# Examining Financial Risk Contagion and Shock Response via Complex Network Analysis of Correlation and Causality in the Sports Industry

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**Abstract**

In today's landscape of financial liberalization and economic integration, the sports industry is not immune to the complex interplay between financial and economic activities. This dynamic environment witnesses the frequent exchange of information within the sports financial market, resulting in a high degree of interaction. Such interaction has not only optimized the allocation of global financial resources in sports but has also amplified the repercussions and dissemination of financial crises within the sports sector. From the global sports financial system to individual sports entities, intricate relationships emerge in economic and financial activities among countries, forming a complex sports financial ecosystem. Understanding and characterizing the patterns of risk propagation and shock responses in the sports financial market is vital. It equips sports market participants and regulators with crucial market insights, aids in policy formulation, and enables proactive measures to prevent and address financial market crises within the sports industry. Considering the multifaceted interactions among various stakeholders in the sports financial market, this study adopts a complex network methodology to examine the dynamics of financial risk contagion and shock response, with a primary focus on the sports industry. This approach offers a valuable perspective, shedding light on the specific intricacies within the sports finance domain

**Keywords:** complex network; Person correlation; Granger causality; sports Financial market; Risk infection

## 1. Introduction

### 1.1 Research background

Uncertainty is a problem that human beings have to face from birth to now, which is related to human survival and development. Since the subprime mortgage crisis in the United States, the world economy has experienced a period of the financial crisis after a period of adjustment and recovery (Liu & Liu, 2020). This is mainly because the world economy is fragile under the circumstances of the relatively tortuous development of the world economy. Therefore, uncertainty is the only certainty in the current world economy. From the perspective of the global economy, due to the emergence of trade networks and capital networks, the economies of countries around the world are increasingly closely linked. At present, the developed countries in the world have not yet recovered from the impact of the financial crisis, while the emerging countries have little impact because of their own. In the future world economic environment, there are still many variables, making the world economy and sports financial markets more unstable. From the perspective of the domestic economy, there are also many unstable factors (Butnariu, Luca, & Apetrei, 2018). In the financial field, the unstable factors of China's sports financial market mainly include the low risk resistance of financial institutions, the hidden accumulation of systematic risks, and the weak supervision of financial institutions. Economically, overcapacity, structural upgrading, insufficient endogenous power of economic growth and other issues are still urgent problems to be solved in the healthy development of China's economy. In order to promote the steady development of the economy, give full play to the resource allocation function of the sports financial market in the economy, and enhance the function of finance as a barometer of the economy. In the financial system, governments and departments should reduce their dynamic links in the financial system, thereby reducing their vulnerability, so as to enhance their ability to withstand risks under the impact of international and domestic markets. At the same time, we should pay attention to the changes of systematic financial institutions and take corresponding measures in time to avoid the large-scale impact caused by the risk diffusion of the sports financial market, so as to reduce the occurrence of systematic risks.

### 1.2 Research Significance

The risk diffusion and shock response of sports financial markets have always been valued by governments and scholars. Especially in the context of frequent global financial crises in recent years, the risk diffusion of sports financial markets and its related problems have become increasingly prominent. In view of the complexity of the sports financial market, this paper conducts an in-depth study on the concept of complex networks, the contagion

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of sports financial risks, and the impact of financial markets (Yuan, Wang, & Wang, 2021). The research of this paper has the following important significance: First, theoretically enrich and improve the risk of China's sports financial market, deepen the understanding of the complexity of the financial market, through the grasp of the overall dynamics of the market, we can make up for the shortcomings of traditional analysis methods, and comprehensively describe the interaction between multiple agents, so as to achieve higher accuracy and reliability; Secondly, according to the actual situation of the sports financial market, a new sports financial market risk diffusion model and prediction method are established (Staeck, Ottoni, & Schindler, 2022). On this basis, the diffusion of financial risks is simulated and the possibility of its occurrence is predicted; Thirdly, a quantitative analysis method of complex network impact response is introduced to describe the invulnerability of sports financial markets under systematic risk, which lays a foundation for the study of sports financial market stability.

