# The Application of Complex Network Analysis in Business Ecosystem Research

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## ABSTRACT

This paper reviews the application of complex network analysis in the study of business ecosystems. First, it elaborates on the research background, significance and theoretical basis, including the basic concepts, analysis methods and related theoretical models of complex networks; second, it outlines the characteristics of business ecosystems and demonstrates the role of complex network methods in ecological structure mapping, dynamic simulation and strategic optimization through case analysis; finally, it discusses the application challenges and development trends. Studies have shown that complex network analysis can effectively reveal the topological structure, resilience and evolution mechanism of business ecosystems, provide scientific tools for enterprise decision-making and ecological management, and support sustainable innovation and value co-creation.

**Keywords:** complex network analysis, business ecosystem, network topology, ecological resilience

## 1. INTRODUCTION

### 1.1 Research background and significance

As a dynamic organizational form, a business ecosystem is composed of multiple participants such as enterprises, suppliers, customers and regulatory agencies, and achieves value creation and sharing through interdependence and cooperation. The complexity of this ecosystem is because the things inside will influence each other, and the influence mode is not a simple linear relationship, and it will also produce some unexpected new features. In addition, the external environment is always changing, so it is difficult to fully understand how it works with the old management methods [1]. Complex network analysis, as an interdisciplinary tool, introduces indicators such as degree centrality, clustering coefficient and intermediary centrality to measure the degree of connectivity, modularity and resilience of ecosystems, which helps us find out those key nodes and understand how the whole system has evolved [2]. In recent years, with the rise of digital platform, the research on business ecosystem has paid more and more attention to the angle of network. For example, in the entrepreneurial ecosystem, people will use network simulation to evaluate its resilience and guide how policies should intervene [3]. The significance of this analysis method lies in that it can make our business decisions more scientific and promote sustainable development and innovation. For example, through text network analysis, we can track the new trend of ecological research and highlight the role of platform and collaboration [4]. Using AI visualization technology, we can make a dynamic knowledge map and help us make ecological decisions smarter [5]. There is also a concrete example of ecological network modeling in the telecommunications industry, which also shows that forward-looking analysis is particularly useful for strategic planning [6]. Generally speaking, complex network analysis enriches business theory and gives us practical tools to deal with the challenges of globalization and technological change.

### 1.2 Research Objectives and Methods

This study wants to systematically see how people use complex network analysis to study business ecosystem, and see what theories, methods and future development directions it uses. We put the existing research data together to explore how this analysis method can be used to draw the structure map of the ecosystem, simulate its dynamic changes, and help optimize the strategy, so as to provide a reference framework for academic research and practical application. Our goal is to find out what is missing in the research and put forward the future research direction to help the business ecosystem become more flexible and innovative.

This study uses the method of literature review, combining qualitative analysis with quantitative analysis. First of all, we

collect relevant papers from academic databases such as Scopus and Web of Science to ensure that they cover different time periods and various types. Then, the core concepts, application cases and challenges are extracted by content analysis tools. Finally, a framework is integrated and evaluated based on network theory. This method emphasizes objectivity and comprehensiveness, avoids our own subjective bias, and makes the results more reliable through cross-validation.

## 2. THEORETICAL FOUNDATIONS OF COMPLEX NETWORK ANALYSIS

### 2.1 Basic Concepts of Complex Networks

A complex network is a system composed of many nodes and edges. Nodes can represent people like companies or us, while edges represent the relationship between them, such as cooperation or competition. Different from the casually connected network, this network has the characteristics of small world, scale-free distribution and community structure. Small-world characteristics mean that the average distance between nodes is short, but the degree of aggregation is high, so that information can be transmitted very quickly; Scale-free distribution means that the number of connections of nodes obeys power law distribution, and only a few central nodes hold most connections [7]. In the business ecosystem, people use these concepts to describe the structure of supply chain or innovation alliance, and help us find out who is the core role and where it is fragile [8]. Complex networks also have dynamic characteristics, such as robustness and adaptability, and external interference may cause a series of failures [9]. These basic concepts originally came from physics and mathematics, and later they were also used in social sciences, which provided a framework for us to analyze how the business ecosystem evolved and was stable [10].

