



# Measuring the Stability of Technical Cooperation Network Based on the Nested Structure Theory

Wenhui Liu, Guoqiang Liang<sup>(✉)</sup>, and Lizhi Xing

College of Economics and Management, Beijing University of Technology, Beijing, China  
liangggq@bjut.edu.cn

**Abstract.** Nested structure is a structural feature that is conducive to system stability formed by co-evolution. In our opinion, it is just like what the biological species do in the mutualistic ecosystem that enterprises collaborate to apply for patents in the technical cooperation network, changing to form one dynamic equilibrium after another. In this paper, a nestedness-based analytical framework is built to reflect the topological stability of the technical cooperation network of Zhongguancun Science Park (Z-Park). We study why this technically mutualistic ecosystem can reach a stable equilibrium with time going by, as well as, we propose an index called Nestedness Disturbance Index (NDI) to study what the role park areas and technical fields play in the steady states.

**Keywords:** Technical cooperation · HETCN model · Nested structure · NODF · Nestedness disturbance index

## 1 Introduction

In the real world, the network is not in a static state but is constantly evolving. The same is true for the technical cooperation network. With the development of science and technology, the number of technical entities is increasing, and the technical cooperation network is in the process of continuous dynamic evolution. However, the present research on the evolution of the technical cooperation network mainly focuses on the change in the overall network structure characteristics, the change in the distribution of network entities, and the distribution of network time and space [1–3]. Few studies focus on the robustness of technical cooperation networks. So this paper aims to propose the robustness measurement of the technical cooperation network.

After learning the relevant researches, we found that “Nestedness” is a structural measure of the overall stability of the ecosystem that seeking evolutionary balance [4–6]. For technical cooperation networks which also seek evolutionary balance, nestedness can be used to measure the robustness of the network, too. While Z-Park as a significance Chinese innovation ecosystem, its technical cooperation network can be a perfect example for this paper. Therefore, this paper takes Z-Park as an example, uses the nested structure to analyze the evolution trend of the robustness of the Z-Park technical cooperation network, and proposes the Nestedness Disturbance Index (NDI) to quantify the impact of different innovation entities on the robustness of the network.

## 2 Literature Review

### 2.1 Theoretical Development

In 1957, when Darlington studied the migration process of species, he found that when terrestrial species waded to the island, they would preferentially choose to inhabit the island closest to the land, and then some of them would reach the next nearest island through the shortest wading distance. As this process repeats, it naturally leads to a decline in the number of species geographically, reflecting the nesting characteristics 5. Based on previous research, Patterson et al. proposed the precise concept of nesting, that is, in a fully nested network, the neighborhood of a node with a lower node degree is a subset of the neighborhood of a node with a higher node degree 6. Dardanelli et al. found that the higher the degree of nesting, the stronger the resilience of the system after external disturbance, and the more stable the network structure [7]. The nested structure reflects the phenomenon that narrow-biological species (species with a lower degree of adaptation to the ecological environment) tend to interact with ubiquitous species (species with a higher degree of adaptation to the ecological environment) in the mutualistic network. The connection between the ubiquitous species constitutes the stable core of the entire ecological network, and the narrow-biological species surround this core so that the entire network structure is more stable [8].

Nested structures also exist in socioeconomic systems [9, 10], traditional and online social networks, and technological and information networks [11]. By reviewing the literature, it can be seen that the cooperation between various entities is an important prerequisite for the formation of the network nested structure.

### 2.2 Formation Mechanism

The reasoning behind the nesting structure was explained by the introduction of a self-organizing network model by Medan et al., who noted that nesting occurs when species switch their interactions in an attempt to increase the centrality of their neighbors [12]. Michael et al. proposed a network formation model in which nodes try to strategically maximize their centrality in the network in the presence of link decay. And both hierarchical organization and network nesting can be the result of a centrality-based network formation process [13]. Suweis et al. proposed a dynamic mechanism. He said that starting from a random species-species interaction matrix, species will reconnect their interactions to maximize their abundance. This dynamic will make the interaction network exhibit Nested structures [6].