## 2. Concept definition

### 2.1 Related concepts of complex networks

In the past twenty years, because of its special advantages in the study of complex systems, the complex network theory has been widely valued. Composite network theory can be used not only to describe complex systems, but also to study complex systems (Galeotti, 2021). As we all know, the use of "system" or "network" to describe the objective world originates from the concept of "world composition". Physics uses a regular network structure to describe the basic structure of matter. These structures are located in a grid, and the interactions between particles in these grids are formed through these grids. In recent years, the concept of "network" has received extensive attention in the academic community, and its application scope has also expanded. It can not only describe the movement law of objective things, but also describe various complex networks, such as the Internet, biological information network, financial network, etc.

### 2.2 Complex financial network and its characteristics

The complex network method refers to studying the complex relationship between individuals in a multi-agent system from the perspective of network. With Watts' articles on the structure and dynamics of small world networks published in Atowre magazine, a research boom has been set off (Dhinaiya, 2018). Complex network methods have been used to explore various realistic complex relational networks, such as the Internet, financial networks, BT networks, etc. In recent years, scholars at home and abroad have classified complex networks and conducted in-depth research on various network characteristics. Firstly, the classification of complex networks is carried out, and regular networks, ER random networks, WS small world networks, etc. are pointed out. The second is to study the network topology. In this process, people can get many important measurement parameters by measuring and describing the characteristics of complex networks. Although the complex network belongs to the category of complex science, its coverage has gone beyond the scope of statistical physics. The later section of this section will introduce the latest research results of finance in detail.

The sports financial market is a complex system with many financial individuals and various sports financial markets. In recent years, many scholars have conducted in-depth discussions on the relationship between individuals in financial markets and different financial markets using the composite network theory (Sookye & Mohamudally-Boolaky, 2019). Through the internal study of the complex network of financial markets, each node corresponds to a different financial system, and the connection of each node reflects the interaction and correlation between different financial entities. Complex network theory has the advantage of complex multi-body system. after it was introduced into the field of sports financial market research, it has shown a thriving trend. This paper mainly analyzes the financial market from the aspects of money market, money market, stock market, gold market, insurance market and futures market. In terms of methods, the minimum spanning tree, correlation threshold method, and Granger causality method are commonly used complex network algorithms for financial market analysis.

### 2.3 Concept of financial market risk

The sports stock market is composed of the sports stock market, foreign exchange market, stock market and other markets. The sports stock market is formed by the joint action of financial institutions, governments, enterprise organizations, individuals and other markets (Bruneau, Flageollet, & Peng, 2020). It constantly evolves in time and space, as shown in Figure 1. sports stock market risk refers to the fluctuation of asset prices in the sports stock market due to the change of some factors, resulting in certain losses. For the risk of the financial market, its asset price fluctuation can be caused by specific factors, or it can be the price of other markets, which is caused by the interaction between markets. In the financial system, there are complex and interrelated relationships among sports stock market. The effective measurement and control of financial market risk are of great significance for maintaining the stability of the sports stock market system and the stable

operation of the economy. The research on sports stock market risk management methods is generally carried out in the following three directions: (1) CAPM (Capital Asset Pricing) is based on the mean variance basis, and uses the ratio of the optimal portfolio to predict the system of internal multiple assets and related risks; (2) Based on the current financial risk management theory, the risk of sports stock market is tested, including stress test, mechanism theory, sensitivity analysis, VaR, volatility analysis, etc; (3) We use random walk, Brownian motion, etc. to describe the price movement pattern of the underlying asset, and measure its risk.

