

Research on Measurement Methods for the Evolution of Targeted Technological Innovation Networks (Postprint)

Authors: Zhai Dongsheng, Wang Meng, Zhang Jie, Sun Wu

Date: 2017-11-08T00:00:00+00:00

Abstract

[Objective] To conduct quantitative analysis of targeted technology innovation networks using patent data and measure the evolution process of technology innovation networks from multiple perspectives. [Methods] Taking targeted technology innovation networks as the research object, targeted technology patent data were retrieved from the Derwent Innovation Index. Dynamic network analysis methods were combined with patent data, dynamic network analysis indicators were applied to technology innovation network analysis, and a measurement system for technology innovation evolution based on patent dynamic networks was constructed. [Results] By analyzing four measurement objects of technology innovation networks and examining changes in network indicators, the development and evolution trends of targeted technology and technology hotspots were revealed at the micro level. [Limitations] The evaluation and measurement indicators for technology innovation networks are not sufficiently comprehensive, and research on the indicators lacks depth. [Conclusion] This method can effectively and comprehensively measure the evolution trends of technology innovation networks and technology hotspots.

Full Text

Preamble

Research on Measuring the Evolution of Targeted Technology Innovation Networks

Zhai Dongsheng, Wang Meng, Zhang Jie, Sun Wu
(School of Economics and Management, Beijing University of Technology, Beijing 100124, China)

Abstract

[Objective] This paper aims to quantitatively analyze the targeted technological innovation network using patent data and measure its evolutionary process from multiple perspectives. **[Methods]** Focusing on targeted technology innovation networks, we retrieved targeted technology patent data from the Derwent Innovations Index Database. By integrating dynamic network analysis methods with patent data, we applied dynamic network analysis indicators to technological innovation network analysis and constructed an evolution measurement system based on patent dynamic networks. **[Results]** We analyzed four measurement objects of the technological innovation network and revealed the evolutionary trends and technological hotspots of targeted technology from the micro-level based on changes in network indicators. **[Limitations]** The evaluation and measurement indicators for technological innovation networks are not sufficiently comprehensive, and the research on these indicators lacks depth. **Conclusions** This method can effectively and comprehensively measure the evolution trends and technological hotspots of technological innovation networks.

Keywords: Technology Innovation Network; Dynamic Network; Patent; Network Evolution

Classification Numbers: F204; G306

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 the current technological innovation process [1]. As the number of participant nodes and relationships between nodes change, technological innovation networks continuously evolve, making the measurement of this evolution a significant research direction [2]. Patents, as the primary output of technological innovation networks, cover extensive technical fields and contain multiple attributes such as inventors, patent assignees, and IPC classifications, representing the latest level of technological innovation to some extent. Therefore, analyzing patent content provides a valuable approach to understanding technological innovation networks.

Dynamic network analysis offers advantages in measuring technological innovation networks due to its specialized indicators and ability to assess changing networks. This study employs dynamic network analysis tools to integrate dynamic network analysis methods with patent information analysis, constructing multi-relational patent data meta-matrices. Based on these matrices and leveraging unique indicators from dynamic network analysis, we establish a patent-based measurement indicator system for technological innovation networks to analyze the evolutionary process from multiple perspectives.

Currently, research on technological innovation networks has become a focal point in innovation studies, with scholars both domestically and internationally investigating various aspects, primarily concentrating on network structure and network evolution. Koka et al. [3] categorized network evolution into four patterns—network expansion, network contraction, network strengthening, and network turbulence—based on two dimensions: changes in external resources and environmental uncertainty, describing network changes at both the network and organizational levels. Rose et al. [4] clarified the meaning and attributes of innovation and proposed two frameworks for measuring innovation, achieving measurement of technological innovation evolution from perspectives of basic investment and intangible assets through comprehensive analysis. Dudzevičiūtė et al. [5] systematically analyzed the relationship between innovation activities, patents, and R&D expenditure, concluding that R&D expenditure and patents serve as key elements for measuring innovation activities. Jiang et al. [2] introduced temporal dimensions from the perspective of network embeddedness measurement to derive evolution equations for technological innovation network structural characteristics, thereby describing the evolution process. Peng [6] utilized complex network theory to study node degree distribution and investigate the structural evolution of innovation networks.

