Research on Graph-Database-Based Construction Techniques for Patent Semantic Knowledge Base (Postprint)

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Abstract

【Purpose】To design and implement a semantically complete and high-performance patent semantic knowledge base for Derwent patent data. 【Application Background】The patent semantic knowledge base serves to store patent data and the semantic relationships among various data items, enabling patent retrieval through semantic relationships. 【Method】By analyzing the semantic relationships contained within and between Derwent patent data, we improve ontology-based patent semantic representation methods, propose a Derwent patent graph data model based on the property graph model, and utilize the Neo4j graph database to store instantiated patent data. 【Results】Taking cloud computing technology as an example, we construct a patent semantic knowledge base that ensures complete semantic information; under large data volume conditions, the query speed achieves 5.35 times that of traditional relational databases. 【Conclusion】The graph database-based patent semantic knowledge base features complete information, clear semantics, and good performance, representing a stable and efficient approach for organizing and storing patent data.

Full Text

Preamble

Measuring Technological Innovation Network Evolution of Targeting Technology

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Abstract

[**Objective**] This paper aims to quantitatively analyze the targeting technological innovation network using patent data, and measure its evolution from multiple perspectives. [**Methods**] We retrieved targeting technology patent data from the Derwent Innovations Index Database and applied dynamic network analysis methods to patent information analysis. By integrating dynamic network analysis indicators into technological innovation network analysis, we constructed a measurement system for technological innovation evolution based on patent dynamic networks. [**Results**] We analyzed four measurement objects of the technological innovation network, revealing the development trends and technology hotspots of targeting technology from a micro-level perspective based on changes in network indicators. [**Limitations**] The evaluation and measurement indicators for technological innovation networks are not sufficiently comprehensive, and more in-depth research on these indicators is needed. [**Conclusion**] The proposed method can effectively and comprehensively measure the evolution trends and technology hotspots of technological innovation networks.

Keywords: Technological innovation network; Dynamic network; Patent; Network evolution

1. Introduction

With the globalization and networking of R&D activities, an increasing number of innovation entities are leveraging innovation networks for technological innovation. The technological innovation network formed through collaboration among different innovation entities has become a crucial organizational form in current technological innovation processes [**?**]. As the number of participant nodes and relationships between nodes change, the technological innovation network evolves, making the measurement of this evolution a significant research direction [**?**]. Patents, as the primary output of technological innovation networks, cover extensive technical fields and contain various attributes such as inventors, patent assignees, and IPC classifications, representing the latest level of technological innovation to some extent. Therefore, analyzing patent content provides valuable insights into innovation networks.

Dynamic network analysis offers advantages in measuring technological innovation networks due to its specialized indicators and ability to measure changing networks. This study integrates dynamic network analysis methods with patent information analysis, constructs multi-relational patent data meta-matrices, and builds a measurement indicator system for technological innovation networks based on dynamic network characteristics. This approach enables multi-perspective analysis of technological innovation network evolution.

Currently, research on technological innovation networks has become a focal point in innovation studies, with scholars both domestically and internationally examining various aspects, primarily concentrating on network structure and evolution. Koka et al. [?] categorized network evolution into four patterns—network expansion, network contraction, network strengthening, and network turbulence—based on external resource changes and environmental uncertainty, describing network changes at both network and organizational levels. Rose et al. [?] clarified the meaning and attributes of innovation and proposed two frameworks for measuring innovation, enabling measurement of technological innovation evolution from perspectives of basic investment and intangible assets through comprehensive analysis. Dudzevičiūtė et al. [?] argued that R&D expenditure and patents could serve as key elements for measuring innovation activities based on systematic analysis of relationships between innovation activities, patents, and R&D spending. Jiang et al. [?] derived evolution equations for technological innovation network structural characteristics by incorporating temporal dimensions from network embeddedness measurements. Peng [?] studied degree distribution of nodes in innovation networks using complex network theory to examine structural evolution.

In recent years, scholars have applied patent information to technological innovation network analysis, initially focusing on static network-level analysis. Chang et al. [?] noted that patent-based innovation network analysis represents an advanced patent analysis technique. Morescalchi et al. [?] studied the evolution of inventor-based technological innovation networks, analyzing four types of networks (patent citation networks, co-inventor networks, R&D laboratory distribution networks, and inventor mobility networks) among OECD member countries using European Patent Office data to examine the impact of geographical distance and boundaries on international connections. Wang [?] constructed a patent analysis framework for industry technological innovation network activity characteristics. Liu et al. [?] studied the driving forces of technological innovation network evolution using patent technology life cycle theory. Wu [?] built a keyword-based weighted network to analyze biofuel field technological innovation network evolution using network analysis and hierarchical analysis methods. Li [?] used social network analysis to study cooperation status and network individual evolution characteristics of patentees in technical fields, employing patent coupling methods to examine technical characteristics. Ribeiro et al. [?] mapped global knowledge flow networks based on patent data, proposing a new method to describe "cross-border" global technological innovation networks. Liu et al. [?] established a "time-domain" analysis framework to analyze structural evolution of the U.S. national technological innovation network using patent data. While these scholars conducted stage-based analyses of technological innovation networks from patent information perspectives and empirical studies from macro perspectives, micro-level dynamic studies of network node evolution remain limited.