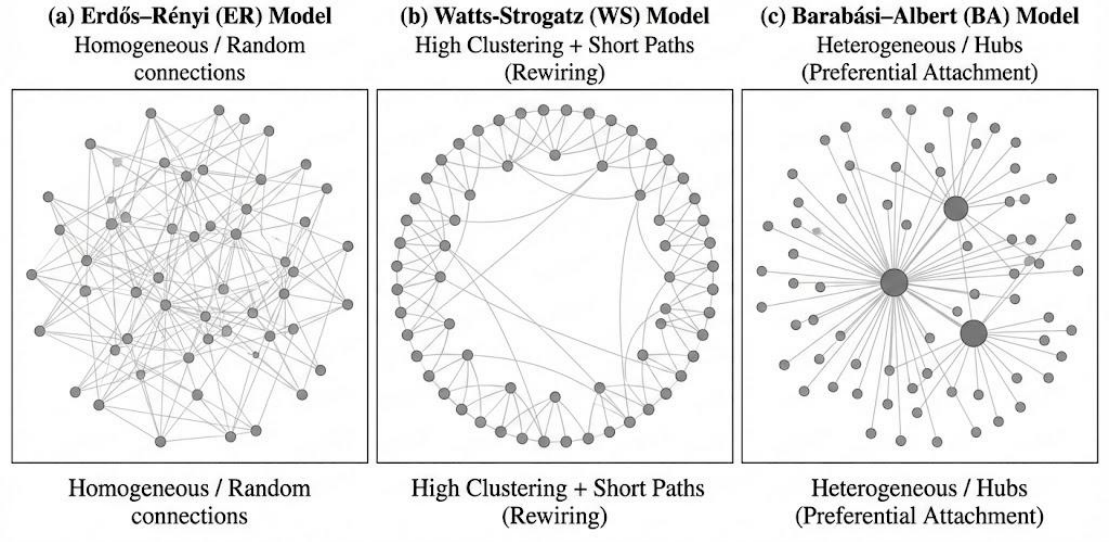
### 2.2 Overview of Network Analysis Methods

Network analysis methods include static methods and dynamic methods. The former mainly depends on structural indicators, such as centrality, modularity and density, which are used to measure what the network looks like; For the latter, time series simulation, such as random walk or diffusion model, will be used to grasp how the network changes step by step [11]. The common static method is Social Network Analysis (SNA), which uses a matrix to represent the network, calculates how important the nodes are, and can be used to evaluate the partnership in business [12]. Dynamic methods, such as Agent Basis Modeling (ABM), will simulate how individuals interact with each other to predict how the whole ecosystem will react [13]. These methods are often used together with data mining technology, such as graph embedding algorithm, which can turn the network into a low-dimensional vector, so that machine learning is more convenient to use [14]. In the study of business ecosystem, the method review emphasizes the need for multi-layer network analysis and the combination of different types of interactions, so that the results will be more accurate [15]. Generally speaking, the network analysis method has changed from describing "what" to predicting "what will happen", which can help us make better decisions.

### 2.3 Related Theoretical Models

Figure 1 shows the structural characteristics of three typical complex network topology models. (a) The ERDS–Ré nyi (ER) model presents a random and uniform connection, with similar degree distribution of all nodes and randomly generated edges[16], which is suitable for benchmark comparison, but it is difficult to capture the heterogeneity of the real ecosystem; (b) Watts-Strogatz (WS) model forms ring structure and random bridge through reconnection mechanism, which realizes high clustering coefficient and short average path length, reflects the characteristics of small world[17], and is helpful to simulate the rapid dissemination and local cooperation of information in business ecology; (c) Barabá si–Albert (BA) model generates scale-free distribution based on priority connection mechanism[18], and a few hub nodes (such as platform enterprises) dominate the network connection, highlighting the heterogeneity of business ecology, the role of key nodes and the evolution mechanism[19].

Figure 1. Comparison of three typical complex network topology models




## 3. APPLICATION OF COMPLEX NETWORK ANALYSIS IN BUSINESS ECOSYSTEMS

### 3.1 Overview of Business Ecosystems

A business ecosystem is an activity network composed of companies [20], institutions and individuals, who share resources and help each other to create value together [21]. This system attaches great importance to the leading role of the platform, modular structure, and the ability to constantly adapt to changes. It is different from the traditional supply chains, and it emphasizes nonlinear interaction and new ideas that pop up suddenly [22]. The research shows that the research on ecosystem has changed from a simple description to a network perspective. Although network theory is not widely used, it can help us to see clearly the relationship between structure and performance [23]. The main characteristics of this system include fuzzy boundaries, many layers of relationships, and sensitivity to external environment, which can promote its transformation to a more sustainable direction [24].