In recent years, scholars have applied patent information to technological innovation network analysis. Initial analyses focused primarily on static network-level assessments. Chang et al. [7] noted that using patents for innovation network analysis represents an advanced patent analysis technique. Morescalchi et al. [8] 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 inter-country connections. Wang [9] constructed a patent analysis framework for industry technological innovation network activity characteristics, providing information for industry technological innovation research. Liu et al. [10] investigated the driving forces of technological innovation network evolution using patent technology life cycle theory. Wu [11] constructed a keyword-based weighted network and combined network analysis with hierarchical analysis to examine the evolution of biofuel technology innovation networks. Li [12] employed social network analysis to study the cooperation status and individual evolution characteristics of patent assignees in technical fields and used patent coupling methods to examine technical characteristics in specific fields. Ribeiro et al. [13] mapped global knowledge flow networks based on patent data, proposing a novel method to describe “cross-border” global technological innovation networks. Liu et al. [14] established a “time-domain” analytical framework and used patent data to analyze the structural evolution of the U.S. national technological innovation network. Although these scholars conducted stage-wise analyses of technological innovation networks from a patent information perspective and performed macro-level empirical studies on patent-based technological innovation network evolution,

they have not yet dynamically examined the micro-level evolution of network nodes.

Domestic scholars have also begun exploring the application of dynamic network analysis in measuring technological innovation network evolution. Liu et al. [15] constructed patent networks with multi-attribute nodes and used dynamic network analysis to examine the evolution and dynamic characteristics of patent networks, conducting empirical research using nanotechnology patents as a case study. Zhai et al. [16] applied dynamic network analysis combined with fields from patent abstracts to analyze the domestic LTE TDD industry status. Li et al. [17] constructed a measurement framework for technological innovation network evolution based on dynamic network analysis, providing a new perspective for such measurements. However, existing perspectives involve relatively single indicators, with algorithms primarily focusing on single dimensions, insufficiently mining patent information, and exhibiting obvious limitations in understanding and recognizing complex innovation networks.

This study integrates patent analysis methods with dynamic network analysis methods, constructing patent dynamic evaluation indicators and incorporating characteristic indicators such as cognitive demand, capability, and centrality to build a technological innovation network evolution measurement model. By examining indicator changes, we study the process of technological development and change, and use ORA visualization tools to analyze dynamic network indicators, enabling multi-perspective analysis and characterization of targeted technological innovation network evolution.

3.1 Factors Influencing Technological Innovation Network Evolution

Technological innovation networks consist of core networks, auxiliary networks, and peripheral support networks [18]. 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. Technological progress drives the evolution of technological innovation networks, and such technical exchange is regional [19] and continuously evolves over time. Therefore, factors influencing technological innovation networks include innovation entities, core technologies in the field, hot technological functions, innovation regions, and time.

(1) Innovation Entities

Enterprises are the primary innovation entities, with their R&D activities serving as the driving force for technological innovation. As the main participants in market economic activities and the link between science and technology markets, enterprises are not only technology demanders and applicators but also technology suppliers, making them the core of technological innovation. Enterprises' patent activities as patent assignees demonstrate their principal role in

technological innovation. Universities and research institutions are technology developers whose R&D activities serve enterprises, but they may also become main entities in technological innovation networks if they master core technologies in the field.

(2) Core Technologies in the Innovation Field

Technology is the carrier of innovation, and successful development of new technologies forms the foundation for innovation generation. Therefore, core technologies influence the direction of innovation development, making their identification particularly important.