After learning the researches, the following conclusions are drawn: (1) Most of the research on nested structure focuses on the formation of nested structure, which is more theoretical. (2) The related researches tend to study the formation process of nested structure in the network, but not enough attention is paid to the function of nested structure in the network.

### 3 Data and Modelling

#### 3.1 Data Sources

This paper takes Z-Park as an example to build the technical cooperation network and selects the enterprises in the list of high-tech enterprises in 2020 that provided on the website of the Administrative Commission of Zhongguancun Science Park as the network nodes. In addition, since the patent is used as an index of R&D output, which better reflects the degree of mutual learning and technology integration between enterprises [14], this paper selected the paper as the index to reflect technical cooperation between enterprises. What’s more, with the help of python, this paper capture the patent application information of the enterprises in the list in the global patent database of PatSnap, including patent publication number, application number, application date, title, application entity, park area, and technical field. Considering that there is a certain time lag between patent data disclosure and storage, the application time is set as 2008–2019. Besides, since the co-occurrence relationship of the patent application entities is used to map the cooperative relationship, this paper only retains the patent information of two or more application entities.

#### 3.2 HETCN Model

Through investigation, it is found that some high-tech enterprises obtain the source of innovation through purchase of patent licenses, and even technology transfer, while some other enterprises achieve innovation independently with the original patent applicant being the current patentee. Combined with the analysis paradigm of the network motif, we classify the relationship between enterprises and patents into five situations. In Fig. 1, the yellow square node at the top is the patent and the blue circular node at the bottom is the relevant entities. The blue solid line between the two types of nodes represents the patent ownership, while the dotted line represents the patent propagation path. The black line indicates a strong patent correlation between enterprises while the dotted line indicates a weak correlation [15].

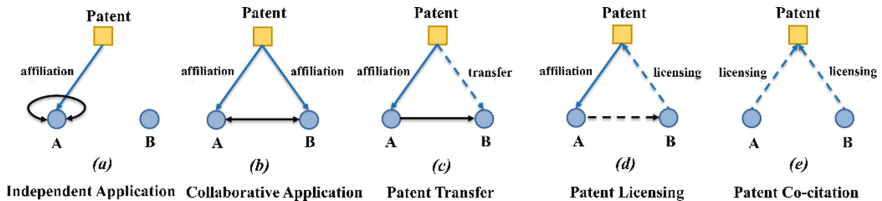


Fig. 1. Schematic diagram of technology diffusion process

After collecting and arranging the data, this paper selects the enterprises that meet the situation(b) as nodes to build a High-Tech Enterprise Technical Cooperation Network (HETCN). It can be represented by a graph  $G = (V, E)$ , where  $V$  is a node-set representing each enterprise, and  $E$  is an edge set, representing the relationship between technical cooperation among various enterprises. Since cooperation is coordinated with each other, the HETCN model constructed in this paper is an undirected network.

### 3.3 Nested Structure of HETCN

The growth mechanism of preferential links in complex networks makes each newly added node tend to be connected to the central node. Therefore, a small number of central nodes with larger node degrees form the core of the network, and other nodes with smaller node degrees are connected to the central node to form the periphery of the network, this “core-periphery” phenomenon is the nested structure discussed in this paper. Due to the heterogeneity of the network itself and the strengthening of the optimization mechanism, the nested structure is formed.

In technical cooperation networks, there are similar “core” and “periphery” entities. However, in such a network structure, although there are still absolute central nodes, the flow of resources leads to the formation of some “sub-center” nodes, which in turn form a balance with the center and conducive to the stability of the network structure. In the following, the node with larger node degrees will be called ubiquitous node while the node with smaller node degrees will be called narrow-biological node.

Figure 2 is a schematic diagram of the Z-Park technology cooperation network drawn by Gephi. As can be seen from the figure, in 2008, the technical cooperation network aggregated to a single ubiquitous node. By 2019, in addition to the largest ubiquitous node, multiple small aggregated ubiquitous nodes have gradually formed, and the nested structure of the technical cooperation network has gradually formed.