In the overview, this ecosystem framework combines the social network theory, which distinguishes unit analysis, relationship types and worldview dimensions, and can help us to do strategic decision-making [25]. These concepts laid the foundation for the analysis of complex networks, with special emphasis on embeddedness and functional networks, which can make things easier and make judgments more objective [26].

### 3.2 Application Case Analysis

The application of complex network analysis in business ecosystem reveals the dynamic characteristics through topological modeling and index evaluation. For example, in the business service ecosystem, we use time-based correlation bipartite graph to simulate the interaction of service entities, such as quantization distribution (following power law characteristics), clustering coefficient (higher value means closer local cooperation) and Herfindahl index (reflecting market concentration), so as to identify key nodes and evolution mechanism [24]. An empirical case is the analysis of marine logistics service network, which shows the power-law cooperation mode (a few ports dominate connectivity) and the influence of economic events, such as the global financial crisis in 2008-2009, which led to the decline of network density, connectivity fluctuation and the shrinking of giant components [27]. Another case focuses on sustainable transformation, which combines business ecosystem and social network theory, analyzes Tesla's second-hand data, and constructs an ecosystem footprint map (covering the multi-functional interaction among automobiles, energy storage and charging networks) to support resource allocation optimization and decarbonization target evaluation [25].

Figure 2. Network structure of key hub nodes and peripheral entities in a business ecosystem (scale-free feature example)

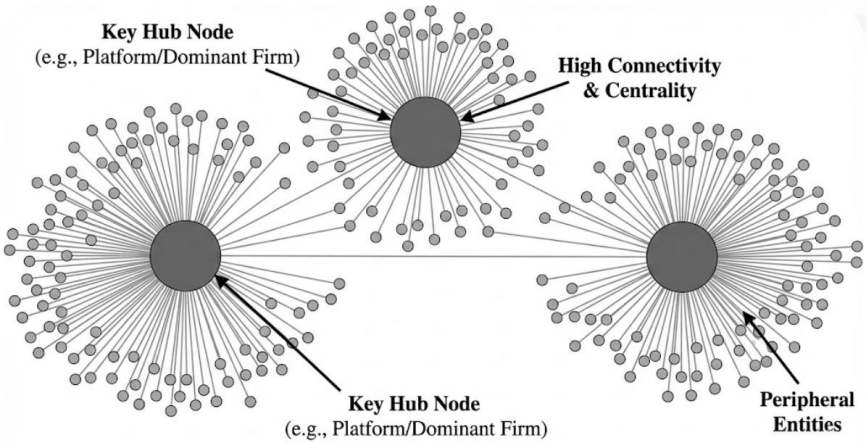



Figure 2 illustrates typical scale-free network structure characteristics in a business ecosystem. A few key hub nodes (such as platforms or leading enterprises) have a very high degree of connectivity and centrality. They are directly connected to a large number of peripheral entities, but peripheral entities are rarely connected to each other. This structure embodies the preferential connection mechanism of Barabási-Albert model. In the business ecosystem of the real world, this shows that platform enterprises dominate the value distribution and resource flow, which improves the system efficiency, but also increases the risk of relying on hub nodes. This feature is reflected in the case of marine logistics service network and Tesla ecosystem. A few core nodes dominate the cooperation mode and affect the resilience of the whole system.

## 4. CONCLUSION

Complex network analysis provides a powerful theoretical tool and method for the study of business ecosystem, which can clearly show what structural characteristics are in the ecosystem, how they change, and what role those key parts play. By reviewing some basic concepts, analytical methods and theoretical models, and then looking at how they are used in the real business ecosystem, we find that complex network analysis can not only help us figure out how enterprises depend on each other, find out where the whole system is strong and prone to problems, but also support us to make strategic decisions and optimize the ecosystem. This method changes the traditional management thinking from simple "who leads who" to the study of complex interactions and sudden new features, which greatly deepens our understanding of the complexity of business ecosystem.

Looking ahead, with the acceleration of digital transformation and the improvement of data availability, the application of complex network analysis in business ecosystem research will be further deepened, and the combination of multi-layer networks, dynamic simulation and artificial intelligence will become the mainstream trend. This will help us build a more resilient and more innovative business ecosystem, provide scientific basis for enterprises to cope with uncertain environment, and ultimately promote sustainable value co-creation and healthy ecological development.

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