(3) Hot Technological Functions in the Innovation Field

Technological functions represent the specific capabilities of a technology and form the basis for whether patented technology can be marketed. The ultimate outcome of technological innovation is reflected in products, whose functions are closely related to technological functions, making them another influencing factor.

(4) Innovation Region

Technological innovation activities are not completed by individual enterprises or research institutions but constitute a regional behavioral activity, making innovation region a factor influencing technological innovation.

(5) Time

To maintain and expand their survival space, members of technological innovation networks continuously adjust their relationships over time, causing innovation entities, core technologies, hot technological functions, and innovation regions to evolve continuously.

Patent data provides rich standardized information. When innovation entities achieve breakthroughs in technical fields, they seek patent protection for their technological innovations. Therefore, patents are closely associated with technological innovation. Innovations in technical fields are first reflected in patents. Patent documents contain detailed information such as inventions, inventors, applicants, application dates, and regions, forming a time series of patent information. Consequently, patent information can reflect technological innovation activities: patent assignees represent innovation entities, IPC classification numbers represent technological innovation fields, patent functions represent innovative technological functions, application locations represent innovation regions, and publication or application dates represent the innovation timeline [5]. Thus, patent information content enables measurement of technological innovation networks.

3.2 Construction of Patent-Based Dynamic Network Meta-Matrix

Dynamic network analysis can be considered an extension of Social Network Analysis (SNA) and Dynamic Network Analysis (DNA) theories and methods,

combining cognitive science, social networks, and multi-agent systems. Dynamic network indicators are developed based on social network indicators, including conventional metrics such as degree and centrality, while expanding to numerous additional indicators that enrich dynamic network analysis methods and enable solutions to more complex problems.

Patent activities belong to technological innovation activities completed by enterprises, universities, research institutions, and R&D individuals. Therefore, patent activities can be viewed as organizational activities composed of these entities. Li et al. [17] used dynamic network analysis to calculate organizational activities by constructing meta-matrices.

The foundation of dynamic network analysis is the meta-matrix, where entities in the matrix represent the knowledge, resources, and tasks possessed by innovation entities. The meta-matrix forms the basis for calculating dynamic network indicators.

Dynamic Indicator Content

Indicator	Formula/Description	Meaning
Cognitive Demand	$X_{1i}, X_{2i}, X_{3i}, X_{4i}, X_{5i}$ represent: other innovation entities associated with entity i , technological functions possessed, technological function similarity, technological uniqueness, and dependence on other innovation entities	Identifies potential leaders in the network. This 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 adjacency matrix of the network, λ is a constant representing proportion	Measures node centrality in the network. Nodes with high authority centrality issue many connections, and the nodes they connect to also have many connections
Closeness Centrality	$C(n) = \frac{1}{n} \sum_{j=1}^n d(n, j)$ is the shortest path between points i and j , g is the number of nodes, examining the distance between innovation entities and other innovation entities	Calculates a node's centrality based on distance concepts

Indicator	Formula/Description	Meaning
Capability	Used to explore the degree of association between entities and other entities, describing their cooperative capabilities	$(RD \cdot 0.5) \cdot 10^i$ is the node, RD is the out-degree centrality of each entity in the network
Human Cost	The sum of knowledge, resources, and tasks possessed by the entity, representing the cost the entity has in the organization	Human cost represents the sum of technical collaborators, technologies, and technological functions possessed by technological innovation entities
Completeness Centrality	The sum of a node's in-degree centrality and out-degree centrality	The sum of a node's in-degree centrality and out-degree centrality
Technological Uniqueness	The degree of knowledge complementarity between two entities	The degree of knowledge complementarity between two entities
Technological Similarity	The degree of knowledge similarity between two entities	The degree of knowledge similarity between two entities
In-degree (Out-degree)	$\sum_{j \neq i} T_{ij}$ represents the node, j represents a node different from i, T represents the technology matrix, T represents technology, F represents technological function	In-degree is the number of connections to a node in a directed network, out-degree is the number of connections from a node

