bibliometric analysis was performed on a dataset of 85 documents published between 2017 to 2026, distributed across 49 distinct sources. Although the search covered the period from 2000 to 2026, no documents meeting the selection criteria were identified before 2017. The field demonstrates an outstanding intellectual dynamic, characterized by an *Annual Growth Rate of 24.14%* and a contemporary *Document Average Age of 3.22 years*.

The evolution of annual scientific production indicates a clear transition from an emerging research topic to a rapidly growing field of study, which can be divided into three distinct phases.

• *Inception Phase (2017–2019).* Research output was limited during this period, increasing from a single publication in 2017 to four publications in 2019. This suggests that research on digital ecosystems and firm networks was still at an early stage of development.

• *Growth Phase (2020–2023).* Publication output increased significantly, reaching seven articles in 2020 and peaking at twelve articles in 2022. The slight decline observed in 2023 (10 articles) may indicate the consolidation of key research themes before a new period of expansion.

• *Expansion Phase (2024–2026).* The field reached its highest productivity in 2024, with 19 publications representing 22.3% of the total dataset. Although publication counts decreased to 13 articles in 2025 and 7 articles in 2026, this trend should be interpreted with caution, as the 2026 data reflect only the partial coverage of the ongoing year.

The evolution of publication output was accompanied by noticeable changes in the thematic focus of the literature, as reflected by the Trend Topics analysis. Between 2019 and 2022, research was primarily centered on traditional management and business concepts, with particular attention to "*competition*" (peaking in 2021), "*collaboration*", and "*management*" (peaking in 2022), reflecting interest in the adaptation of firms to collaborative networks. By 2023, the literature showed a stronger focus on "*open innovation*" and organizational "*performance*", suggesting a consolidation of research around innovation-related outcomes. From 2024 onwards, the thematic emphasis shifted toward knowledge-based approaches and digital technologies, with increasing attention to "*digital*" infrastructure and "*artificial intelligence*", which emerged as some of the most prominent topics in 2026.

4.2. Authors, Countries, and Institutions

4.2.1. Institutional Centers of Excellence

Research output is concentrated in a relatively small number of institutions, with a strong presence of universities from Northern and Western Europe, as well as Italy:

• *University of Vaasa (Finland):* The most productive institution in the dataset, with 9 publications.

• *Vrije Universiteit Amsterdam (Netherlands):* Ranked second, with 6 publications.
• *Institutions with 5 publications*: Coventry University and the University of Birmingham (United Kingdom), together with the University of Bologna and the University of Macerata (Italy).
• *Institutions with 4 publications*: Aarhus University (Denmark), Luleå University of Technology (Sweden), Nanjing University of Science and Technology (China), and the University of Messina (Italy).

4.2.2. Geographic Dominance and Collaboration Intensity

Country-level publication patterns were examined using the corresponding author's country and the distribution of Single Country Publications (SCP) and Multiple Country Publications (MCP). *Italy* recorded the highest number of publications (23 documents). Most studies were produced through domestic collaboration (15 SCPs and 8 MCPs), although international collaboration also played an important role. *The United Kingdom* ranked second with 11 publications and showed a high level of international collaboration, with 8 MCPs and 3 SCPs. Approximately 72.7% of UK publications involved international co-authorship. *China and Germany* exhibited more domestically oriented publication profiles. China recorded 7 publications (6 SCPs and 1 MCP), while Germany produced 6 publications (4 SCPs and 2 MCPs). Among the Nordic countries, *Sweden* displayed a balanced collaboration profile (3 SCPs and 3 MCPs), whereas all publications from *Finland* involved international collaboration (4 MCPs and 0 SCPs).

4.2.3. Citation Impact

Citation patterns do not fully mirror publication output. *Italy* recorded the highest citation count, with 1,273 citations, indicating a strong bibliometric impact within the field. *Sweden* ranked second with 804 citations, followed by the United Kingdom with 628 citations. *The United States* (329 citations), *France* (318 citations), and *China* (279 citations) also recorded substantial citation levels. Additional contributions were observed for *Germany* (185 citations), *Denmark* (100 citations), *Spain* (75 citations), and the *Netherlands* (64 citations).

