Development and Evolution Characteristics of Regional Patents from a Complex Network Perspective: A Case Study of Yangzhou Region (Postprint)

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Abstract

[Purpose / Significance] This study investigates the evolutionary characteristics of regional patents in terms of patentee cooperation and patent application domains from a complex network perspective, providing a reference for research methodologies in regional patent analysis. [Method / Process] Based on invention patent application data from the Yangzhou region during 1985–2020, this research employs complex network methodologies to examine the developmental evolution of regional patents. Patentee cooperation networks and IPC technology classification cooperation networks are constructed for three distinct periods of patent development, with statistical properties including degree distribution, dyad project degree distribution, project size distribution, clustering coefficient, and assortativity being analyzed. [Results / Conclusion] Analysis of the statistical results reveals that cooperation among patentees has not strengthened with the growth of the network (in patent application volume). Across different periods, the majority of patents maintain independent patentees. From the perspective of the IPC technology classification cooperation network, the vast majority of patents involve two IPC technology fields (according to IPC main class), and the interdisciplinary crossover among technology domains covered by patents has not intensified with network development. Furthermore, the project size distribution of the IPC technology classification cooperation network exhibits a power-law distribution across different developmental periods, indicating that, when viewed by IPC main class, the number of patents within each IPC class demonstrates that most patents are concentrated in a minority of IPC technology fields.

Full Text

The Development and Evolution Characteristics of Regional Patents from the Perspective of Complex Networks——A Case Study of Yangzhou Area

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Abstract:
[Purpose/significance] This study examines the development and evolution characteristics of regional patents from the perspective of complex networks, focusing on patentee cooperation and patent application domains, thereby providing a methodological reference for regional patent research. [Method/process] Based on invention patent data from the Yangzhou region spanning 1985–2020, this paper employs complex network methodologies to investigate the developmental evolution of regional patents. Specifically, we construct patentee cooperation networks and IPC technology classification cooperation networks across three distinct periods of patent development, analyzing statistical properties including degree distribution, node-pair degree distribution, act-size distribution, clustering coefficient, and assortativity. [Result/conclusion] Statistical analysis reveals that collaboration among patentees has not strengthened with network growth (increasing patent applications), and most patents remain held by independent patentees across all periods. From the IPC technology classification cooperation network perspective, the vast majority of patents involve only two IPC technology fields (at the IPC classification main class level), and technological cross-fertilization has not intensified with network development. Furthermore, the act-size distribution of the IPC technology classification cooperation network exhibits a power-law distribution across different developmental stages, indicating that most patents are concentrated in a small number of IPC technology fields.

Keywords: complex networks; patentee cooperation networks; IPC technology classification cooperation network; statistical properties; power-law distribution

2 Data Sources and Description

The patent data used in this study were obtained from the World Intellectual Property Organization patent database, which contains comprehensive information including patent application numbers, inventor names, applicant names, applicant countries and addresses, technology classification numbers, application dates, and publication dates. Given that invention patents demonstrate greater novelty and innovativeness compared to design patents and utility model patents, and better reflect the innovation level of applicants, we preprocessed the data by retaining only invention patents from Yangzhou region in the China Intellectual Property Administration database for 1985–2020. This yielded a total of 54,714 invention patent applications. Figure 2 [Figure 2: see original paper] illustrates the annual number of invention patent applications in Yangzhou from

1985 to 2020. Based on several key inflection points visible in the figure, we divided patent development in Yangzhou into three temporal phases.

As shown in Figure 2, invention patent applications remained minimal from 1985 to 2010, with only a few hundred or even dozens of applications each year, except for 1,139 applications in 2010. We designate this period as the exploratory development phase. From 2011 to 2015, the number of invention patent applications increased annually and grew rapidly, exceeding 5,000 applications by 2015. This period is termed the transitional development phase. From 2016 to 2020, invention patent applications exhibited explosive growth. The relatively low numbers for 2019 and 2020 are closely related to the 18-month lag between application and publication dates, as most patents applied for in these two years had not yet been published. We refer to this period as the innovation-driven development phase.