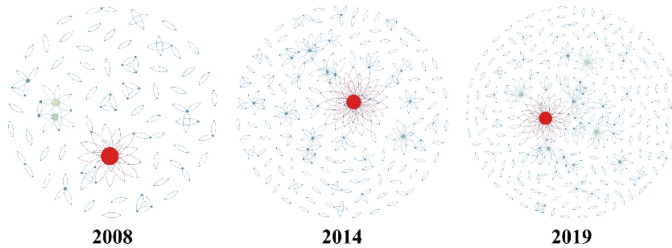


Fig. 2. The evolution trend of enterprise technical cooperation network

## 4 Methodology

### 4.1 Adjacency Matrix Rearrangement

This paper rearranges the adjacency matrix according to the size of the node degree to make it show the hidden nested features in the network, as shown in Fig. 3.

The blue dots in the figure represent the nodes in the network, while the blue squares indicate that there is an edge between the two nodes. What’s more, the white indicates that there is no connection between the two nodes. In the rearranged adjacency matrix, the uppermost and leftmost nodes have the strongest ubiquity, and the lowermost and rightmost nodes have the strongest narrowness [16].

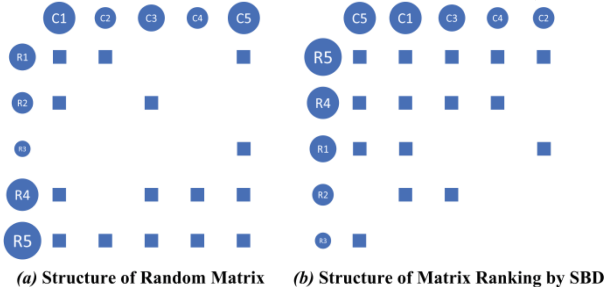


Fig. 3. Sorting of network adjacency matrix based on SBD algorithm

### 4.2 Measurement of the Nestedness

This paper use *NODF* index to calculate the nestedness of networks, which is based on two basic properties: Decreasing Fill (*DF*) and Paired Overlap (*PO*) [16].

Given that a matrix has  $m$  rows and  $n$  columns, and  $MT$  is the number of elements valued at 1 in any row or column. For any pair of rows  $(i, j)(i < j)$ , if  $MT_i > MT_j$ , then  $DF_{ij} = 100$ , otherwise  $DF_{ij} = 0$ ; the same is true for columns.

For any pair of rows  $(i, j)(i < j)$ , ( $PO_{ij}$ ) refers to the percentage of 10s in a given row  $j$  that is located at identical column positions to the 10s observed in a row  $i$ ; the same is true for columns. Therefore, for any up-to-down row pair, or any left-to-right column pair, the degree of paired nestedness ( $N_{paired}$ ) can be expressed by Eq. (1):

$$N_{paired} = \begin{cases} 0, & \text{if } DF_{paired} = 0 \\ PO, & \text{if } DF_{paired} = 100 \end{cases} \tag{1}$$

There are  $m(m - 1)/2$  row pairs in row  $m$ , and  $n(n - 1)/2$  column pairs in column  $n$ . Thus, the nestedness of the entire network can be calculated by ‘‘averaging all paired values of rows and columns’’

$$NODF = \frac{\sum N_{paired}}{\left[ \frac{m(m-1)}{2} \right] + \left[ \frac{n(n-1)}{2} \right]} \times 100 \tag{2}$$

where the *NODF* value ranges from 0 to 100, with  $NODF = 0$  indicating a non-nested network structure and  $NODF = 100$  indicating a fully nested network structure.