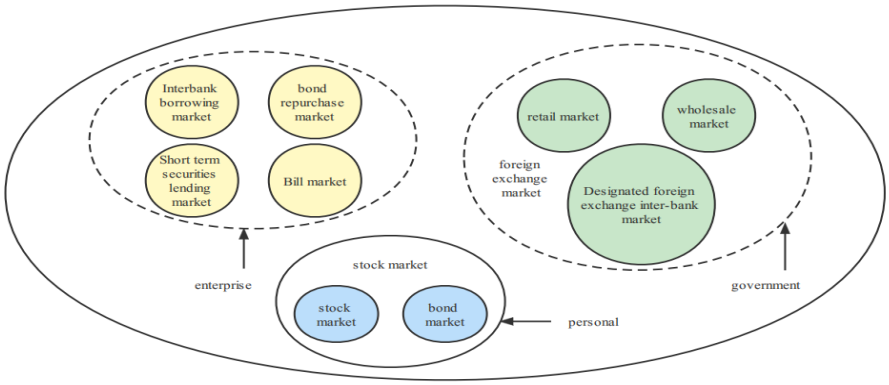


***Figure 1.*** Temporal and Spatial Evolution Structure of sports stock market

### 2.4 Definition of risk contagion

Through the investigation of the existing literature, there are few researches on risk contagion, most of which are about the whole financial system, as shown in Figure 2. Up to now, there is no universally accepted definition of hazard propagation. The concept of risk contagion has two definitions. One is the basic risk transmission, mainly including the monsoon effect and spillover effect; The second is the net transmission phenomenon in risk transfer, that is, the net transmission effect. Fundamentally based risk diffusion focuses on the correlation between markets (Zhu, 2020). Risk contagion is considered to be due to the close financial relationship between trade and the infected market, and financial risk will be extended to the infected market through such means. These expectations are determined by the economic, political and cultural similarities between countries. This paper argues that the risk transfer of sports stock and financial markets has both fundamental effects and the spread of net risks. We will comprehensively analyze the interaction between these two definitions. Therefore, this paper defines it as a phenomenon which changes in the financial assets of one country cause changes in the financial assets of other countries.

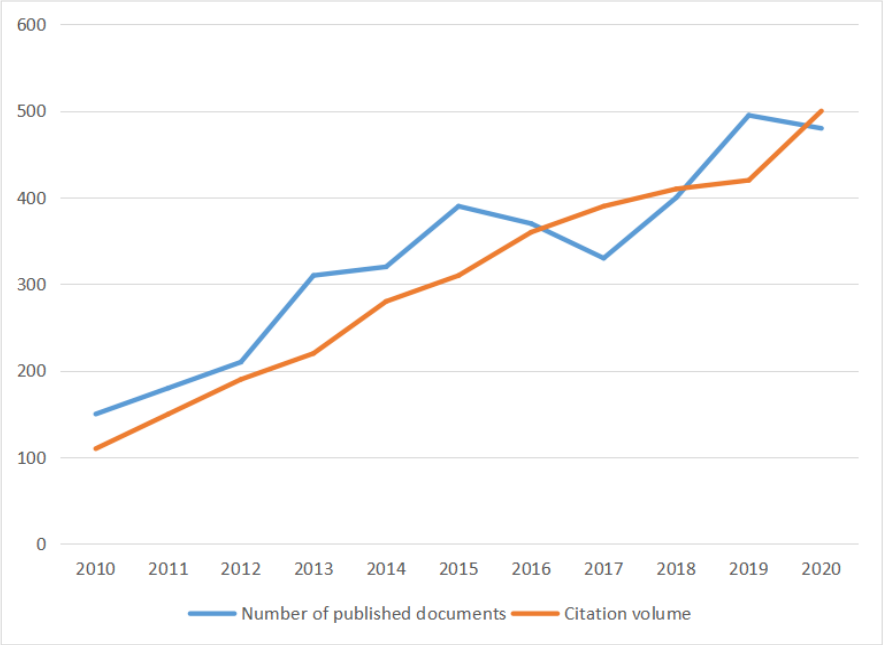


***Figure 2.*** Number of documents and citations on systematic risk published annually

## 3. Methodology

### 3.1 Construction of financial risk contagion model

The transmission mode of financial risk includes: S represents profitable financial institutions, I represents crisis financial institutions, R represents risk-free financial institutions, and D represents bankrupt financial institutions (Zhu, Yang, & Ye, 2018). The propagation mechanism of this model is that at the initial stage of financial risk spread, many profitable financial institutions will also lead to risk spread because of their connection with financial institutions in crisis(β). In a crisis, financial institutions can escape from the crisis and have a certain ability to protect themselves due to the assistance of regulators. However, this ability is only temporary, and it may be ineffective to save(α) The probability of falling back into the financial crisis; In the process of crisis spreading, if we can't get assistance in time, we will have a failure rate(δ) The way to die, so completely out of the process of risk diffusion. Its model structure is shown in Figure 3.