Domestic scholars have also preliminarily explored dynamic network analysis applications in technological innovation network evolution measurement. Liu et al. [?] constructed patent networks with multi-attribute nodes, analyzing patent network evolution and dynamic characteristics using dynamic network analysis with nanotechnology patents as a case study. Zhai et al. [?] used dynamic network analysis combined with patent abstract field analysis to examine domestic LTE TDD industry status. Li et al. [?] built a measurement framework for technological innovation network evolution based on dynamic network analysis, providing a new perspective for evolution measurement. However, existing perspectives involve relatively single indicators with algorithms focusing on single dimensions, insufficiently mining patent information and showing obvious limitations in understanding complex innovation networks.

This study integrates patent analysis methods with dynamic network analysis, constructs patent dynamic evaluation indicators, and incorporates characteristic indicators such as cognitive demand, capabilities, and centrality to build a technological innovation network evolution measurement model. By studying indicator changes, we analyze technological development processes and use ORA visualization tools to analyze dynamic network indicators, enabling multi-perspective analysis and characterization of targeting technological innovation network evolution.

3. Methodology

3.1 Factors Influencing Technological Innovation Network Evolution

Technological innovation networks consist of core networks, auxiliary networks, and peripheral support networks [?]. Formal and informal information exchange among enterprises, universities, research institutions, and governments promotes innovation generation and development. Innovation entities exchange core technical information through networks to market technological functions. This technical exchange is regional [?] and evolves over time. Therefore, factors influencing technological innovation networks include innovation entities, core technologies in the field, hot technology functions, innovation regions, and time.

(1) Innovation Entities
Enterprises are the primary innovation entities, with R&D activities driving technological innovation. As market economy participants connecting technology and markets, enterprises serve as both technology demanders/appliers and suppliers, making them the main innovation entities. Patent activities by enterprises as patentees demonstrate their innovation subjectivity. Universities and research institutions are technology developers serving enterprises, but they may become innovation network subjects if they master core technologies in the field.

(2) Core Technologies in the Field
Technology serves as the carrier of innovation, with successful new technology R&D forming the foundation for innovation generation. Therefore, core technologies influence innovation development directions, making their identification particularly important.

(3) Hot Technology Functions in the Field
Technology functions indicate what specific tasks a technology can accomplish and form the basis for patent technology marketization. As final innovation

outcomes manifest in products whose functions closely relate to technology functions, technology functions also influence technological innovation.

(4) Innovation Regions
Technological innovation activities are not completed by individual enterprises or research institutions but constitute regional behavioral activities, making innovation regions another influencing factor.

(5) Time
To maintain and expand their survival space, members in technological innovation networks continuously adjust relationships over time, causing innovation entities, core technologies, hot technology functions, and innovation regions to evolve continuously.

Patent data provides rich standardized information. Innovation entities seek patent protection for breakthroughs in technical fields, making patents closely associated with technological innovation. Technological innovation in a field first appears in patents. Patent documents contain detailed information about inventions, inventors, applicants, application times, and regions, forming time series of patent information. Therefore, patent information can reflect technological innovation activities, with patentees representing innovation entities, IPC classifications representing technological fields, patent functions representing innovative technology functions, application locations representing innovation regions, and publication/application dates representing the innovation timeline [?]. Consequently, patent information content enables measurement of technological innovation networks.

3.2 Constructing Patent-Based Dynamic Network Meta-Matrices

Dynamic network analysis extends Social Network Analysis (SNA) and Dynamic Network Analysis (DNA) theories and methods, combining cognitive science, social networks, and multi-agent systems. Dynamic network indicators develop from social network indicators, including conventional metrics like degree and centrality while expanding numerous additional indicators that enrich dynamic network analysis methods and enable solving more problems.

Patent activities belong to technological innovation activities completed by enterprises, universities, research institutions, and individual researchers. Therefore, patent activities can be viewed as organizational activities composed of these entities. Li et al. [?] used dynamic network analysis to calculate organizational activities through meta-matrix construction.