### 4.3 Nestedness Disturbance Index

In this paper, by removing any entity in the sub-network and calculating the *NODF* of the network composed of the remaining entities, we can measure the contribution of the entity to the technical cooperation network nesting. On this basis, this paper proposes the Nestedness Disturbance Index (*NDI*) as an index to measure the role of different agents in maintaining network nesting, which is expressed by Eq. (3):

$$NDI = \frac{(NODF_{Original} - NODF_{Remove})}{NODF_{Original}} \times 100 \tag{3}$$

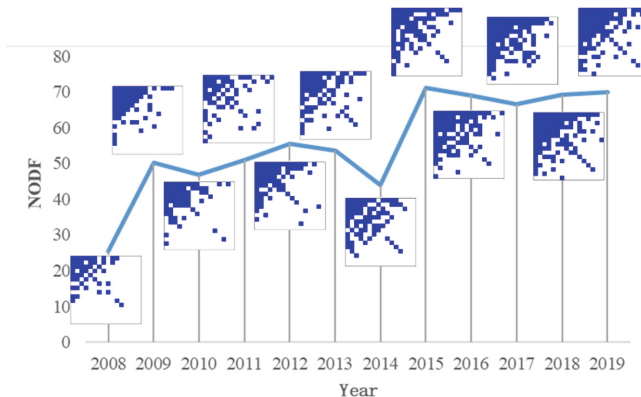
Among them,  $NODF_{Original}$  represents the original  $NODF$  value of the technical cooperation network,  $NODF_{Remove}$  represents the  $NODF$  value of the network after removing an entity. A positive  $NDI$  value means that the  $NODF$  value of the technical cooperation network decreases after removing an innovation entity, that is, the entity has a positive impact on maintaining the nesting of the network structure where it is located, and vice versa. This index is universal for measuring the contribution of any node in the network to the nesting of the network.

## 5 Results and Discussion

### 5.1 Park Area Scale Empirical Analysis

#### 5.1.1 Evolutionary Trend of Nestedness

According to the key field “affiliated park area” of the captured patent data, the HETCN is classified and aggregated, and finally formed Changping (CP) Park, Chaoyang (CY) Park, Dongcheng (DC) Park, Daxing-Yizhuang (DX-YZ) Park, Fangshan (FS) Park, Fengtai (FT) Park, Haidian (HD) Park, Huairou (HR) Park, Mentougou (MTG) Park, Miyun (MY) Park, Pinggu (PG) Park, Shijingshan (SJS) Park, Shunyi (SY) Park, Tongzhou (TZ) Park, Xicheng (XC) Park and Yanqing (YQ) Park such 16 nodes. Then this paper formed the technical cooperation networks from 2008 to 2019 and measured the  $NODF$  value of them, as shown in Fig. 4. Dividing the Z-Park into 16 parks may lead to area planning so that different parks may not integrate and complement each other. However, as can be seen from Fig. 4, from 2008 to 2019, the  $NODF$  value of HETCN at the park area scale fluctuated upward, that is, the degree of nesting among the parks gradually deepened.



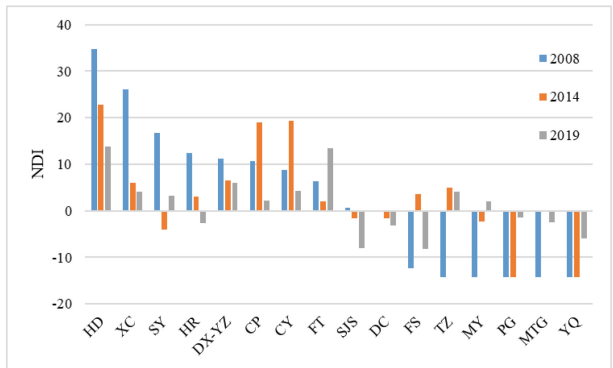
**Fig. 4.** Trends of the nested structure of HETCN at the park area scale from 2008 to 2019

The heat map in Fig. 4 can more clearly show the changes in the layout of technical cooperation in each park. It can be seen from the figure that the technical cooperation relationship between the parks gradually penetrates from the upper left corner of the adjacency matrix to the bottom, and the phenomenon of technology monopoly among a few

parks gradually weakened by the diffusion of technology among the ubiquitous parks. While the interaction between the narrow-biological and ubiquitous parks is enhanced, the technology spreads from the network center to the outer layers, making the entire Z-Park more stable [17].