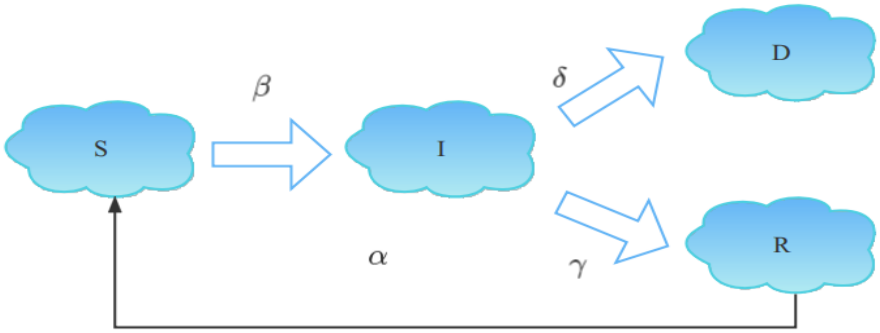


***Figure 3.*** Schematic diagram of financial risk contagion model

At present, there are two main ways to build a financial risk network: one is through the actual business transactions between banks, or through the actual business transaction data between banks, or through the real transaction data of banks; The second is to establish a stock trading system using information such as stock prices and daily returns (Ding, 2021). Because the data such as stock price and daily rate of return are relatively easy to obtain and can timely reflect the market risk and possible transmission path, stock price and daily rate of return have become a research hotspot. A complex financial network is constructed by using the closing data of the trading day of the listed banks. The noise elimination technology is used to eliminate the noise in the market, thus improving the risk diffusion degree of each node in the network. At the same time, the risk diffusion trend of each node in the network is studied by using the Granger causality test.

In the directed implicit right risk communication network, different financial institutions have different distribution and contact levels, and different industries and financial institutions of different sizes have different subject attributes. Therefore, when a financial crisis occurs, the risk contagion is different. However, the infection range, speed, depth and other indicators in the model have a collinear relationship, and the weight of each indicator is only 25%, without taking into account different degrees of influence (Mazzocchetti et al., 2020). In addition, this study did not combine the subject characteristics of different financial institutions with the marginal contribution of risk. Therefore, based on the analysis of the existing model, the financial institutions' subject attributes and complex network characteristics are combined to improve it, and a comprehensive score, node strength value, infection depth and node attack capability are obtained, as shown in Table 1.

**Table 1**

*Risk infectivity assessment model*

| Metrics | meaning | method |
|---|---|---|
| Subject attribute score | Measure the subject attribute score from three aspects of financial institution scale, complexity and risk | Index system method |
| Node strength value | Weighted boundary value of this node connecting to other nodes in risk contagion network | Strength value |
| Depth of infection | Remove the most unimportant peripheral nodes and get the number of layers stripped when obtaining the most infectious inner nodes | decomposition method |
| Node vulnerability | When the whole network is attacked, the node's ability to spread the risk to other nodes | LeaderRank algorithm |

On the basis of the existing financial institution identification indicators, four indicators of scale, complexity, risk and profitability are adopted, and the standardized equal weight method is used to comprehensively evaluate the subject attributes of each financial institution to obtain the risk contagion of each financial institution (Dimovska & Materassi, 2020). The basic principle of the equivalence method is: the average weight of the four indicators is 15%; The second indicator is the same at each level. In order to verify the robustness of the equal weight method, this paper determines a theoretical interval for each weight value, so that the weight value changes within this interval, and conducts a correlation test for the ranking change caused by the weight value change. Table 2 shows the method of selecting the second indicator from the first indicator and a specific weighted value.

**Table 2**

*Contribution of subject attributes to risk infectivity*

| Level I indicators | Secondary indicators | weight | Weight range |
|---|---|---|---|
| scale | Proportion of total assets to GDP=total assets/GDP | 12.5% | [7.5%，17.5%] |
| complexity | Proportion of financial liabilities in total liabilities=financial liabilities/total liabilities | 5.8% | [3.5%，8.5%] |
| Risk | General risk reserve | 5.8% | [3.5%，17.5%] |
| profitability | Profit rate of net assets=net profit/average net assets | 12.5% | [3.5%，17.5%] |

### 3.2 Building a Financial Complex Network of Person Relationships

The correlation coefficients of the two variables are Kendall and Pearson respectively. In the sports stock and financial market, the Pearson correlation coefficient is usually used to measure the linear dependence of two time series (Elliott, Georg, & Hazell, 2021). In 1896, Carl Pearson first proposed a standard method to calculate the correlation coefficient, and the Pearson correlation coefficient is the best. Pearson correlation coefficient is the ratio of the product of the covariance of two independent random variables and the standard deviation of these two variables. Pearson correlation coefficient is - 1 to 1. In the case of 0, these two variables have no linear correlation; If it is a positive number, it indicates that the two variables have a positive linear relationship; If it is a negative value, it means that the two variables have a negative linear relationship (Pagnotta, Dhamala, & Plomp, 2018). The greater the absolute value of the Pearson correlation coefficient, the stronger the linear dependence between the two variables. When constructing a complex network, the distance must be described first, and the positive and negative correlations described by Pearson correlation coefficients have equal relations. Therefore, after obtaining the Pearson correlation coefficient matrix, the absolute value of each coefficient must be calculated first, and then the distance must be calculated.