The foundation of dynamic network analysis is the meta-matrix, whose entities include people, knowledge/resources, tasks/events, and organizations. Relationships between entities build interconnected networks. In dynamic networks, node categories include: Agent (decision-makers playing dominant roles in networks), Resource (materials or products used to complete tasks), Knowledge (cognitive abilities and skills of agents), Task (tasks or goals of agents or organizations), Organization (collections of agents with common tasks), Location (places where tasks occur or where agents are located), and Time (when tasks occur) [?]. Meta-matrix meanings vary based on different ontology class definitions. This study constructs a patent information meta-matrix based on patent information ontology classes for analysis.

Patent information ontology classes include patentees, IPC classifications, patent functions, application countries, and application years. Based on these ontology classes, we can construct a meta-matrix as shown in Table 1 .

Table 1 Patent Data Meta-Matrix

	Patentee (Agent)	Patent IPC (Knowledge)	Patent Function (Task)	Application Country (Location)	Application Year (Time)
Technological Innovation Entity	Technological Innovation Subject	Technological Innovation Field Core Technology	Technological Innovation Field Core Technology Function	Technological Innovation Regional Distribution	Technological Innovation Process

Combining technological innovation network theory, the patentee × patentee matrix constitutes the technological innovation subject network, patentee × IPC matrix constitutes the innovation field technology network, patentee × technology function matrix constitutes the innovation field technology function network, and patentee × location matrix constitutes the regional distribution network. Adding a time axis creates time series. This study uses the constructed patent information meta-matrix for multi-modal analysis of patent data, measuring technological innovation networks through patent information.

3.3 Important Indicators in Dynamic Network Analysis

Dynamic network indicators develop from social network indicators, including conventional degree and centrality metrics while expanding numerous additional indicators. Dynamic networks contain many characteristic indicators. This study selects the following indicators from the ORA User’ s Guide [?]: Cognitive Demand, Authority Centrality, Closeness Centrality, Capabilities, Personnel Cost, Total Degree Centrality, Correlation Distinctiveness, Correlation Similarity, and In/Out Degree Centrality to construct a patent-based technological innovation network measurement indicator system. Indicator meanings are shown in Table 2 .

Table 2 Dynamic Indicator Content

Indicator	Formula	Symbol Meaning	Description
Cognitive Demand	$X_{1i}, X_{2i}, X_{3i}, X_{4i}, X_{5i}$ represent: other innovation subjects, technology functions, technology function similarity, technology uniqueness, and dependency on other innovation subjects associated with innovation subject i	Identifies potential leaders in the network. The entity connects to the most people, organizations, tasks, and events.	
Authority Centrality	X_i represents the weight of vertex i in the network, A represents the network adjacency matrix, λ is a proportional constant	Measures node centrality in the network. Nodes with high authority centrality issue many connections, and their connected nodes also have many connections.	
Closeness Centrality	$C(n_i) = \frac{1}{\sum_{j=1}^{g} d(n_i, n_j)}$ where $d(n_i, n_j)$ is the shortest path between points i and j, g is the number of nodes	Calculates a node’ s centrality based on distance concept. Examines distances between innovation subjects and other subjects.	

Indicator	Formula	Symbol Meaning	Description
Capabilities	$(RD_i + 0.5) \times 10$ where i is a node, RD is the out-degree centrality of each entity in the network	Explores the degree of association between an entity and other entities, describing cooperation capabilities.	
Personnel Cost	Sum of knowledge, resources, and tasks owned by the subject, representing costs in the organization	Represents the total of technology collaborators, technologies, and technology functions owned by technological innovation subjects.	
Total Degree Centrality	Sum of in-degree and out-degree centrality of a node	Sum of in-degree and out-degree centrality of a node.	
Correlation Distinctiveness	$\sum_{j \neq i}(PT_{ij} - PT_{ji})$ where i represents a node, j represents a different node, PT represents the technology matrix, T represents technology	Complementarity of knowledge between two subjects.	
Correlation Similarity	$\sum_{j \neq i}(PT_{ij} + PT_{ji})$	Similarity of knowledge between two subjects.	

Indicator	Formula	Symbol Meaning	Description
In/Out Degree Centrality	$X(i, j)$ where i is matrix row, j is matrix column, m is number of rows, n is number of columns	In-degree is the number of connections to a node in a directed network; out-degree is the number of connections from a node.	

3.4 Technological Innovation Network Measurement Model

We construct a measurement model for technological innovation network evolution using dynamic network evaluation indicators to identify changes in patent innovation networks. The model measures technological innovation subjects, core technologies, hot technology functions, and innovation regions separately, as shown in Table 3 .

