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Research on Business Risks of Green Vegetable Supply Chain Network based on SIR Model

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Abstract

The green vegetable supply chain network is abstracted into a complex network. By analyzing the similarity between the green vegetable supply chain network and the virus transmission network, the SIR model in the complex network transmission dynamics is used to simulate the risk transmission process of the green vegetable supply chain network. This paper studies the impact of the green vegetable supply chain dominated by core green vegetable suppliers on restraining the spread of risks in the overall supply chain network. The core green vegetable suppliers establish a comprehensive and collaborative partnership and put the crisis management function into the supply chain management platform. And the green vegetable supply chain carried out by this can more effectively control the occurrence and spread of supply chain security risks. Thus establishing risks evasion supply chain changes the weak integration situation of the green vegetable supply chain.

Keywords

Green vegetable supply chain; SIR model; Green vegetables core supply enterprise; Simulation analysis.

1. INTRODUCTION

With the increasingly development of the economy and society and the improvement of consumption levels, people's health awareness and nutrition awareness is increasing day by day and the requirement for high nutrition and harmlessness of green vegetables is increasing accordingly. At the same time, consumers are both satisfied with the rich variety and the high quality of green vegetables. Therefore, advocating clean agricultural production methods and vigorously developing green vegetables is to meet the urgent needs of current social life, and it is also the general direction of the future development of the green vegetable industry.

Compared with the industrial products supply chain, the green vegetables supply chain has the randomness on the connection and the vulnerability of the structure, which is highly sensitive to risks. First is the large randomness of connections in the green vegetables supply chain node. The weak organization of the members of the green vegetable supply chain makes the green vegetables supply chain's connection nodes changeable. Factors such as changes in farmers' behavior patterns, price signals, and natural disasters often lead to frequent reorganization of the green vegetables supply chain, which in turn changes the level of the green vegetables supply chain. Second is the great vulnerability of the structure. Factors such as low specialization, rough division of labor, lack of deep processing and other factors of the node lead to the poor visibility of the green vegetable supply chain and difficulties in coordinating into an integrated structure. Once there is a risk impact, the green vegetable supply chain is likely to break and collapse. After all, the main reason is the lack of core enterprises with leadership and authority in the traditional green vegetable supply chain, which aggravates the poor

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controllability of the green vegetables supply chain. Therefore, cultivating core green vegetable suppliers, implementing supply chain integration and building an efficient and safe green vegetables supply chain are the practical requirements for ensuring food safety in our country.

2. RELATED DEFINITIONS AND RISK TRANSMISSION BASIS

2.1. Green Vegetables

Green vegetables, a general term for nutritious and green vegetables, refer to non-polluting, safe and high-quality products that follow the principles of sustainable development and are organized in accordance with the green food quality standard system under the premise of a good ecological environment of the place of production, and are recognized by the China Green Food Development Center to allow the use of green food marks. Safety means that strict monitoring and controlling are adopted to prevent the pollution of toxic and harmful substances to all links in the production process and it must ensure that the content of toxic and harmful substances in green vegetables is below the safety standards and does no harm to human health. High-quality means that the product quality of green vegetables meets the standard requirements. Nutrition refers to the inherent quality of green vegetables, that is, different green vegetable varieties are rich in various substances that are beneficial to human health to ensure human nutritional needs.

Green vegetables are divided into two categories: A-grade and AA-grade. AA-grade green vegetables are organic green vegetables which contain no synthetic fertilizers, pesticides, growth regulators and other substances which are harmful to the environment and health. A-level green vegetables are generally referred as green vegetables. Under the premise of meeting the environmental quality of the production place, the limited use of restricted chemical synthetic substances is allowed, and biological technology and physical methods are actively adopted.