To conduct an in-depth analysis of patents applied for by universities, enterprises, and university-enterprise joint applicants, we constructed patent cooperation networks and IPC technology classification cooperation networks for Yangzhou region. This approach enables us to investigate regional patent development evolution, identify the development level of advantageous technological fields, and assess the role and evolutionary trends of research organizations in regional industrial scientific and technological innovation, thereby providing theoretical foundations for policymakers to explore regional industrial development potential during the 14th Five-Year Plan period, optimize regional industrial structures, and promote high-quality, sustainable economic development.

3 Patentee Cooperation Network

A single invention patent application typically includes one or more patentees, which may be individuals, enterprises, universities, or research institutions. Patents with multiple patentees reflect collaborative relationships among them. To analyze these cooperative relationships, we constructed a patentee cooperation network where each patent serves as an act and each patentee as a node. An edge between two patentees is established if they jointly applied for a patent. Using invention patent data from Yangzhou region (1985–2020), we divided the data into three periods—1985–2010 (exploratory development), 2011–2015 (transitional development), and 2016–2020 (innovation-driven development)—and constructed corresponding patentee cooperation networks for each period to examine various aspects of collaborative relationships.

3.1 Degree Distribution

Degree represents the number of neighbors for each node in a network, and to some extent, a higher degree indicates greater node importance. In the patentee cooperation network, where patentees serve as nodes, a node's degree represents the number of other patentees with whom it has collaborative ties. A higher degree indicates more extensive cooperation with other patentees. Figure 3

[Figure 3: see original paper] shows the degree distribution across the three developmental periods, where k denotes node degree and $P(k)$ represents the number of nodes with degree k. The degree distributions for all three periods follow a power-law distribution, indicating that the vast majority of patentees have very small degrees, while only a tiny fraction have large degrees. This suggests that collaborative patent applications are relatively rare, with most patentees cooperating only once with others, and many patents having a single independent patentee.

3.2 Node-pair Degree Distribution

Node-pair degree (D) refers to the number of acts in which a pair of nodes jointly participates. In the patentee cooperation network, node-pair degree represents the number of patents jointly applied for by two patentees, with $P(D)$ denoting the total number of node-pairs with node-pair degree D. A larger node-pair degree indicates more joint patent applications and stronger collaboration between the two patentees. Figure 4 [Figure 4: see original paper] presents the node-pair degree distribution across the three periods. All three distributions approximate a power-law distribution, with the vast majority of node-pairs having node-pair degrees of 0 or 1, and only a small minority exhibiting larger values. This demonstrates that pairwise collaboration among patentees is uncommon, with most patentees cooperating only once or not at all, and few maintaining stable, long-term collaborative relationships.

3.3 Act-size Distribution

Act-size (T) represents the number of nodes contained in each act. In the patentee cooperation network, act-size refers to the number of patentees involved in a single patent, with $P(T)$ denoting the number of acts of size T and $P(T' \geq T)$ representing the cumulative distribution. Figure 5 [Figure 5: see original paper] shows the act-size distribution for the three periods. All three periods exhibit clear power-law distributions, indicating that the vast majority of patents involve only two patentees, with only a small number of patents having multiple joint patentees. This further confirms that collaboration among patentees has remained relatively limited throughout all developmental stages, a pattern closely related to the exclusive nature of patent rights.

3.4 Clustering Coefficient and Assortativity of Patentee Cooperation Network

The clustering coefficient measures the degree of network clustering, representing the probability that neighbors of a given node are also connected to each other. In the patentee cooperation network, it indicates the likelihood that collaborators of a particular patentee also collaborate with one another. Table 1 presents the average clustering coefficients for the three periods: 0.377504 for 1985–2010, 0.381426 for 2011–2015, and 0.225938 for 2016–2020. The average

clustering coefficient does not increase with network growth and actually decreases in the 2016–2020 period, suggesting that collaboration among patentees has not strengthened over time.

Assortativity coefficient (r), ranging from -1 to 1, measures degree-degree correlation in a network. A positive r indicates positive correlation (high-degree nodes tend to connect with high-degree nodes), while a negative r indicates negative correlation. In the 1985–2010 network, the average assortativity coefficient is 0.429981, indicating that highly collaborative patentees tended to cooperate with other active patentees. However, the coefficients for 2011–2015 (0.0835138) and 2016–2020 (-0.11285) approach zero or become negative, suggesting that connections become degree-independent and more random in later periods, with no clear preferential collaboration patterns.