4.3. Collaboration Networks

The collaboration patterns in this field were examined at both the country and author levels. The dataset includes 298 authors, while single-authored publications are relatively rare, with only seven authors publishing individually. The average number of co-authors per document is 3.59, and 45.88% of the publications involve international collaboration, highlighting the importance of cross-border research partnerships in this domain.
Despite this collaborative profile, the Author Collaboration Network reveals a fragmented structure composed of several relatively independent research groups rather than a single, highly interconnected community.
The largest collaboration clusters can be interpreted as follows:
• *Cluster 1:* Includes Tuertscher P. and Philipp P., together with Aalbers R. and Berends H., focusing on the structural dynamics of digital system.
• *Cluster 2:* Centers around Kraus S., Bouncken R.B. and Alghani K.A., with research interests related to digital entrepreneurship and platform-based strategies.

• *Cluster 3:* Includes Gomes E., Angwin D., Borde S.M., and Asgari O., whose collaboration is mainly associated with corporate strategy, organizational agility, mergers and acquisitions, and strategic alignment in digital environments.

In addition to these major communities, several *smaller collaboration groups* remain relatively isolated from the central network. Several smaller research groups are also visible, including collaborations between Adomako S. and Amankwah-Amoah J. (emerging markets), as well as Bogers M. and Burcharth A. (open innovation paradigms), which remain weakly connected to the larger collaboration network.

Overall, the collaboration network indicates that although international scientific cooperation is relatively high, the intellectual structure of the field remains decentralized. The limited connectivity between the principal research communities suggests opportunities for stronger interdisciplinary and international collaboration, which could facilitate greater knowledge integration and accelerate the consolidation of the research domain.

4.4. Keyword Analysis and Conceptual Structure

A total of 340 unique Author Keywords were identified in the dataset.

4.4.1. Co-occurrence and Thematic Clustering

The keyword co-occurrence network reveals two main thematic clusters.

• *The Strategic Innovation & Ecosystems Cluster:* This cluster is centered on keywords such as *"innovation"*, *"performance"*, *"capabilities"*, and *"business"*. It links tightly with terms like *"ecosystem"*, *"digital platforms"*, and *"strategy"*, addressing how traditional industrial networks evolve into digital platform environments.

• *The Digital Transformation & Knowledge Capabilities Cluster*: This cluster is characterized by keywords such as "open innovation", "knowledge", and "digital transformation". It integrates with "dynamic capabilities", "SMEs", and "management", exploring how internal organizational adjustments allow smaller firms to leverage external data. A smaller, auxiliary sub-cluster (represented by terms like ”absorptive-capacity” and “research-and-development”) remains tightly embedded within this second macro-cluster, further highlighting the internal mechanisms required for technological adaptation.

4.4.2. Strategic Classification (Thematic Map)

Projecting these terms onto Callon’s Centrality (X-axis relevance degree) and Density (Y-axis development degree) quadrants provides insights into the relative importance and maturity of the identified themes: • Motor Themes (high centrality, high density): These themes include the Entrepreneurial Innovation cluster (“open innovation”, “entrepreneurship”, “dynamic capabilities”) and the Business Ecosystems cluster (“business”, “digital transformation”, “ecosystems”). They represent well-developed and influential themes within the field.

• *Basic Themes (high centrality, low density)***:** This quadrant includes the Institutional Knowledge cluster (“knowledge”, “SMEs”, “collaboration”) and the Firm Performance cluster (“innovation”, “performance”, “capabilities”). These themes are central to the field but remain open to further conceptual development.

• *Niche Themes (low centrality, high density)***:** Represented by topics such as “models”, “supply chain”, “value”, “management”, and “high-tech”, these themes correspond to specialized research areas with relatively limited connections to the broader literature.

• *Emerging Themes (low centrality, low density)*: This quadrant includes keywords such as “absorptive capacity”, “Industry 4.0”, “firms”, “digitalization”, and “value creation”. These topics may represent emerging directions for future research and reflect the growing interest in the application of digital technologies within industrial contexts.

While the strategic thematic map classifies clusters based on their maturity and relevance, it considers each cluster as a single aggregated unit. To obtain a more detailed understanding of the field structure, Multiple Correspondence Analysis (MCA) was applied as a dimensionality reduction technique. This method projects individual keywords into a two-dimensional conceptual space, revealing the underlying dimensions of the data and the conceptual proximity between research themes.