Indicator	Formula/Description	Meaning
Meta-matrix Element	$X(i, j)$ $X(i, j)$ i is the row of the matrix, j is the column of the matrix, m is the number of rows, n is the number of columns	Meta-matrix element

Technological Innovation Network Evaluation Indicator System

Measurement Object	Dynamic Network Indicator	Patent Dynamic Network Indicator Content	Technological Innovation Network Analysis Content
Innovation Entity	Cognitive Demand	Potential leaders in the technical field, possessing key technologies and key technological functions	Potential leaders in the technical field, possessing key technologies and key technological functions
	Authority Centrality	Patent assignees in core positions in the patent cooperation network	Innovation entities occupying dominant positions in the technological innovation network
	Closeness Centrality	Distance between patent assignees and other nodes in the network, calculating a node's centrality based on distance concepts	Measuring the closeness between innovation entities and other entities
	Capability	Degree of association between patent assignees and other patent assignees, representing the cooperative capabilities of patent assignees	Measuring the degree of association between innovation entities and other entities, and their cooperative capabilities
	Human Cost	Technologies and technological functions possessed by patent assignees	Technologies and technological functions possessed by innovation entities
Technological Innovation Field	Completeness Centrality	Sum of in-degree and out-degree centrality of IPC	Measuring core technologies in the innovation field

Measurement Object	Dynamic Network Indicator	Patent Dynamic Network Indicator Content	Technological Innovation Network Analysis Content
	Technological Uniqueness	Degree of difference between IPCs of a patent assignee and other patent assignees	Degree of difference in technologies among innovation entities
	Technological Similarity	Degree of similarity between IPCs of a patent assignee and other patent assignees	Degree of similarity in technologies among innovation entities
Hot Technological Functions	Completeness Centrality	Sum of in-degree and out-degree centrality of technological functions	Measuring hot technological functions in the innovation field
	Technological Uniqueness	Degree of difference between technological functions of a patent assignee and other patent assignees	Degree of difference in technological functions among innovation entities
Innovation Region	In-degree Centrality	In-degree centrality of patent application countries	Measuring technological innovation regions

4 Empirical Study on Targeted Technology Innovation Network Evolution

We conducted a detailed decomposition of targeted technology, listing as many keywords as possible related to the biomedical technology theme. 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 records. We cleaned the patent data using script-based cleaning strategies and cyclic cleaning strategies. The script-based strategy primarily addressed complex field content through pattern recognition methods combining defined rules, using regular expressions to construct identification and splitting points. The cyclic cleaning strategy was mainly used for splitting and extracting simple fields. The two cleaning strategy processes are shown in [Figure 1: see original paper] and [Figure 2: see original paper].

4.1 Evolution Analysis of Innovation Entities

(1) Innovation Entity Cognitive Demand

As shown in , larger indicator values indicate stronger R&D team strength of the patent assignee, suggesting the potential for that assignee to become a leader in the technical field.

Cognitive Demand Indicators

The top-ranked enterprises differ across each phase, and indicator values remain relatively small (below 0.05) in all phases, indicating that no absolute leading enterprise or institution has emerged in the targeted technology field. However, companies such as Blue Pharmaceutical Company and Insert Therapeutics currently show higher cognitive demand, suggesting they possess strong R&D teams and core patent technologies, potentially becoming leaders in the targeted technology field in the coming years. Meanwhile, cognitive demand indicator values show a year-by-year increasing trend, with maximum values rising from 0.026 to 0.036, indicating that a leader in the targeted technology field will likely emerge soon. When the cognitive demand indicator reaches 0.2, it signifies that a leading entity in the targeted technology field has established itself.

(2) Authority Centrality

Innovation entity authority centrality reflects the trend of strong-strong alliances in technology cooperation. Larger indicator values indicate higher status of the patent assignee in the cooperation network and that its cooperating innovation entities also possess relatively high centrality.