Table 1 Average assortativity coefficient and average clustering coefficient of patentee cooperation networks across three periods

4 IPC Technology Classification Cooperation Network

The IPC (International Patent Classification) classification number represents the internationally standardized patent documentation classification system. IPC employs a hierarchical structure combining function and application (functionality-dominant, application-supplementary), organized by section, subsection, class, subclass, main group, and subgroup. When an invention patent involves different technical themes across multiple technical fields that constitute inventive information, multiple classification numbers are assigned, reflecting cross-disciplinary technological intersections. To investigate these cross-field collaborative relationships, we constructed an IPC technology classification cooperation network where IPC main classes serve as acts and patents as nodes. An edge between two patents is established if they share the same IPC main class, thereby creating a network of cooperative relationships across different technology fields. We constructed three corresponding networks for the periods 1985–2010, 2011–2015, and 2016–2020.

4.1 Act Degree Distribution

In the IPC technology classification cooperation network, a node's act degree refers to the number of IPC main classes assigned to a patent. A higher act degree indicates broader technological coverage. Figure 6 [Figure 6: see original paper] shows the act degree distribution across the three periods, where *P(h)* represents the number of patents with act degree h. All three distributions exhibit peak distributions with a common characteristic: the vast majority of patents have an act degree of 2, meaning most patents involve only two IPC main classes. This indicates limited technological cross-fertilization, a pattern that persists regardless of network development scale, as patents typically protect specific technologies within particular fields.

4.2 Act-size Distribution

In the IPC technology classification cooperation network, act-size (T) refers to the number of patents contained within an IPC technology field (at the main class level). A larger act-size indicates stronger innovation activity and more frequent innovation in that field. Figure 7 [Figure 7: see original paper] presents both non-cumulative and cumulative act-size distributions for the three periods, all showing clear power-law distributions. This indicates that most IPC technology fields contain relatively few patents, while only a small number of fields contain many patents. This uneven distribution remains consistent across developmental periods.

Table 2 lists the top three IPC main classes by patent count for each period, reflecting the evolution of technological development in Yangzhou across different eras and indicating broader shifts in regional industrial development.

Table 2 Top three IPC main classes by patent count across different developmental periods

4.3 Clustering Coefficient and Assortativity of IPC Technology Classification Cooperation Network

In the IPC technology classification cooperation network, the clustering coefficient represents the probability of connections between nodes (patents). Table 3 shows the average clustering coefficients across the three periods. All values exceed 0.6 and increase over time, indicating growing network clustering as the IPC technology classification cooperation network develops. The assortativity coefficients remain around 0.5 for all periods, demonstrating positive degree correlation. This suggests that new patents tend to emerge in IPC technology fields that already contain numerous patents, showing a preferential attachment pattern across all developmental stages.

Table 3 Average assortativity coefficient and average clustering coefficient of IPC technology classification cooperation networks across three periods

5 Conclusions

Using complex network analysis methods for social collaboration networks, this study examined invention patent data from Yangzhou region (1985–2020) to construct patentee cooperation networks and IPC technology classification cooperation networks for three distinct developmental periods. By analyzing the properties of both network types across these periods, we provide a novel descriptive approach and network construction framework for patent big data analysis.

From the patentee cooperation network perspective, collaboration among patentees has not strengthened with network growth (increasing patent applications), and most patents remain held by independent patentees. During the 1985–2010

exploratory development period, patentees tended to collaborate with more active network participants, but this characteristic gradually diminished over time, giving way to more random collaboration patterns. This indicates that Yangzhou's patentee cooperation network maintained a dispersed, random network structure throughout the 1985–2020 period.

From the IPC technology classification cooperation network perspective, the vast majority of patents involve only two IPC technology fields (at the main class level), and technological cross-fertilization has not intensified with network development. The act-size distribution consistently follows a power-law distribution across periods, indicating that most patents concentrate in a small number of IPC technology fields. However, the specific fields of concentration change over time, reflecting the evolution of regional industrial patent development and, to some extent, broader industrial development patterns.

The study's findings, while based on Yangzhou's patent application data, reveal general patterns in patentee cooperation that likely possess broader applicability. We hope these insights can provide valuable references for assessing regional scientific and technological innovation capabilities and evaluating development trends across different regions.

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Note: Figure translations are in progress. See original paper for figures.