**5.1.2 Simulation of the Robustness**

This section calculates the *NDI* of each park in 2008, 2014, and 2019, as shown in Fig. 5. On the one hand, it analyzes the overall impact of each park on the robustness of the technical cooperation network from a global perspective. On the other hand, from the perspective of time-series changes, the role of each park in maintaining network stability is studied, then we can identify which park plays a key role in maintaining the stability of HETCN.



**Fig. 5.** *NDI* of each park in 2008, 2014 and 2019

On the whole, an important player in improving the nesting of the network is the ubiquitous park, which is also an important factor affecting the robustness of the technical cooperation network. In contrast, the perturbation of the narrow-biological park is weak and has the opposite effect in improving the nesting. Further observation of the time-series changes of the *NDI* index of the parks shows that the *NDI* of the ubiquitous parks is decreasing year by year, and the *NDI* of the narrow-biological parks is increasing year by year. That is to say, the influence of the ubiquitous parks on the robustness of HETCN is gradually weakening, while the importance of the narrow-biological parks is gradually increasing. This shows that the technical connections between the various parks are gradually intensive, and they are truly moving towards the balanced development of each park.

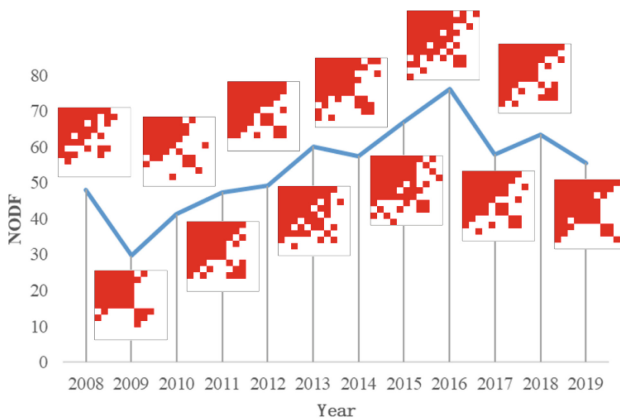
From an individual perspective, HD Park is the biggest factor affecting the robustness of the technical cooperation network at the park area scale. As the park with the most ubiquity, HD Park always ranks first in *NDI* value. Its removal will lead to a substantial reduction in the scale of the entire HETCN and rapid transmission of technical risks, which will seriously affect the technology-related enterprises in other parks. In turn, it will cause a strong disturbance to the robustness of HETCN.

In the figure, the NDI value of FT Park has risen significantly. From 2008 to 2019, its NDI ranking has risen to second place. In 2002, a large number of corporate headquarters have successively settled in, which has promoted the technical connection between FT Park and other parks, making FT Park play an increasingly critical role in maintaining the stability of HETCN.

## 5.2 Technical Field Scale Analysis

### 5.2.1 Evolutionary Trend of Nestedness

According to the key field “technical field” of the captured patent data, the HETCN is classified and aggregated, and finally formed Advanced Manufacturing Technology (AMT), Aerospace Technology (AT), Bioengineering and New Medicine (BNM), Electronics and Information Technology (EIT), Environmental Protection Technology (EPT), Modern Agricultural Technology (MAT), Maritime Engineering Technology (MET), Nuclear Application Technology (NAT), New Energy Technology (NET), New Materials and Applications (NMA) and Related to the top ten above (REL) such 11 nodes. Then this paper formed the technical cooperation networks from 2008 to 2019 and measured the *NODF* value of them, as shown in Fig. 6. It can be seen that from 2008 to 2019, the *NODF* value of HETCN at the technical field scale fluctuated continuously, but the overall value increased, and the degree of nesting in each technical field gradually deepened. This shows that high-tech enterprises in different fields have gradually formed a stable technical cooperation relationship.