Table 3 Technological Innovation Network Evaluation Indicator System

Measurement Object	Dynamic Network Indicators	Patent Dynamic Network Indicator Content	Technological Innovation Network Analysis Content
Technological Innovation Subject	Cognitive Demand	Potential leaders in the technology field, possessing key technologies and functions	Technological innovation subjects dominating the network
	Authority Centrality	Patentees in core positions in patent cooperation networks	Innovation subjects in core positions in technological innovation networks
	Closeness Centrality	Distances between patentees and other nodes in the network, calculating node centrality based on distance concept	Measuring closeness between innovation subjects and other subjects

Measurement Object	Dynamic Network Indicators	Patent Dynamic Network Indicator Content	Technological Innovation Network Analysis Content
	Capabilities	Degree of association between patentees and other patentees, representing cooperation capabilities	Measuring association degree and cooperation capabilities between innovation subjects
	Personnel Cost	Total of technologies and technology functions owned by patentees	Total of innovative technologies and functions owned by innovation subjects
Technological Innovation Field Core Technology	Total Degree Centrality	Sum of in-degree and out-degree centrality of IPC	Measuring core technologies in innovation fields
	Technology Uniqueness	Degree of difference between patentees' IPCs	Degree of difference in technologies among innovation subjects
	Technology Similarity	Degree of similarity between patentees' IPCs	Degree of similarity in technologies among innovation subjects
Technological Innovation Field Hot Technology Function	Total Degree Centrality	Sum of in-degree and out-degree centrality of technology functions	Measuring hot technology functions in innovation fields
	Technology Uniqueness	Degree of difference between patentees' technology functions	Degree of difference in technology functions among innovation subjects

Measurement Object	Dynamic Network Indicators	Patent Dynamic Network Indicator Content	Technological Innovation Network Analysis Content
Technological Innovation Region	In-degree Centrality	In-degree centrality of patent application countries	Measuring technological innovation regions

4. Empirical Study of Targeting Technological Innovation Network Evolution

We decomposed targeting technology in detail, listing keywords related to biomedical technology themes as comprehensively as possible. We combined search elements from four aspects—technical field, technical problem, technical effect, and technical means—and repeatedly revised the search expression based on retrieval results. The final search expression was: TS=(targeted AND ("drug delivery" OR "drug release")). Using the Derwent Innovations Index (DII) database as the data source with a date range from January 2006 to December 2014, we retrieved 645 patent entries. We cleaned the patent data using script-based cleaning strategies and cyclic cleaning strategies. The script-based strategy primarily addressed relatively complex field content, employing pattern recognition methods combining defined rules and using regular expressions to construct identification and splitting points. The cyclic cleaning strategy was mainly used for simple field splitting and extraction. The two cleaning strategy processes are shown in Figure 1 [Figure 1: see original paper] and Figure 2 [Figure 2: see original paper].

4.1 Evolution Analysis of Technological Innovation Subjects

(1) Innovation Subject Cognitive Demand
As shown in Table 4 , higher indicator values indicate stronger R&D team strength of the patentee, suggesting the patentee may become a potential leader in the technology field.

Table 4 Cognitive Demand Indicators

2006–2008	2009–2011	2012–2014
Massachusetts Institute of Technology SmithKline Beecham Corporation	SmithKline Beecham Corporation Tianyou International Holdings Co., Ltd.	Massachusetts Institute of Technology Tianyou International Holdings Co., Ltd.

2006–2008	2009–2011	2012–2014
Tianyou International Holdings Co., Ltd.	Crowiey M M	Crowiey M M
Crowiey M M	Keen J M	Keen J M
Keen J M	Baxter Healthcare Corporation	Baxter Healthcare Corporation
Baxter Healthcare Corporation	Baxter International Inc.	Baxter International Inc.
NAL Pharmaceutical Co., Ltd.	NAL Pharmaceutical Co., Ltd.	NAL Pharmaceutical Co., Ltd.
Tyco Healthcare Group	Tyco Healthcare Group	Tyco Healthcare Group
Bio-Bedst Corporation	Bio-Bedst Corporation	Bio-Bedst Corporation
Azure Pharmaceuticals	Azure Pharmaceuticals	Azure Pharmaceuticals
Insert Therapeutics	Insert Therapeutics	Insert Therapeutics
Koninklijke Philips Electronics N.V.	Koninklijke Philips Electronics N.V.	Koninklijke Philips Electronics N.V.
Anpac Technology Co., Ltd.	Anpac Technology Co., Ltd.	Anpac Technology Co., Ltd.
BioKier Corporation	BioKier Corporation	BioKier Corporation

The top-ranked enterprises differ across each phase, with indicator values remaining relatively small (below 0.05), indicating that no absolute leading enterprise or institution has emerged in the targeting technology field. However, Azure Pharmaceuticals and Insert Therapeutics currently show higher cognitive demand, suggesting they possess strong R&D teams and core patent technologies, potentially becoming leaders in targeting technology in coming years. Additionally, cognitive demand indicator values show a yearly increasing trend, with maximum values rising from 0.026 to 0.036, indicating that leaders in targeting technology will emerge soon. When cognitive demand reaches 0.2, it signifies that leading entities have appeared in the field.

