Analysis on Complex Network Characteristics of Multinational Corporations' Technology Spillovers in Host Countries
Yan CHANG¹,*, Zi-tong HUANG² and Fu-you JIANG³

¹State Grid Energy Research Institute, China
²Beijing Institute of Technology, China
³State Grid Sichuan Electric Power Company, CHINA

*Corresponding author

Keywords: Multinational corporation, Technology spillovers, Complex network.

Abstract. Embedding NIS into multinational R & D center can be analyzed from the perspective of complex network theory. First, Embedding NIS into multinational R & D center is essentially to make it an open system, in which multinational R & D center is the subject of external innovation to exchange resources (including talents, technology, etc.) with the outside world. In order to integrate into the innovation environment of the host country, the multinational R & D center must constantly interact with the host country's innovation subject (the innovation subject mainly refers to the government, universities, enterprises, agents, etc.) to exchange information and knowledge. Through these innovative activities, multinational R & D centers have established a network system with various types of links established by these innovative subjects. The research results show that the diffusion of R & D centers are more complicated, but they have obvious regularity and stability. Transnational R & D center has the awareness of preferred embedding merit, however, with the deepening of embeddedness, transnational R & D centers are gradually emerging in the host country's national innovation system, and they have a strong linkage and positive correlationship.

Introduction

In the context of R & D globalization, the openness of national innovation system is becoming more and more important. Globalization of R & D reflects the globalization trend such as economic globalization in the field of science and technology. The global distribution of R & D resources and the global sharing of R & D results have become its main connotation. As Patel puts it, "R & D is moving towards globalization, with advanced technology-based multinationals setting up R & D centers around the world to implement them." Foreign R & D center embedded in the host country NIS is driven by its own interests, at the same time, foreign R & D center has become an important way for the host country to realize innovation and globalization.

The Meaning of Technology Spillover Effect

Blomstrom (1998) defines the spillovers of FDI as an external effect that multinational companies implement FDI in their host countries can lead to great progress of local technology and productivity, however, multinational company itself cannot obtain the whole benefits. He divides the FDI Spillover Effect in the host country into two categories: one called “Productivity Spillovers”, which means the host country gains advanced technology by introducing FDI to improve productivity; the other one called “Market Access Spillovers”, refers to the host country enterprises sell their products to international markets by introducing FDI and with the help of great power from multinational companies.

FDI technology spillover effect has both narrow sense and broad sense. FDI technology spillover effect in the narrow sense refers to the multinational enterprises investing directly in the host country, especially in the developing countries. The advanced production technology, operating philosophy and management experience are infiltrated into the local enterprises through some
involuntary spillover channels. This can improve the host country enterprise’s technology level, thereby stimulate economic growth of domestic departments, which reflects economic externalities. FDI technology spillover effect in the broad sense includes technology diffusion and technology transfer. In the discussion of FDI effects, foreign literature generally does not distinguish technology spillovers, technology diffusion and technology transfer strictly. In this paper, the generalized FDI technology spillover effect is adopted.

The research on complex networks includes the small-world network model proposed by Watts & Strogatz (1998), the scale-free network model proposed by Barabasi & Albert (1998), the biological evolution model and the neural network model proposed by Bak & Sneppen (1993). From the perspective of network’s nature, the so-called network are complex relationships composed by interactive entities in the system. But from the perspective of graphical situation showed by the complex network, the complex networks $G(V, E)$ are the graphics mainly connected by the point $V$ and the line $E$, in which the set of lines are showed by $V = \{v_1, v_2, v_3, ... v_n\}$ and the set of points are showed by $E = \{e_1, e_2, e_3, ... e_n\}$. Complex networks have the following core concepts:

**Conceptual Definition and the Establishment of Research Framework**

**Degree and Degree Distribution**

The so-called degree represents the connection line of one point. But the measurement of degree does not means the number of lines connected by the point directly. The reason is that there may be an extra line between two points in the network. Assume $k_i$ as the degree of point $i$. The average of the degrees of all points is denoted by $\langle k \rangle$. It can be seen from the characteristic of networks that any lines connect two points, therefore the average degree can be expressed as:

$$\langle k \rangle = \frac{1}{N} \sum_{i=1}^{N} k_i = \frac{2M}{N}$$  \hspace{1cm} (1)

In this formula, we use $M$ to show the total number of lines and $N$ to show the total number of points.

The so-called degree distribution shows the strength of the network connection. We use $P(k)$ to show the degree distribution, which means the probability when the degree is $k$ on a point.

$$P(k) = \frac{1}{N} \sum_{i=1}^{N} \delta(k - k_i)$$  \hspace{1cm} (2)

Through a lot of research, scholars have found that the scope of degree shows different distributions which is influenced by the change of network framework. In a complex network, the stronger the interaction, the greater the degree, then the greater they are influenced by each other.