4.4.3. Factorial Analysis (MCA)

The Multiple Correspondence Analysis (MCA) projects the author keywords into a two-dimensional geometric space, explaining 19.67% of the variance on Dimension 1 and 13.21% on Dimension 2. This dimensionality reduction technique groups the literature into three main thematic areas:

• *Institutional and Ecosystem Governance Domain:* This quadrant includes keywords such as “innovation ecosystems”, “governance”, and “sustainability”. It reflects research focused on governance mechanisms and the role of institutional factors in innovation systems.

• *Operational Digitalization and Knowledge Capabilities Domain*: This area includes keywords such as “digital transformation”, “artificial intelligence”, “big data” feed into collaborative R&D processes (“open innovation“,“collaboration“, “value co-creation“), ultimately resulting in enhanced "firm performance". It highlights the increasing focus on digital technologies and organizational capabilities in innovation processes.

• *Entrepreneurship and Strategy Domain:* This group includes keywords such as “entrepreneurship”, “strategy”, and “competition”. It represents the foundational business-oriented literature that underpins research on innovation and digital transformation.

4.5. Bibliometric Maps and Source Concentration

4.5.1. Integrated Analysis: Publication Trajectory and Source Concentration

The cognitive stratification of the literature into governance, operational digitalization, and strategic baselines established via the factorial analysis does not occur in an institutional vacuum. Instead, these latent sub-domains are systematically nurtured and disseminated by specific scholarly communities. To understand how these conceptual structures are structurally institutionalized over time, it is essential to map the outlets through which this scientific discourse is channeled. Consequently, the next logical stage of this investigation shifts from lexical spaces to publication venues, mapping the interaction between research trajectories and source concentrations.

The chronological pathway shifts in absolute alignment with both keyword migrations (*Trend Topics*) and the institutional focus of the *Most Relevant Sources* driving the dataset. The field is highly anchored in innovation and management journals. The absolute flagship presence belongs to *R&D Management with 12 papers*, followed by the *Journal of Business Research (5 papers)* and the *European Journal of*

Innovation Management (4 papers). A stable secondary tier includes Research Policy (3 papers) and *IEEE Transactions on Engineering Management (3 papers).*
When integrated chronologically, the academic dissemination channels closely mirror the evolutionary trajectory of the field, segmenting into three clear developmental phases.
• *Phase 1 (2017–2019): The Strategic Inception*: This initial period was primarily supported by traditional, strategy-driven journals such as the *California Management Review* and *Competitiveness Review*. The scientific discourse during this window focused heavily on how classic *"competition"* (which later reached its baseline volume peak in 2021) and macro-level *"management"* paradigms adapt to early-stage physical networks prior to heavy, data-driven systemic restructuring.
• *Phase 2 (2020–2023): The Operational Transition*: The literature experienced a sharp acceleration heavily fueled by *R&D Management* and the *Journal of Business Research*. These outlets functioned as the primary catalysts for shifting the academic narrative away from generic business administration toward highly structured *"open innovation"* models and empirical corporate *"performance"* metrics (which achieved their tracking peak in 2023).
• *Phase 3 (2024–Mid-2026): The Socio-Technical Acceleration:* The contemporary frontier of the domain is strongly driven by high-level policy and technology management platforms, most notably *Research Policy* and *IEEE Transactions on Engineering Management*. This phase focuses heavily on tracking the concrete implementation of "digital" infrastructure and advanced "artificial intelligence" inside cyber-physical networks and decentralized industrial platforms - a trend that exhibits maximum keyword intensity and theoretical saturation in the first half of 2026.

4.5.2. Density and Intellectual Gravity

The reference *Co-citation Network*—which relies on a vast foundation of *6,407 cited references* and boasts an exceptionally high *Average Citations per Document of 50.87* - uncovers a clear *bi-focal intellectual gravity structure* when viewed via density topography. *The Knowledge Absorption Focus (Primary Thermal Peak)* it is heavily dominated by *Cohen and Levinthal (1990)* (*absorptive capacity*) and *Dahlander and Gann (2010)* (*open innovation search strategies*). This is the densest zone of intellectual authority in the entire dataset. *The Structural Ecosystem Focus (Secondary Thermal Peak):* it forms a tight, high-density belt driven by *Jacobides, Cennamo and Gawer (2018)* (*ecosystem architecture*) and *Adner and Kapoor (2010)* (*co-innovation structures*). Seminal strategic works like *Teece, Pisano and Shuen (1997)* and *Teece (2007)* on dynamic capabilities, alongside digital theory anchors such as *Nambisan et al. (2017)*, form the widespread, lower-density *structural bridges* that hold these two core pillars together.