As shown by the indicator changes in , central network nodes differ in each phase, indicating that network central positions are continuously changing. During 2006-2008, the enterprise with high authority centrality was Tianyou International Holdings Limited. During 2009-2011, the indicator was high for research individuals such as Bernai J J. During 2012-2014, Blue Pharmaceutical Company became prominent, indicating that these enterprises had broad R&D scopes and cooperation in different phases. Authority centrality indicator values are concentrated above 0.4, suggesting high network centralization and close communication among technological innovation entities.

Authority Centrality Indicators

(3) Closeness Centrality

Closeness centrality calculates the centrality degree of an innovation entity in the technological innovation network, measuring the distance between the innovation entity and other innovation entities in the network.

As shown in , enterprises with high indicator values differ across phases. These enterprises' R&D teams cooperate closely, with relatively low dependence on others for their technological development and a larger number of jointly applied patents. However, indicator values are relatively small in each phase, while

authority centrality indicators are relatively high, indicating that targeted technology is currently widely distributed.

Closeness Centrality Indicators

(4) Capability

Capability represents the degree of association between nodes in the network. In the patent information meta-matrix constructed in this study, which includes cooperation networks, technology networks, and function networks, the capability indicator can measure the cooperative team strength and R&D capabilities of patent assignees.

As shown in , these enterprises are closely connected with other rights holders and have outstanding partners and R&D capabilities. The capability indicator values of top-ranked technological innovation entities are close to 1, indicating that these entities possess relatively large R&D teams in the targeted technology field.

Capability Indicators

(5) Human Cost

The human cost indicator represents the sum of collaborators, technologies, and technological functions connected to the innovation entity. A high human cost value for an innovation entity indicates that the patents it applies for involve broad technical fields and that it possesses numerous R&D personnel.

As shown in , enterprises with higher human 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 that R&D personnel mobility in these companies within the targeted technology field is relatively high.

Human Cost Indicators

4.2 Core Technology Analysis in Technological Innovation Fields

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

(1) Completeness Centrality

Completeness centrality represents the sum of a node's in-degree and out-degree centrality. In technological innovation networks, it can be used to measure core

technologies. Higher completeness centrality indicator values indicate that the technical field is a hot R&D area.

As shown in , indicator values for top-ranked hot technical fields have increased since 2008. During 2012–2014, the value for A61P-35/00 reached 0.489, indicating that research hotspots in the targeted technology field have become increasingly concentrated and the technology has matured. Among them, A61K represents medicinal preparations, A61P represents specific therapeutic activities of compounds or pharmaceutical preparations, and A61M represents devices for introducing media into the human body or onto it.

Completeness Centrality Indicators

(2) Technological Uniqueness

Technological uniqueness measures the degree of difference in technical fields researched by patent assignees. Higher technological uniqueness indicator values indicate that innovation entities are developing new technical fields and actively innovating.

This indicator measures the degree of technological complementarity between two innovation entities, representing the difference in IPCs between a patent assignee and other patent assignees in the technological innovation network. As shown in , these patent assignees research relatively unique technical fields with strong innovation. Their technical fields show relatively high degrees of difference compared to other innovation entities, indicating they are actively seeking technological breakthroughs.

Technological Uniqueness Indicators

(3) Technological Similarity

Technological similarity measures the similarity of technologies between two innovation entities. In the patent information meta-matrix, it represents the degree of difference in technical fields researched by patent assignees and other patent assignees. Higher technological similarity indicator values indicate that innovation entities research similar technical fields, potentially leading to patent infringement or competition.

As shown in , these innovation entities have relatively high similarity with other entities in their technical fields, potentially indicating competitive relationships or infringement issues. The indicator values are slightly smaller compared to technological uniqueness values, suggesting that targeted technology development is not yet mature and that similar technologies among enterprises are relatively few.