Although Pearson-related technology has many advantages and application prospects, it also has some disadvantages. First, the Pearson correlation method was used to obtain the linear relationship between the two variables, rather than the nonlinear relationship. In addition, the Pearson correlation coefficient does not include the influence of the third variable in this analysis, and this factor will also have a strong correlation.

### 3.3 Financial Complex Network Analysis of Granger Causality

The Granger causality method is a very common analysis method. When studying the causality between variables, it often requires that the time series of a variable is much more than that of a variable (Zheng & Song, 2018). However, in practical applications, the length of time series that can be extracted is very limited. Among thousands of genetic variables, the length of each variable is very short. At this time, the dimension of the variable is greater than the length of the time series. If the general Granger causality method is used to examine the internal causality, an incorrect conclusion will be drawn. This paper introduces a new idea based on Granger causality, conditional Granger causality and partial correlation Granger causality, and introduces Granger causality into a complex financial network. Through the analysis of simulation data, it shows that the model proposed in this paper can better reflect the real relationship between variables in the complex financial system.

In theory, Granger's causality test can use three models: horizontal VAR, differential VAR, and VEC. In these three models, the number of variables, lag, single integration of variables, and dimensions of cointegration space will be very different (Chen, Wang, & Yao, 2021). Therefore, different researchers can easily obtain different test results without carefully analyzing economic principles and carefully considering the details of the test. Here, we will link the actual operation process of the Granger causality test with the previous chapter, as shown in Figure 4.