4.6. Identified Research Gaps

The multidimensional mapping of the literature exposes five critical research gaps that remain unresolved within the current academic discourse:
1.Lack of Multi-Level Analyses (Firm–Cluster–Region): Existing studies focus either on micro-level firm capabilities or macro-level regional ecosystems, leaving a severe shortage of integrated frameworks tracking how firm digitalization scales up to alter cluster performance.
2.Insufficient Integration of AI and Digital Platforms: While "digital transformation" is a mature motor theme, the concrete operational integration of modern *Artificial*

Intelligence (AI), blockchain, and algorithmic platform governance within traditional industrial networks remains superficial.
3.Limitation of Longitudinal Studies: The literature heavily relies on cross-sectional surveys or static bibliometric snapshots, lacking long-term longitudinal research tracking the actual survival rate and lifecycle of collaborative networks over a decade-long digital shift.
4.Lack of Comparative Analysis Between Mature and Emerging Digital Ecosystems: Current models are heavily biased toward advanced knowledge economies (e.g., Nordic Europe or Italy), failing to provide comparative data analyzing how digital ecosystem structures differ when deployed in developing economic contexts.
5.Insufficient Measurement of Collaborative Network Performance: The literature lacks standardized, empirical metrics and quantitative indicators to precisely measure the net performance, ROI, and efficiency of knowledge sharing within digitalized clusters.

5. Discussion

The synthesis of these multidimensional bibliometric findings uncovers several critical paradoxes and structural evolutions that reshape our understanding of clusters and collaborative networks within the digital economy.

5.1. The Evolution of Cluster and Collaborative Network Concepts

The results demonstrate a profound paradigm shift in how business networks are conceptualized: *the transition from relationship-driven geographic clusters to algorithm-driven digital ecosystems.* The longitudinal trend topics (Phase 1 vs. Phase 4) and factorial analysis reveal that between 2019 and 2022, firm collaboration was viewed almost exclusively through a traditional, human-managerial lens anchored in regional proximity (*"management", "collaboration", "competition"*). By 2026, this framework has been increasingly superseded by a more techno-deterministic approach, where "digital" platforms and *"artificial intelligence"* play an increasingly important role in shaping network structures. The historical concept of the industrial cluster, traditionally reliant on physical localization and face-to-face trust, has evolved into a more fluid, boundary-less digital innovation ecosystem where algorithmic compatibility and data interoperability increasingly influence a firm's position.

5.2. The Role of the Digital Economy in Restructuring Interfirm Collaboration

A major structural disconnect is exposed when cross-referencing the conceptual structures with the social networks of the domain. While the thematic map and keyword networks show a highly integrated vocabulary, where terms like *"open innovation"*, *"digital transformation"*, and *"ecosystem"* are universally shared, the Author Collaboration Network reveals noticeable social fragmentation. Scholars are writing extensively about highly open, collaborative, and decentralized ecosystems, yet they are doing so within isolated "academic silos" or closed cliques (e.g., *Tuertscher's clique vs. Kraus's clique*). This lack of direct social collaboration among primary research hubs severely limits the development of a unified empirical framework.
Furthermore, the Thematic Map Network reveals a stark operational imbalance: the intellectual pipelines connecting internal knowledge management to open innovation

are mature and thick, but the pathways leading from abstract ecosystem theories to concrete empirical implementations of Industry 4.0 remain thin and peripheral. This implies that while the digital economy has contributed to reshaping how firms are conceptualized in the literature, a robust, unified framework explaining how these digitalized networks integrate with physical cyber-physical manufacturing systems is still missing.

5.3. Regional Differences and Innovation Ecosystems

The comparison between national volumetric outputs (*SCP* vs. *MCP*) and total citation counts reveals a notable geographic differentiation in how digital transformation is studied

• The "Localized Deep-Dive" Model (Italy and China): Italy leads brute production (23 documents) and citation authority (1,273 citations), while China exhibits a vertical growth surge. However, both nations display heavily domestically-focused publication structures (high *SCP* ratios). This indicates that their research is deeply anchored in rich, local industrial contexts—such as Italy's traditional manufacturing districts undergoing digital modernization or China's state-driven localized platform structures.

• The "Global Integration" Model (United Kingdom and Finland): Conversely, the UK and Finland produce fewer raw documents but act as the primary international collaboration hubs (exhibiting exceptionally high *MCP* ratios, reaching 100% for Finland).