Technological Similarity Indicators

4.3 Technology Function Evolution Analysis

The evolution of the technology function network is shown in [Figure 4: see original paper] (solid points represent patent assignees, hollow points represent

technology functions). During 2006–2008, the network structure mostly featured multiple innovation entities connecting to a single technology function, with many innovation entities but few technology functions. During 2009–2011, both innovation entities and technology functions decreased. During 2012–2014, the numbers of both innovation entities and technology functions increased significantly, indicating technological breakthroughs and a notable increase in obtained technology functions.

(1) Completeness Centrality

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

Completeness Centrality Indicators

(2) Technological Uniqueness

As shown in , Koninklijke Philips Electronics consistently ranks high in technological uniqueness with stable performance. These innovation entities' technology application achievements show differences compared to other innovation entities, providing certain competitive advantages.

Technological Uniqueness Indicators

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 the regional distribution of patent assignees. Larger indicator values represent more patent assignees in that region.

As shown in , although the national distribution of patent assignees in the targeted technology field is relatively dispersed, the U.S. indicator value is significantly higher than other countries and consistently ranks first, indicating that U.S. innovation capability in targeted technology far exceeds others. Canada ranks second, and notably, China has recently replaced South Korea as the third-ranked country in patent applications, demonstrating enhanced innovation capability in targeted technology, though still with a considerable gap compared to the United States. Overall, core nodes show little change.

In-degree Centrality Indicators

Conclusions

The above analysis reveals that within the targeted technology field, the innovation network constructed from patents has undergone changes. Under different measurement indicator perspectives, some key nodes have gradually moved out

of critical positions while others have increased in importance, becoming key nodes:

- (1) In measuring the evolution of technological innovation entities, network changes reflect that innovation entities and their capabilities in the targeted technology field are continuously changing and 更迭. Under different measurement indicators, some key nodes show significant changes, indicating that innovation entities and their capabilities in the targeted technology field are in constant flux. Blue Pharmaceutical Company and Insert Therapeutics have gradually moved into key positions over time across various measurement perspectives, becoming major patent assignees. Overall, their technological innovation capabilities are stronger than other patent assignees.
- (2) In measuring core technologies in the innovation field, rankings across time periods show that core technology fields in targeted technology have undergone certain changes. Among them, A61P-035/00 maintains a stable first-place ranking, representing a recent R&D hotspot in targeted technology innovation. Meanwhile, A61K-47/48 has risen in ranking, becoming a new R&D hotspot. From the perspectives of uniqueness and similarity indicators, patent assignee rankings vary significantly across phases, with technological uniqueness values slightly larger than similarity values. This indicates that targeted technology development is not yet mature, and enterprises are actively seeking innovation.
- (3) In measuring technology functions, rankings across phases show significant changes in targeted technology functions. Indicator values for each technology function exceed 0.01 in all phases, indicating that diseases treated or functions performed by targeted technology are relatively dispersed and widely applied. In the analysis of technology function uniqueness, Koninklijke Philips Electronics consistently ranks high with stable performance, possessing unique technology functions and strong competitive advantages.
- (4) In measuring innovation region evolution, rankings across phases show that the United States has the most patents in targeted technology, followed by Canada. Notably, China has recently replaced South Korea as the third-ranked country in patent applications, indicating enhanced innovation capability, though still with a considerable gap compared to the United States. Overall, core nodes show little change.

This study conducted empirical analysis using targeted technology patent data from 2006–2014, revealing that China lacks core technologies and has not formed advantageous technology industries. Indicator analysis shows that global targeted technology R&D has evolved from targeted drug delivery and specific drug production technologies to treating specific diseases, while domestic development largely remains at the drug production stage. Dynamic network indicator values show that foreign enterprises rank at the top, indicating that

domestic enterprises lag behind in core technologies and technological innovation. Furthermore, technological innovation is dominated by universities and research institutes rather than enterprises, and a technological innovation network centered on enterprises has not yet formed. Comparing Chinese and U.S. technologies reveals that domestic innovation entities in targeted technology are primarily universities rather than enterprises, indicating that a sound technology development model has not yet been established in this field.