**Fig. 6.** Trends of the nested structure of HETCN at the technical field scale from 2008 to 2019

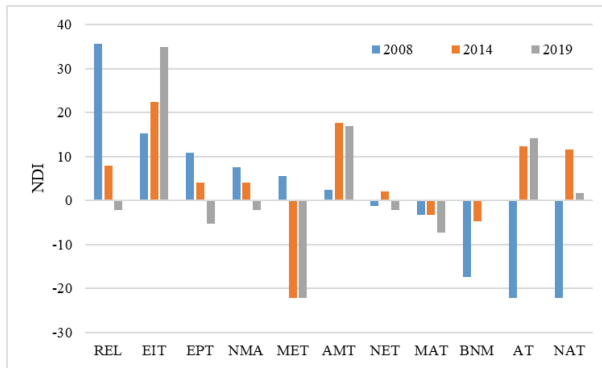
The heatmaps in Fig. 6 provide a clearer picture of the evolution of technical partnerships across technology domains. It can be seen from the figure that the technical cooperation relationship between enterprises gradually penetrates from the upper left corner of the adjacency matrix to the bottom, so we can learn that the scope of technology diffusion increases and the connection between different technical fields is gradually



established. In addition, the integration of different technical fields shows certain modularity, which shows that a mature integration trend has been formed between some technical fields.

### 5.2.2 Simulation of the Robustness

This section calculates the *NDI* of each technical field in HETCN in 2008, 2014, and 2019. On the one hand, the overall impact of each technical field on the robustness of the technical cooperation network is analyzed from a global perspective. On the other hand, from the perspective of time-series changes, we studied the role of various technical fields in maintaining network stability so that we can identify the technical fields that play a key role in maintaining the stability of HETCN, as shown in Fig. 7.



**Fig. 7.** *NDI* of each technology field in 2008, 2014 and 2019

On the whole, compared with the innovation network at the park area scale, the *NDI* value of each technology field in the technology field scale innovation network does not change significantly in time series. In 2019, the number of technical fields with a negative *NDI* increased, and the number of technical fields that supported the stability of HETCN decreased. Due to the strong technical versatility and wide range of technology diffusion, enterprises in the field of ubiquitous technology have technology cross-integration with most technical fields.

From an individual level, EIT is the technology field with the strongest ubiquity and the strongest disturbance to the robustness of HETCN. In the era of Industry 4.0, information technology drives the development of the manufacturing industry, and the manufacturing industry is deeply integrated into information technology and becomes a part of the information industry. EIT, as the most basic and necessary technical form in various fields, plays an important role in the robustness of the entire HETCN.

However, NAT, as a technical field with strong narrowness, has a strong disturbance to the robustness of HETCN, and this characteristic is not found in different parks. Since technological diversity is the premise of technological integration and diffusion, and also a necessary condition to achieve innovation, this paper makes certain conjectures. The

reason why NAT has strong narrowness and strong nesting perturbation is that the strong professionalism makes it get rid of dependence and become an indispensable technical feature.

## 6 Conclusion

This paper takes Z-Park as an example to construct a network model of enterprise technology cooperation. Based on the two keywords of “affiliated park area” and “affiliated technical field” in the patent information, this paper uses the nesting structure as the evaluation index of the robustness of the technical cooperation network. On this basis, this paper proposed NDI to identify the key parks and technical fields with the strongest disturbance to the robustness of the technical cooperation network. The conclusions of the study are as followed.

With the increase in technical cooperation between ubiquitous and narrow-biological entities, technological resources spread from the core of the network to the periphery, and the technical relationship is more stable. Due to the scarcity of technical resources, there is competition for resources among innovation entities, and their ubiquity existence is one after another. However, the ubiquity of the main body has not changed much in a short period. In addition, due to the wide range of technical associations, the ubiquitous entities are easy to conduct risks and have a strong disturbing effect on the robustness of the technical cooperation network. While narrow-biological entities, due to the small scope of technological diffusion and the peripheral dependence of the network, has weak risk transmission ability, and will not disturb the robustness of the technical cooperation network.

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