(2) Authority Centrality
Innovation subject authority centrality reflects the trend of strong-strong alliances in technology cooperation. Higher values indicate higher status of the patentee in the cooperation network, with connected innovation subjects also having relatively high centrality.

As shown in Table 5 , central network nodes differ across phases, indicating continuous changes in network center positions. During 2006–2008, Tianyou International Holdings Co., Ltd. had high authority centrality. During 2009–2011, individual researchers like Bernai J J showed high values. During 2012–2014, Azure Pharmaceuticals became prominent, indicating these enterprises had broad R&D scopes and cooperation in different phases. Authority centrality values concentrate above 0.4, suggesting relatively high network centralization and close communication among technological innovation subjects.

Table 5 Authority Centrality Indicators

2006–2008	2009–2011	2012–2014
Tianyou International Holdings Co., Ltd.	Bernai J J, et al.	Azure Pharmaceuticals
Auxilum Pharmaceuticals	Lucas G	Fetzer O S
Crowiey M M	CHIMERA Pharmaceuticals	Crawford T C
Keen J M	Biazquez A, et al.	Reiter L A
Koieng J J	Castro A, et al.	Insert Therapeutics

(3) Closeness Centrality

Closeness centrality calculates the centrality degree of an innovation subject in the technological innovation network, measuring distances between innovation subjects.

As shown in Table 6 , enterprises with high indicator values differ across phases, indicating close cooperation among their R&D teams, relatively low dependence on others' technology R&D, and numerous co-applied patents. Indicator values remain relatively small across phases, while authority centrality values are relatively high, suggesting that targeting technology is currently dispersed.

Table 6 Closeness Centrality Indicators

2006–2008	2009–2011	2012–2014
NAT Technology Research Co., Ltd.	CHIMERA Pharmaceuticals	DAVOLTERRA Corporation
University of New Delhi	Bae Y H	Baxter Healthcare Corporation
Chaudhuri A	Keen J M	CHIMERA Pharmaceuticals
Krishnan A	Azure Pharmaceuticals	Bae Y H
Kumar V V	Fetzer O S	Azure Pharmaceuticals
DAVOLTERRA Corporation	Crawford T C	Fetzer O S
Paris Public Assistance Hospital	Hwang J	Crawford T C
Andremont A	Insert Therapeutics	Hwang J
Keen J M		Insert Therapeutics

(4) Capabilities

Capabilities represent the degree of association between nodes in a network. In the patent information meta-matrix constructed in this study, which includes cooperation networks, technology networks, and function networks, the capabilities indicator can measure the cooperation team strength and R&D capabilities of patentees.

As shown in Table 7 , these enterprises maintain close connections with other patentees, demonstrating outstanding partners and R&D capabilities. The capabilities indicator values of top-ranked technological innovation subjects approach 1, indicating these subjects possess relatively large R&D teams in the targeting technology field.

Table 7 Capabilities Indicators

2006-2008	2009-2011	2012-2014
Massachusetts Institute of Technology	Massachusetts Institute of Technology	Azure Pharmaceuticals
Baxter Healthcare Corporation	Baxter Healthcare Corporation	Insert Therapeutics
NAL Pharmaceutical Co., Ltd.	NAL Pharmaceutical Co., Ltd.	Eliasof S
Tyco Healthcare Group	Tyco Healthcare Group	BioKier Corporation
Wayne State University	DAVOLTERRA Corporation	University of Melbourne, Australia
DAVOLTERRA Corporation		Auxilum Pharmaceuticals
		Burke S E
		Choi D K M

(5) Personnel Cost

The personnel cost indicator represents the total of collaborators, technologies, and technology functions connected to an innovation subject. High personnel cost values indicate that the innovation subject' s patents involve broad technology fields and possess numerous R&D personnel.

As shown in Table 8 , enterprises with high personnel costs vary significantly across phases. Overall, indicator values peaked during 2009-2011 and decreased noticeably during 2012-2014, with substantial changes in enterprise rankings. This suggests relatively high R&D personnel mobility in targeting technology field companies.