**Average Path Length, APL**

Assuming that the distance between point $i$ and point $j$ is $d_{ij}$, we define $d_{ij}$ the number of lines of shortest distance between two points. Then, $L$ is defined as the average distance containing all points in the network:

$$L = \frac{2}{N(N-1)} \sum_{i=1}^{N} \sum_{j=i+1}^{N} d_{ij}$$  \hspace{1cm} (3)

In this formula, $N$ represents the number of points in the network. The longest distance in the network is diameter, presented by $D$. 


\[ D = \max \{d_{ij}\} \quad i, j = 1, 2, \ldots, N \quad i \neq j \]

\( L \) and \( D \) represent the efficiency of network transmission.

### Clustering Coefficient

Suppose that point \( i \) is connected to point \( j \), point \( j \) is connected to point \( m \), and point \( i \) is connected to point \( m \). This is called "clustering feature" in the network. Here we use the Clustering Coefficient to represent this feature.

Assuming there are \( n_i \) edges connected to point \( i \), then the other points connected to the \( n_i \) edges are the neighbors. Through theoretical analysis, we can see that the edge connected with \( n_i \) points has at most \( \frac{n_i(n_i - 1)}{2} \), but in the real network, actually \( n_i \) can connect \( E_i \) edges, then \( C_i \) is equal to \( \frac{E_i}{2E_i} \), expressed as:

\[
C_i = \frac{n_i(n_i - 1)}{2}
\]

Then, the entire network \( C \) is the mean \( C_i \) at a random point \( i \), expressed as:

\[
C = \frac{1}{N} \sum_{i=1}^{N} C_i
\]

The higher the clustering coefficient is, the more connections between the subject and the whole network are and the more important the position is, which means the core position in the whole network.

### Betweenness

Betweenness means the number of shortest lines that pass a certain point. It represents the point's influence in the whole network. Here, we use \( B_n \) to represent the betweenness of \( n \) points, expressed as:

\[
B_n = \sum_{i,j}^{} \frac{g_{ij}}{g_{ij}} \quad i, j \neq n, \quad i \neq j
\]

In this formula, \( g_{ij} \) represents the number of shortest lines that pass \( i, j \), \( g_{ij} \) represents the number of shortest lines that pass point \( n \) in both \( i \) path and \( j \) path.

### Degree-Degree Correlation

Assuming that points with large degrees in the network are more likely to be connected with the large-degree points, we call this phenomenon positive connections. Assuming that points with large degrees in the network are more likely to be connected with the small-degree points, we call this phenomenon negative connections. Newman use the Pearson correlation coefficient \( r(-1 < r < 1) \) between degrees to show their degree of correlation, calculated as follows:

\[
r = \frac{\frac{1}{M} \sum_{i,j} j_i k_j - \left[\frac{1}{M} \sum_{i} \frac{1}{2} (j_i + k_i)\right]}{\frac{1}{M} \sum_{i} \frac{1}{2} (j_i^2 + k_i^2) - \left[\frac{1}{M} \sum_{i} \frac{1}{2} (j_i + k_i)\right]}
\]

In this formula, \( j_i \) and \( k_i \) represent degree at point \( i \) and \( j \). \( M \) represents the total number included in the whole network. The scope of \( r \) is \((-1, 1)\). When \( r > 0 \), it is a positive connection; when \( r < 0 \), it is a negative connection; when \( r = 0 \), it is not relevant.

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Clustering-Degree Correlation

Assume the average clustering coefficient of point $k$ is $C(k)$, then the relationship between $C(k)$ and $k$ is called Clustering-Degree Correlation. Through a large number of empirical studies, foreign scholars show that, the relationship between $C(k)$ and $k$ is as follows:

$$C(k) \propto k^{-1}$$

In general, cluster correlation expresses the hierarchical nature of the network.

The Establishment of Complex Network

The BA model in complex network systems is now introduced into the field of management to explain the complexity of social network systems. BA model introduces the concept of scale-free on the basis of the SW model, and has strong applicability to the multinational companies’ embedding into the national innovation system of the host country.