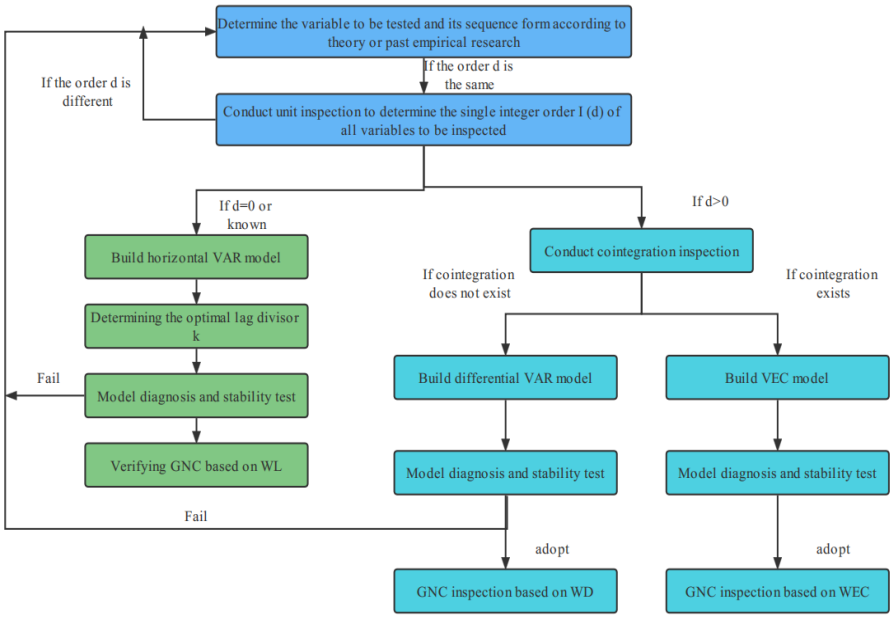


***Figure 4.*** Flow Chart of Granger Causality Test Practice Procedure

### 3.4 Comparison of risk contagion between Person correlation and Granger causality

The research on risk contagion in sports stock market based on Person correlation and Granger causality is a research category of financial market risk under the complex network theory. Composite network theory is the common theoretical basis of the two, but in terms of risk contagion basis and sample data demand, it has the following characteristics: (1) The sports financial market complex network based on correlation is a filtering technology based on financial correlation. The basis of this algorithm is to calculate the correlation of each financial time series, convert it into Euclidean distance, and eliminate it through MST, PMFG and other filtering technologies, so as to finally obtain a complex sports stock market network without weight. On the basis of Granger causality, a complex financial market network is established by using Granger test. In this network, the edge represents the weight of the Granger causality. (2) The spread of sports stock market risk based on Person correlation is based on the correlation between nodes, that is, the possibility of financial risk diffusion is determined according to the correlation between nodes, so as to determine the possibility of financial risk diffusion. In this kind of network, different connections can affect each other, and financial risks will also spread to each other (Restrepo, Uribe, & Manotas, 2018). This paper analyzes the problem of risk diffusion in sports stock market from the perspective of Granger causality, and believes that the connection between the two nodes usually does not interact, and the financial risk has certain directionality.

### 3.5 Measuring method of financial risk contagion

In the past ten years, the outbreak of many financial crises has made the academic community conduct more research on the risk measurement of the financial system, especially the impact of risk diffusion. However, there are different opinions on how to choose the appropriate measurement method in different time and space situations. From the macro perspective, we can use the macroeconomic and financial indicator system to comprehensively evaluate the overall changes of the macroeconomic and financial, and measure the economic risk according to the real and normal empirical differences of the indicators; From the micro perspective, we can start from a single financial institution to conduct risk assessment on a single financial institution (Seffers, 2019). However, it is impossible to know where the risks of the financial system come from, how the risks develop, how the risks spread, and when effective measures can be taken to prevent the occurrence of the financial crisis only depending on macroeconomic and financial indicators; Using the latter method, we usually simply select a representative large institution. No matter how we modify and accumulate indicators, it is difficult to reflect the actual risks of the financial system.

The biggest feature of the financial system is the mutual influence of risks among institutions. Therefore, we must understand the risks of the financial system from the perspective of risk transmission. In this crisis, the financial system will become very fragile. It can be seen from the collapse of a financial institution that the collapse of one financial institution will lead to the same crisis for other financial institutions. On the basis of summary, the measurement method using this idea is shown in Figure 5.

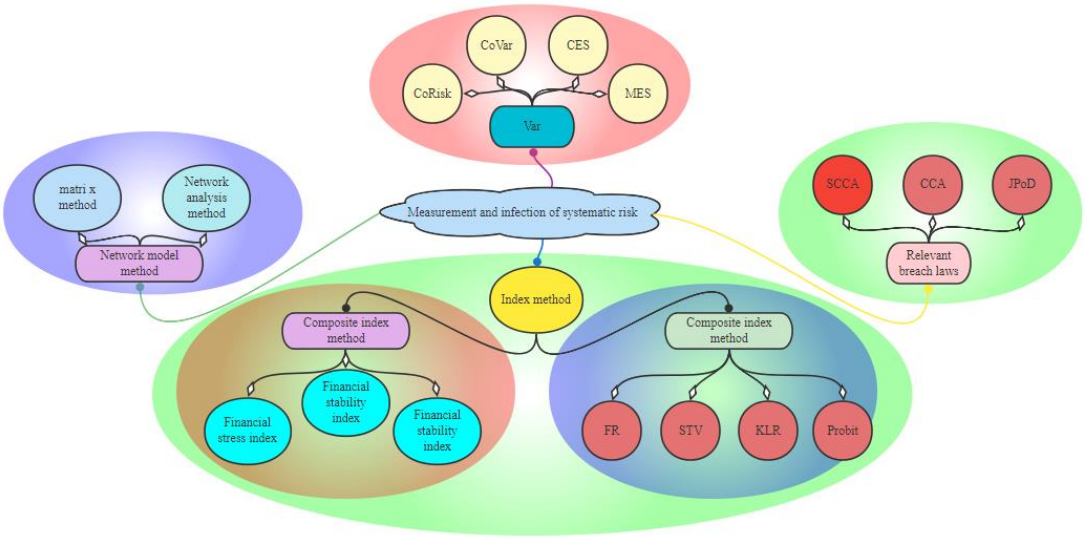


***Figure 5.*** Systematic risk measurement methods

According to Figure 5, we can learn that there are three methods for measuring systematic risk, namely conditional value at risk, mathematical model analysis method and multivariate GARCH model method. This paper introduces the application of these three systematic risk measurement methods in financial risk.