Table 8 Personnel Cost Indicators

2006-2008	2009-2011	2012-2014
Auxilum Pharmaceuticals	DAVOLTERRA Corporation	DAVOLTERRA Corporation
Massachusetts Institute of Technology	Baxter Healthcare Corporation	Baxter Healthcare Corporation

2006–2008	2009–2011	2012–2014
Crowley M M	CHIMERA Pharmaceuticals	CHIMERA Pharmaceuticals
Keen J M	Bae Y H	Bae Y H
	Azure Pharmaceuticals	Azure Pharmaceuticals
	Fetzer O S	Fetzer O S
	Crawford T C	Crawford T C
		Insert Therapeutics
		Kipke D R

4.2 Core Technology Evolution Analysis in Technological Innovation Fields

The technology network evolution is shown in Figure 3 [Figure 3: see original paper] (solid points represent patentees, hollow points represent patent IPCs). During 2006–2008, numerous hot technology fields existed, primarily concentrated in A61K-047/34, A61K-031/568, etc., representing medical preparations characterized by non-effective ingredients and pharmaceutical preparations containing organic active ingredients. During 2009–2011, decreased patent applications led to reduced R&D activities in hot technologies. During 2012–2014, hot technology fields increased again, mainly including A61P-035/00, C08B-037/16, etc., representing antineoplastic agents and polysaccharides and their derivatives.

(1) Total Degree Centrality
Total degree centrality represents the sum of in-degree and out-degree centrality of a node. In technological innovation networks, it measures core technologies. Higher total degree centrality values indicate hot technology fields.

As shown in Table 9 , indicator values for top-ranked hot technology fields increased from 2008 onward. During 2012–2014, A61P-35/00 reached 0.489, indicating increasingly concentrated research hotspots and maturing technology in the targeting technology field. A61K represents medical preparations, A61P represents specific therapeutic activities of compounds or pharmaceutical preparations, and A61M represents devices for introducing media into the human body.

Table 9 Total Degree Centrality Indicators

2006–2008	2009–2011	2012–2014
A61K-009/14	A61P-035/00	A61P-035/00
A61P-035/00	A61K-47/32	A61K-47/48
A61K-047	A61K-38/00	A61K-009/14
A61K-000/00	A61K-009/127	A61K-49/00
A61K-039	A61K-31/00	A61M-37/00

(2) Technology Uniqueness
Technology uniqueness measures the degree of difference in technology fields researched by patentees. Higher technology uniqueness values indicate that innovation subjects are developing new technology fields and actively innovating.

This indicator measures the degree of technological complementarity between two innovation subjects, representing the difference degree between a patentee' s IPC and other patentees' IPCs in the technological innovation network. As shown in Table 10 , these patentees research relatively unique technology fields with innovative characteristics. Their technology fields show relatively high difference degrees compared to other subjects, indicating they are seeking technological breakthroughs and actively innovating.

Table 10 Technology Uniqueness Indicators

2006–2008	2009–2011	2012–2014
SmithKline Beecham Corporation	SmithKline Beecham Corporation	Massachusetts Institute of Technology
Massachusetts Institute of Technology	Massachusetts Institute of Technology	Koninklijke Philips Electronics N.V.
Auxilum Pharmaceuticals	Auxilum Pharmaceuticals	Medtronic, Inc.
SYNTHONICS Corporation	SYNTHONICS Corporation	Rutten J J G
		NANODEX Corporation

(3) Technology Similarity
Technology similarity measures the similarity of technology fields between two innovation subjects. In the patent information meta-matrix, it represents the difference degree between a patentee' s technology field and other patentees' technology fields. Higher technology similarity values indicate that innovation subjects research similar technology fields, potentially leading to patent infringement or competition.

As shown in Table 11 , these innovation subjects' technology fields show high similarity with other subjects, potentially indicating competitive relationships or infringement issues. Compared to technology uniqueness indicators, these values are slightly lower, suggesting that targeting technology field development remains immature with relatively few similar technologies among enterprises.

Table 11 Technology Similarity Indicators

2006-2008	2009-2011	2012-2014
CHIMERACORE Corporation	CHIMERA Corporation	CHIMERA Corporation
CHIMEROS Corporation	CHIMERA Corporation	CHIMERA Corporation
University of Texas	University of Texas	University of Texas
Tel Aviv University	Tel Aviv University	Tel Aviv University
DAVOLTERRA Corporation	DAVOLTERRA Corporation	DAVOLTERRA Corporation
Sandia Corporation	Sandia Corporation	Sandia Corporation
University of Mexico	University of Mexico	University of Mexico
Santok Corporation	Santok Corporation	Santok Corporation
Jansen Biotech, Inc.	Jansen Biotech, Inc.	Jansen Biotech, Inc.
Paris Public Assistance Hospital	Paris Public Assistance Hospital	Paris Public Assistance Hospital
Georgia State University	Georgia State University	Georgia State University
Boston Children' s Hospital	Boston Children' s Hospital	Boston Children' s Hospital
Massachusetts Institute of Technology	Massachusetts Institute of Technology	Massachusetts Institute of Technology
PCI Corporation	PCI Corporation	PCI Corporation