In order to analyze the interaction between the innovation subjects in the network, we take three innovation subjects in the network as an example to analyze the interaction in the innovation network. If there are two innovation subjects in the host country’s innovation systems choose to accept multinational R & D centers, which means to accept multinational R & D center’s embedding, at this time, the probability of multinational R & D center’s embedding is:

$$q_n^i = \frac{C_n^3 C_{n_i}^i C_{n_i}^{i-1} + C_{n_i}^{i-1} C_{n_i}^{i-2} + 3p_n^i(p_n^i-1)p_n^{i-1} + p_n^i(p_n^i-1)(p_n^i-2)}{C_n^3 t_n(t_n-1)(t_n-2)}$$

In this formula, $t_n$ represents the accept quantity at point $n$. Suppose $p_n^i >> 2$, $t_n >> 2$, then when $n \rightarrow \infty$, $t_n \rightarrow 1$, $t_n \rightarrow \infty$, $p_n^i \rightarrow 1$, $p_n^i \rightarrow 2$, $p_n^i \rightarrow 1$, assume $X_n^i = p_n^i / t_n$, $p_n^i = 1 - p_n^i$, we can draw a conclusion as follows:

$$q_n^i \approx 3(X_n^i)^2(1 - X_n^i) + (X_n^i)^3$$

(9)

Assume $X(n, 1)$ and $q(n, 1)$ agree with formula(3-5) $X_n^i, q_n^i$. Suppose the fixed point $x_1 = 0, x_2 = 0.5, x_3 = 1.0$. Using the BA network analysis method, we get Figure 1 and 2; Suppose the number of innovation subjects in the innovation network increases to 5, we can get:

$$q_n^i \approx (X_n^i)^2 + 5(X_n^i)^3(1 - X_n^i) + 10(X_n^i)^3(1 - X_n^i)^2$$

(10)

![Figure 1. Three-person function relationship simulation diagram.](image1)

![Figure 2. Five-person function relationship simulation diagram.](image2)

It can be seen from the analysis above, both three-person and five-person in the innovation network represent the network evolution process of embedding NIS into the multinational R & D center, and through the interaction with the innovation subjects, forming an agglomeration effect, which is important for enhancing the NIS ability of the host country.
The development of complex network brings a new perspective to solve problems for the innovation research. At present, some scholars have studied the innovation from the network perspective. Freeman (1991) argues that the innovation subjects present a growing trend through formal or informal network interactions, but he only applies the concept of the network and does not carry out deep analysis. The study argues that innovation is a kind of social activity that builds networks and uses cross-border alliances and the development of software products in the network as a case to carry out an empirical research. The purpose of the study is to challenge and transcend the view that “there is fairly high degree of trust in the relationship between innovation networks” and to understand the innovation network as a stable and dynamic interaction between the subjects. This paper believes that the theory of complex networks is applicable to the analysis of embedding NIS into multinational R & D centers. In fact, the multinational R & D centers entering the host country is entering the host country's innovation network. We can not only analyze the network characteristics and structure by simulation analysis method, but also search for its interaction mechanism from structural equation perspective.

Conclusion

Based on the simulation model of the complex system theory, this research explores the multinational R & D center embedding and the open national innovation system construction, focusing on the interaction and dynamic evolution process. The results show that: (1) In the process of embedding the R & D center into the host country's innovation system, the degree of interaction between the host country's innovation subject and the multinational R & D center is proportional to the opening degree and the embedding depth. (2) Because of the interaction of non-linear factors in the system, when the system fluctuation reaches critical point, the system will evaluate from the initial state to the new state and continue moving towards the advanced and ordered direction; (3) During the initial embedding process, multinational R & D center only interact with surrounding innovation subjects, which means that multinational R & D centers in the host country is still in the exploratory stage. With the deepening of embedding, the multinational R & D center begins to expand to the whole industrial chain of the host country and deep into it. But at this moment, the interaction between R & D center and host country innovation subject is still not frequent and there remains blank area. With the further development of the embedding, the multinational R & D centers extend to the industrial chain of the host country to make the biggest gains, and the relationship between the host countries innovation subjects is gradually building. With the multinational R & D center in the host country deeping into the whole industry chain, interaction of the innovation subjects show a "blowout" situation.

With China's opening, the R & D centers of multinational corporations have settled in China. They have become an important part of China's innovation activities. The R & D centers are an important part and force of China's national innovation system. From the simulation results above, we can see that there is still an interactive vacuum. The probable problem is that the grasp of the innovation subjects in the host country is not comprehensive and the effect of government, universities and other innovation subjects is ignored. Our government plans to build an open national innovation system, the embedded R & D center is bound to bring development to the open innovation trend. In the context of the innovation system incorporated into the host country, there are obvious correlation characteristics in the network relationship between the Chinese innovator and the multinational R & D center. Therefore, it’s necessary for policy makers to promote organic integration and synergistic development of national innovation subjects driven by the interdisciplinary R & D centers, and to promote the interaction to form organic linkages and form an open exchange mechanism of knowledge, information, capital and talent. So as to realize the collaborative development of macro innovation environment and micro innovation subject.

Acknowledgement

This research was financially supported by the State Grid’s science and technology projects—
Research on Key Technology of Industrial Ecosystem Construction and Collaborative Development.

References