Recommendations

Patent documents, as important carriers of scientific and technological innovation achievements, fully record technological inventions and reveal technological development processes. Using patent information to measure technological innovation network evolution provides decision support for enterprises and governments. This study constructs a patent dynamic network-based measurement model for technological innovation network evolution, enriching measurement methods. Since dynamic networks contain numerous indicators, industry technological innovation network evolution measurements can select different indicator combinations based on analysts' subjective needs.

Indicator analysis reveals that during 2006–2008, core technology fields involved IPCs such as A61K-009/14 (fine particles, powders), A61P-035/00 (antineoplastic agents), and A61K-047 (medicinal preparations characterized by non-effective ingredients). During 2009–2011, core technology fields concentrated on A61P-035/00 (antineoplastic agents), A61K-47/32 (macromolecular compounds), and A61K-38/00 (medicinal preparations containing peptides). During 2012–2014, core technology fields focused on A61P-035/00 (antineoplastic agents), A61K-47/48 (non-effective ingredients chemically bonded to active ingredients), and A61K-009/14 (fine particles, powders). These R&D hotspots demonstrate that every 环节 in targeted drug delivery systems is crucial, with countries intensifying R&D in different technical aspects. For Chinese enterprises, this represents both opportunities and challenges—core competencies can be established in any 环节. We recommend:

1. **Strengthening R&D investment in core technologies** to establish technological advantages. Through knowledge network analysis, we find that global targeted technology has evolved from drug delivery to disease treatment, while domestic development remains largely at the drug production stage. Dynamic network indicators show foreign enterprises ranking at the top, indicating domestic enterprises lag in core technologies and innovation.
2. **Proactively establishing inter-enterprise technological innovation alliances.** Analysis of targeted technology cooperation networks and indicators reveals low levels of R&D cooperation and industrial concentration in China's targeted technology field, resulting in low patent product conversion rates. Establishing industry-university-research al-

liances and increasing patent technology product conversion will promote healthy enterprise development and improve benefits.

3. **Rational layout and correct technology investment selection.** Current global targeted technology involves numerous diseases and various carriers and formulations. Some technologies have been developed for many years without breakthroughs, increasing investment risks. Other technologies involve lower risks and can develop into competitive advantages—these should be vigorously developed.

Limitations and Future Research

This study empirically validates the feasibility of the patent dynamic network-based technological innovation network measurement system using targeted technology. However, several limitations remain:

1. The constructed patent information meta-matrix is not comprehensive enough. Future research should deeply mine various fields of patent information to build more comprehensive meta-matrices.
2. The constructed measurement evaluation indicators for patent-based technological innovation networks are not sufficiently rich. Dynamic networks contain many unique evaluation indicators that have not been fully applied to technological innovation network measurement.

References

- [1] Shi Chengqi, Dang Xinghua. Evolution of the Innovation Network: A Literature Review and an Agenda for Future Research [J]. *Science & Technology Progress and Policy*, 2013, 30(7): 156-160.
- [2] Jiang Junfeng, Dang Xinghua, Xue Weixian. An Evolutionary Model for Techno-innovation Network Structure: Analysis from the Viewpoint of the Embeddedness of Network [J]. *Systems Engineering*, 2007, 25(2): 11-17.
- [3] Koka B R, Prescott J E. The Evolution of Interfirm Networks: Environment Effects on Patterns of Network Change [J]. *Academy of Management Review*, 2006, 31(3): 721-737.
- [4] Rose S, Shipp S, Lal B, et al. Frameworks for Measuring Innovation: Initial Approaches [M]. <http://www.studymode.com/essays/Frameworks-For-Measuring-Innovation-1425052.html>.
- [5] Dudzevičiūtė G, Tvaronavičienė M. Measurement Framework of Innovation Activity: Theoretical Approaches' Analysis [J]. *Journal of Security & Sustainability Issues*, 2011, 1(1): 63-75.
- [6] Peng Dun. Research on Evolution of Techno-innovation Network in High-tech Industry—Application of Complex Networks [D]. Changsha: Hunan University, 2010.