4.3 Technology Function Evolution Analysis

The technology function network evolution process is shown in Figure 4 [Figure 4: see original paper] (solid points represent patentees, hollow points represent technology functions). During 2006-2008, the network structure mostly featured multiple innovation subjects connecting to one technology function, with many innovation subjects but few technology functions. During 2009-2011, both innovation subjects and technology functions decreased. During 2012-2014, both innovation subjects and technology functions increased significantly, indicating technological breakthroughs and notably increased technology functions in this phase.

(1) Total Degree Centrality

As shown in Table 12 , technology application results during 2006-2008 mainly concentrated on medical equipment and drug delivery. During 2009-2011, they focused on medical drug preparation. During 2012-2014, they concentrated on treating specific diseases and delivering drugs to diseased cells or tissues.

Table 12 Total Degree Centrality Indicators

2006–2008	2009–2011	2012–2014
Produce target genes	Produce target genes	Produce target genes
Biomedical equipment or tissues	Biomedical equipment or tissues	Biomedical equipment or tissues
Directional cell drug delivery	Directional cell drug delivery	Directional cell drug delivery
Produce hot-melt extruded laminates	Reduce infection and promote healing	Reduce infection and promote healing
Reduce infection and promote healing	Vaccination, treatment, imaging	Vaccination, treatment, imaging
Vaccination, treatment, imaging	Eliminate	Eliminate
Eliminate	Gram-negative bacteria	Gram-negative bacteria
Gram-negative bacteria	Core-shell particle encapsulation	Core-shell particle encapsulation
Core-shell particle encapsulation	Biologically active carboxylic acids	Biologically active carboxylic acids
Biologically active carboxylic acids	Deliver drugs to specific cells	Deliver drugs to specific cells
	Treat or prevent tumors	Treat or prevent tumors
	Treat cancer, allergies	Treat cancer, allergies
	Deliver monomer drugs	Deliver monomer drugs
	Deliver drugs to cerebrospinal fluid	Deliver drugs to cerebrospinal fluid
	Treat solid tumors	Treat solid tumors

(2) Technology Uniqueness

As shown in Table 13 , Koninklijke Philips Electronics N.V. ranks high and stable in technology uniqueness. These innovation subjects' technology application results show differences compared to other subjects, possessing certain competitive advantages.

Table 13 Technology Uniqueness Indicators

2006–2008	2009–2011	2012–2014
Massachusetts Institute of Technology	Koninklijke Philips Electronics N.V.	Massachusetts Institute of Technology
Koninklijke Philips Electronics N.V.	Medtronic, Inc.	Koninklijke Philips Electronics N.V.
Medtronic, Inc.	Rutten J J G	Emory University
Rutten J J G	NANODEX Corporation	Massachusetts Institute of Technology
NANODEX Corporation		U.S. Department of Health and Human Services

2006-2008	2009-2011	2012-2014
		Koninklijke Philips Electronics N.V. Azure Pharmaceuticals Chen Z Ethicon, Inc. ANPAC Biomedical Corporation

4.4 Innovation Region Evolution Analysis

In-degree represents the number of connections to a node in a directed network. Using patent application countries as nodes, we measure the in-degree centrality indicator of patent application countries to characterize and describe the regional distribution of patentees. Higher values indicate more patentees in that region.

As shown in Table 14 , although patentees in the targeting technology field are distributed across many countries, the U.S. indicator value is significantly higher than other countries and consistently ranks first, demonstrating that U.S. innovation capability in targeting technology far exceeds other nations.

Table 14 In-degree Centrality Indicators

2006-2008	2009-2011	2012-2014
0.005 WO US	0.005 WO US	0.005 WO US

The above analysis reveals that the innovation network constructed from patents in the targeting technology field has undergone changes, manifested as some key nodes gradually moving out of critical positions while others increase in importance and become key nodes under different measurement indicator perspectives:

(1) **In measuring technological innovation subject evolution**, network changes reflect continuous changes and turnover of innovation subjects and capabilities in the targeting technology field. Under different measurement indicators, some key nodes show significant changes, indicating that innovation subjects and their capabilities in targeting technology are constantly changing. Azure Pharmaceuticals and Insert Therapeutics gradually occupy key positions over time across various measurement perspectives, becoming major patentees. Overall, their technological innovation capabilities are stronger than other patentees.