(1) Conditional value at risk

VaR method has the ability to express market risk concisely, concisely and accurately, and uses strict probability statistics theory to quantify the price fluctuation risk of various financial assets into specific values. By definition, VaR refers to the maximum possible loss of an asset in a certain period of time. However, the traditional VaR method can only quantitatively analyze the risks of enterprises, and cannot reasonably explain the risk diffusion among institutions.

(2) Mathematical model analysis method

The basic principle of the mathematical model method is based on the use of mathematical analysis methods to predict the probability that an institution is in danger at the same time when it is in crisis or bankruptcy, so that the risk of the system can be measured from two perspectives: first, whether the risks among the various entities in the monitoring system will affect each other; Second, determine the maximum risk propagation path and direction. The representative methods are matrix method and network simulation analysis method.

(3) Multivariate GARCH model method

The GARCH model is a popular method at present, which is based on the correlation between financial institutions and the volatility spillover between markets. Its basic idea is: when the crisis comes, various economic factors that dominate the operation of financial institutions tend to be unified gradually, thus increasing the potential systemic risk; The stock price reflects the market's prediction of the future earnings of institutions, and the higher the correlation between the stock price and the stock price, the more systematic risks may be brought. The method is to establish a binary or multivariate GARCH model, eliminate the volatility clustering in the financial time series, and then use the residual method to find the hidden correlation, so as to obtain the potential risk of the financial system.

## 4. Result analysis and discussion

### 4.1 Prevention of systematic risks

#### 4.1.1 Functional and differentiated network supervision

This paper analyzes the system risk from the perspective of network construction. First, determine the method of network construction, and construct a complete financial network topology according to the relationship between financial institutions, as shown in Figure 6. It will be more effective to use the "functional" online supervision mode to replace the traditional separate supervision mode, and to conduct classified and targeted macro-prudential supervision. From the perspective of systemic risk spread under the architecture, systemically important financial institutions are large in scale and closely connected with other financial institutions. Therefore, they are easy to become the source and disseminator of risks. Once a default occurs, it will have a great negative impact on the entire market. Therefore, we should focus on the entire economic and financial relationship network, closely monitor the industries with high systemic importance, and implement differential control according to the importance of the system.

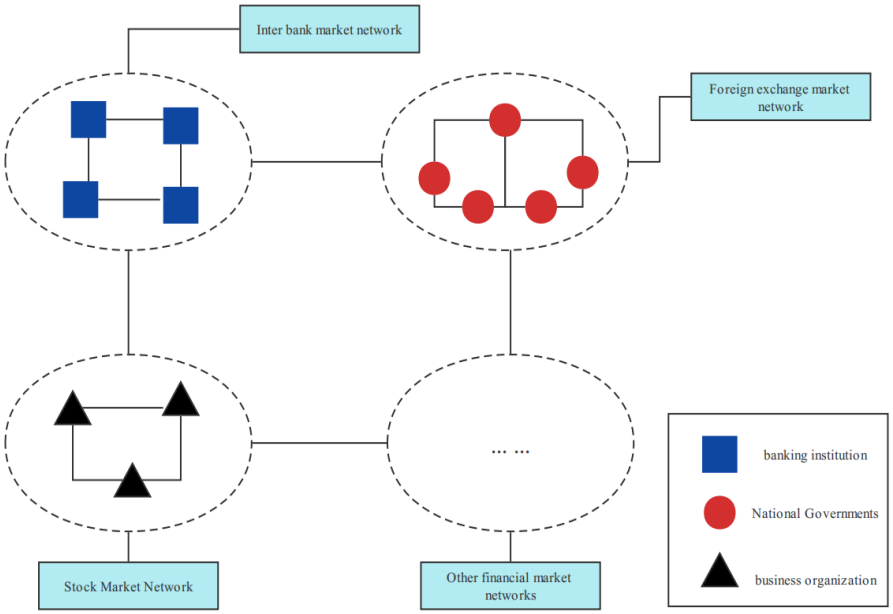


***Figure 6.*** Sports Financial Market Network

#### 4.1.2 Establish an intelligent pre warning system

In today's increasingly mature and widely used artificial intelligence and big data analysis technology, a comprehensive intelligent early warning system has been built by using artificial intelligence and big data analysis technology, in-depth mining, in-depth analysis and data visualization to improve risk monitoring and processing capabilities (Zhu & Milanović, 2021). In recent years, many scholars have applied decision trees and neural networks to the classification training of risk index data, effectively predicting the economic operation and making a good early warning of the economic crisis. Through the research of network finance, we can give early warning to the potential risks of network finance, and effectively block them, providing the basis for risk management, and ensuring their healthy development.