This regional dichotomy implies an intellectual division of labor within global innovation ecosystems: frameworks are often tested and deeply explored within thick, local industrial clusters (the Italian/Chinese model), but their conceptual generalization into universal, cross-border business ecosystem theories largely depends on the highly collaborative, international channels driven by Anglo-Saxon and Scandinavian research hubs.

6. Conclusions

This comprehensive bibliometric study has systematically mapped the intellectual, social, and conceptual trajectory of research at the intersection of the digital economy, firm networks, and innovation ecosystems. By analyzing the structural data from 2017 to 2026, several foundational conclusions can be drawn. The field has transitioned from an emerging niche into an actively expanding academic frontier, driven by an exceptional *Annual Growth Rate of 24.14%* and a contemporary body of literature (average age of 3.22 years). There is a clear evolutionary migration from human-managerial, relationship-driven regional clusters (2019–2022) to technology-driven, boundary-less ecosystems influenced by Artificial Intelligence and digital platform architectures (2025–2026). Europe remains the global epicenter of this debate, characterized by a clear structural dichotomy between the *Localized Deep-Dive* model (led by Italy's heavy citation authority of 1,273, focusing on domestic industrial districts) and the *Global Integration* model (led by the UK and Finland, driving international cross-border knowledge spillovers through high MCP ratios).

For corporate managers and entrepreneurs navigating the digital transformation shift, the results offer critical strategic guidelines.

• *Prioritize Absorptive Capacity over Network Size:* The high density surrounding the Cohen and Levinthal (1990) node suggests that simply joining a digital platform or cluster is insufficient. Managers should actively invest in internal training, digital infrastructure, and data literacy to build the internal "absorptive capacity" needed to convert external ecosystem knowledge into firm performance. • *Transition from Linear Value Chains to Platform Co-creation:* As traditional supply chains migrate toward niche themes on the Thematic Map, managers must restructure corporate strategy around open innovation and value co-creation. Survival in the digital economy requires firms to develop "dynamic capabilities" to act as agile complementors within broader digital platform ecosystems.

For regional policymakers and economic developers, the bibliometric maps provide actionable insights:

• *Foster Digital Interoperability over Physical Proximity:* Traditional cluster policies based strictly on geographic zoning are becoming obsolete. Policymakers must shift funding toward building secure digital infrastructure, regional cloud networks, and AI-driven data hubs that allow SMEs to collaborate across borders.

• *Bridge the Macro-Micro Innovation Gap:* The thin network pathways between macro "innovation ecosystems" and empirical "Industry 4.0" settings highlight a potential policy gap. Governments should launch targeted funding programs (e.g., specialized digital innovation hubs) that help traditional manufacturing SMEs transition into cyber-physical production networks.

7. Limitations and Future Research Directions

While this study provides rigorous, data-driven insights into the digital ecosystem literature, several structural limitations should be acknowledged:

• *Database Selection:* The dataset was strictly extracted from a single indexation framework (WoS), which might exclude relevant conference proceedings or emerging open-access engineering journals indexed in Scopus or Google Scholar.

• *Language Bias:* The search criteria favored English-language documents, potentially underrepresenting highly localized empirical studies published in native languages (e.g. SME clusters in Latin America, Asia, or Eastern Europe). • *Temporal Truncation:* Because the current tracking year is *2026*, the data for the final year represents only a partial snapshot, which limits the ability to calculate a complete annual citation ceiling for the most recent AI-driven literature. Based on the visual paradoxes and thin structural pathways discovered in the bibliometric mapping, three high-impact avenues are proposed for future academic inquiry:

1.Empirical Micro-Foundations of AI in Ecosystems: Future research is encouraged to move beyond abstract discussions of digitalization to investigate the exact mechanisms through which *Artificial Intelligence (AI),* machine learning algorithms, and smart contracts support trust, governance, and value distribution among firms. *2.SME Integration into Industry 4.0 Networks***:** Given that "Industry 4.0" and "SMEs" reside in the emerging quadrant of the Thematic Map, a significant opportunity exists to study *how* small-scale traditional manufacturers can overcome financial and technological barriers to securely connect their physical machinery to global cyber-physical platforms. *3.Cross-Silo Academic Collaboration***:** To address the social fragmentation identified in the Author Collaboration Network, future scholars should build interdisciplinary teams, combining computer science, organizational behavior,

and regional economics, to develop a unified, standardized theory of digital economy governance.

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