- [7] Chang P L, Wu C C, Leu H J. Using Patent Analyses to Monitor the Technological Trends in an Emerging Field of Technology: A Case of Carbon Nanotube Field Emission Display [J]. *Scientometrics*, 2010, 82(1): 5-19.
- [8] Morescalchi A, Pammolli F, Penner O, et al. The Evolution of Networks of Innovators Within and Across Borders: Evidence from Patent Data [J]. *Research Policy*, 2015, 44(3): 651-668.
- [9] Wang Yanling. Technology Innovation Research in Particular Technology Area on the Basis of Patent Analysis: Analysis Framework [J]. *Studies of Science of Science*, 2009, 27(4): 622-628.
- [10] Liu Xiaoyan, Ruan Pingnan, Li Feifan. Driving Forces of the Technological Innovation Network Evolution Based on Patent [J]. *Forum on Science and Technology in China*, 2014(3): 136-141.
- [11] Wu C C. Constructing a Weighted Keyword-based Patent Network Approach to Identify Technological Trends and Evolution in a Field of Green Energy: A Case of Biofuels [J]. *Quality & Quantity*, 2016, 50(1): 1-23.
- [12] Li Yingmin. The Research on the Evolutionary of Global Innovation Network Based on Patent Analysis—Case of Panel Display Technology Field [D]. Dalian: Dalian University of Technology, 2013.
- [13] Ribeiro L C, Kruss G, Britto G, et al. A Methodology for Unveiling Global Innovation Networks: Patent Citations as Clues to Cross Border Knowledge Flows [J]. *Scientometrics*, 2014, 101(1): 1-23.
- [14] Liu Fengzhao, Fu Yao, Sun Yutao. The Distribution Structure Evolution of the US Technological Innovation Based on the Patent Output [J]. *Studies of Science of Science*, 2013, 31(7): 1086-1092.
- [15] Liu Tong, Guo Lugang, Yang Guancan. Evolution of Patent Cooperation Network Based on Dynamic Network Analysis: Taking Nano Technology as an Example [J]. *Journal of Intelligence*, 2014, 33(11): 88-93.
- [16] Zhai Dongsheng, Sun Wu, Zhang Jie. LTE TDD Technology Patent Analysis Based on the Dynamic Network Analysis [J]. *Journal of Intelligence*, 2014, 33(7): 63-69.
- [17] Li Dengjie, Zhai Dongsheng, Feng Xiuzhen, et al. Study of the Evolution of Technology Innovation Network in TCM Technology Based on Dynamic Network [J]. *Journal of the China Society for Scientific and Technical Information*, 2015, 34(11): 1164-1172.
- [18] Wu Jianlong, Wang Hongqi. Research on Innovation Network Architecture of High Technology Enterprises Cluster Based on Patent Analysis [J]. *Forum on Science and Technology in China*, 2010(8): 74-80.
- [19] Sun Yaowu. The Research on Technological Innovation Network of High-Tech Enterprises Based on Technology Standards [D]. Changsha: Hunan University, 2007.

[20] Carley K M. Dynamic Network Analysis [M]. Alphascript Publishing, 2003: 1-13.

[21] Carley K M, Reminga J, Storrick J, et al. ORA User' s Guide [C]. In: Proceedings of the 15th ACM SIGKDD International Conference on Knowledge Discovery and Data Mining. 2009.

Conflict of Interest Statement

All authors declare no conflict of interest.

Author Contributions

Zhai Dongsheng: Conceived research ideas, designed research methodology

Wang Meng: Collected and cleaned data, conducted experiments, drafted manuscript

Zhang Jie: Designed research methodology

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>.

[1] Wang Meng. Patent.xlsx. Targeted technology patent data.

Received: June 21, 2016

Revised: October 16, 2016

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

Source: ChinaXiv –Machine translation. Verify with original.