### 4.2 Countermeasures and suggestions for controlling financial risks

(1) Build risk early warning mechanism

To establish a sound risk early warning and control mechanism, we must select indicators with internal and external potential factors, establish relevant sub-market risk monitoring indicators, and identify risks according to indicator changes. At present, with the development of the digital economy, financial science and technology, artificial intelligence, statistics and other means continue to innovate, and a new risk early warning model has been built. When the external environment of the sports stock market, it will affect the possibility and loss of its occurrence, and the risk warning will be carried out through the changed indicators. In addition to establishing a risk early warning mechanism, the most important is the internal control mechanism of the sports stock market. In general, risks in the sports stock market can easily be covered up in the short term, but in the long run, risks in the financial system will gradually expand over time, thus affecting the entire financial system. Real time monitoring, early warning, management and key monitoring of different types of sub-markets can effectively prevent their occurrence and deterioration and reduce the scope of their spread.

(2) Perfection of financial laws and regulations

With the continuous popularization and development of Internet technology, financial risks are characterized by concealment, complexity and expansion. In addition to establishing effective early warning mechanism, risk isolation mechanism and financial supervision mechanism, corresponding laws and regulations must be formulated to prevent and manage financial risks. First of all, we should detail the legal responsibilities of financial supervision departments, the contents and responsibilities of their evaluation, and make clear the punishment, rewards and punishments. Secondly, with the development of China's economy, a large number of financial innovations have emerged, but the corresponding regulatory laws and regulations are relatively backward (Kobayashi & Masuda, 2021). In addition, there should be a sound prevention mechanism within financial institutions. We should start from the internal control, establish the corresponding financial risk prevention and control system, and realize the timely discovery and prevention of financial risks.

(3) Optimize the financial supervision system

Financial supervision is a necessary means to prevent and resolve financial risks. The greater the strength of the regulatory authority, the more conducive to risk prevention. The regulatory objective is to take into account the development of the financial market and promote financial innovation and system innovation on the basis of preventing financial risks. The establishment of financial supervision system must be combined with the reality of financial development. At present, network finance is playing an increasingly prominent role in China's financial system, and various types of Internet plus finance have spread throughout the entire financial industry. China lacks innovative experience in risk management. We can improve the financial supervision system and promote the healthy and orderly development of the financial market by cooperating with countries and institutions with good online financial risk prevention mechanisms. On this basis, to improve China's financial supervision system, we should use Internet technology, improve the perfect financial supervision system and strengthen external supervision of the sports stock market in accordance with the principles of matching, full coverage, independence, effectiveness, etc. Use Internet technology to conduct all-round supervision on different types of financial participants and their financing, trading activities, organization, coordination and supervision. At the same time, strengthen the monitoring of various financial risks, strengthen functional supervision and implement joint-supervision.

## 5. Conclusion

The examination of risk propagation and its ramifications within financial markets, particularly in the realm of sports and sport stocks, remains a central and pressing concern. Recent global economic challenges, epitomized by events such as the U.S. subprime mortgage crisis and the European debt crisis, have underscored the salience of risk transmission dynamics within China's sports financial markets and related domains. The phenomenon of risk contagion within sports and sport stock markets constitutes a critical sphere of inquiry.

This paper has undertaken a comprehensive review and synthesis of pertinent domestic and international research, approaching the subject from multiple dimensions, with a specific focus on sports and sport stocks. It encompasses the concept of complex networks, the construction of financial risk contagion models tailored to the sports industry, and research on financial complex networks involving person correlation and Granger causality analysis within the sports finance sector. By delving into these facets, this study not only provides robust support for discerning the underlying principles governing risk transmission among sports financial markets and sport stocks but also furnishes a valuable theoretical and practical reference for regulatory bodies. These insights inform the development of regulatory policies and the formulation of corresponding rescue measures tailored to the unique dynamics of the sports and sport stock financial market

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