(2) **In measuring core technologies in technological innovation fields**, rankings across time periods show certain changes in targeting technology

core fields. A61P-035/00 maintains stable ranking and first place, representing a recent R&D hotspot in targeting technology innovation. Meanwhile, A61K-47/48 has risen in ranking, becoming a new R&D hotspot. From uniqueness and similarity indicators, patentee rankings vary significantly across phases, with technology uniqueness values slightly higher than technology similarity values, indicating that targeting technology development remains immature and enterprises are actively seeking innovation.

(3) **In measuring technology functions**, rankings across phases show significant changes in targeting technology functions. Indicator values for each technology function exceed 0.01 across phases, suggesting that diseases treated or functions in targeting technology are relatively dispersed with wide technology applications. In technology function uniqueness analysis, Koninklijke Philips Electronics N.V. ranks high and stable, possessing unique technology functions and strong competitive advantages.

(4) **In measuring technological innovation region evolution**, rankings across phases show the U.S. has the most patents in targeting technology, followed by Canada. Notably, China has recently replaced South Korea as the third-ranked country in patent applications, indicating enhanced innovation capability in targeting technology, though still significantly behind the U.S. Overall, core nodes show little change.

5. Conclusions and Recommendations

This study conducted empirical analysis using targeting technology patent data from 2006–2014, revealing that China lacks core technologies and has not formed advantageous technology industries. Analysis shows that global targeting technology R&D has evolved from targeted drug delivery and specific drug production technologies to specific disease treatment technologies, while China mostly remains at the drug production stage. Dynamic network indicator values show foreign enterprises ranking at the top, indicating that domestic enterprises lag behind in core technologies and technological innovation. Innovation is dominated by universities and research institutes rather than enterprises, and a technology innovation network with enterprises as the core has not yet formed.

Patent literature, as an important carrier of technological innovation achievements, fully records technological inventions and reveals technology development processes. Patent information can measure technological innovation network evolution, providing decision support for enterprises and governments. This study integrates patent analysis methods with dynamic network analysis, constructing a patent dynamic network-based technological innovation network measurement model that enriches measurement methods for technological innovation networks. Since dynamic networks contain numerous indicators, industry technological innovation network evolution measurement can select different indicator combinations based on analysts' subjective needs.

Recommendations: Enterprises should strengthen R&D investment in core technologies to establish technological advantages. Knowledge network analysis reveals that during 2006–2008, core technology fields involved IPCs such as A61K-009/14 (fine granules, powders), A61P-035/00 (antineoplastic agents), and A61K-047 (medical preparations characterized by non-effective ingredients). During 2009–2011, core technology fields focused on A61P-035/00 (antineoplastic agents), A61K-47/32 (polymer compounds), and A61K-38/00 (medical preparations containing peptides). During 2012–2014, core technology fields concentrated on A61P-035/00 (antineoplastic agents), A61K-47/48 (non-effective ingredients chemically bonded to effective ingredients), and A61K-009/14 (fine granules, powders). These R&D hotspots show that every link in targeted drug delivery systems is crucial, with countries increasing R&D in different technical links. For Chinese enterprises, this presents both opportunities and challenges to form core advantages in any link. Enterprises should proactively establish inter-enterprise technology innovation alliances. Analysis of targeting technology cooperation networks and indicators shows low R&D cooperation and low industry concentration in China' s targeting technology field, resulting in low patent product conversion rates. Therefore, establishing industry-university-research alliances and increasing patent technology product conversion will promote healthy enterprise development and improve benefits. Enterprises should also make rational layouts and correctly select investment technologies. Analysis shows global targeting technology involves many diseases and carrier/formulation types. Some technologies have been developed for years without breakthroughs, increasing investment risks. Other technologies involve lower risks and can develop into technological advantages, warranting vigorous development.

This study conducted empirical research on the patent dynamic network-based technological innovation network measurement system using targeting technology field data, verifying its feasibility. However, limitations remain: (1) The constructed patent information meta-matrix is not comprehensive enough and should deeply mine various patent information fields to establish a more complete meta-matrix. (2) The constructed patent network-based technological innovation network measurement indicators are not rich enough, as dynamic networks contain many unique evaluation indicators that have not been sufficiently applied to technological innovation network measurement.

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Conflict of Interest Statement

All authors declare no conflict of interest.

Author Contributions

Zhai Dongsheng: Conceived research ideas and designed research framework;
Wang Meng: Collected and cleaned data, conducted experiments, drafted manuscript;
Zhang Jie: Designed research framework;
Sun Wu, Wang Meng: Revised final manuscript version.

Supporting Data

Supporting data is available in the journal's online version at http://www.infotech.ac.cn.
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Note: Figure translations are in progress. See original paper for figures.