2.2. Risk Transmission Basis

The sources of corporate network risk are diversified. It may come from the economic network environment, or the company's own problems. In the beginning, the spread of risk is limited to an organization, and this risk is mild, slow, and not easily detectable. With the self-organization of the inner organization, this risk will sometimes be absorbed within the enterprise. But when the organization is unable to digest and absorb, the flow of risk will continue to accumulate and risk overflow occurs. Along with the operation of inter-enterprise relations, risks are transmitted and diffused among various interest nodes within the network organization through a certain path or channel, leading to the expansion of the entire risk state (see Figure 1).

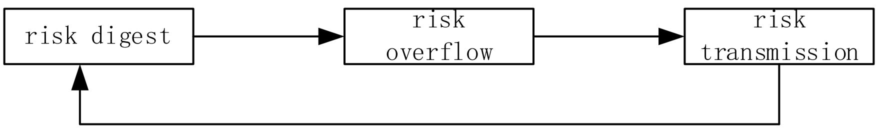

Figure 1. Risk transmission pathway of node enterprises

3. MODEL ESTABLISHMENT

3.1. Model Suitability Analysis

This research abstracts the green vegetable supply chain into a complex network, abstracts each member of the supply chain into nodes, and abstracts the mutual movement between nodes (such as logistics, capital flow, information flow) into edges between nodes (or Arc). This

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research studies the impact of the green vegetable supply chain dominated by core green vegetable suppliers on the suppression of the risk propagation of the green vegetable supply chain network by using SIR model to simulate the risk propagation process of the green vegetable supply chain network.

The representative achievement of transmission dynamics in complex networks is the successful transplantation of classic infectious disease models based on homogeneous networks to complex networks, and explains several phenomena of virus transmission based on this. The SIR model is the most classic and basic model among infectious disease models. Among them, the nodes in the network are in one of four states, that is, susceptible state (S), infectious state (I) and removed state (R).

Susceptible state (S) indicates that the node enterprise is currently in a healthy state, but if the amount of risk in the network exceeds its risk threshold, it is susceptible to be infected by other risks.

Infectious state (I) indicates that the node enterprise is currently infected by the risk, and the risk is overflowing.

Removed state (R) indicates that the node enterprise has eliminated the risk threat through its own continuous adjustment, and returned to the health state in the network once again.

The spread of risks in the green vegetables supply chain network has the following similarities with the spread of viruses;

First is the similarity of spreading network. The green vegetables supply chain network is highly similar to the virus-infected social network, and they both have the complexity of a complex network which can be demonstrated in the following two aspects. On the one hand, network contains numerous nodes, that is, there are a large number of nodes. On the other hand, the connection relationship between nodes in the network is complex. It does not have a completely deterministic connection relationship like a regular network or a completely uncertain connection relationship like a random network. It is somewhere in between.

Second is the similarity of spreading objects. The object of the virus transmission is people, and each person is an independent individual. Due to each individual has a different physique and immunity, the resistance to the virus is not the same. Every individual's social circle is different, and the ability of the virus to spread out through the individual is also different. The core companies in the green vegetables supply chain, as well as growers, processors, distributors, retailers and final consumers can be regarded as intelligent subjects. Each subject can communicate with the environment and other subjects. In the process of communicating they can learn or accumulate experience, and change its structure and behavior based on the learned experience so that the entire supply chain system is continuously optimized on this basis.

Third is the similarity of spreading process. The spread of the virus is generally transmitted by the infected individual to the surrounding individuals in the process of social contact. The more and more frequent the contact between the infected individual and the surrounding individuals, the faster the spread of the virus. In the green vegetable supply chain, risks are also conductive, that is, the backward transmission of production risks, the two-way transmission of circulation risks, and the forward transmission of consumption risks. The most affected ones are in the upstream and downstream members with whom they have direct business dealings once a member is infected by risks and suffers from a crisis (such as operating difficulties, financial crisis). The larger the business volume and business scope of the infected member, the greater the scope of its influence.

Fourth is the similarity of spreading periods. During the spread of the virus, there are usually incubation periods, outbreak periods, and recovery periods. There are similar stages in the risk

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spreading process of the green vegetable supply chain. During the incubation period, a small number of members of the green vegetables supply chain are infected by risks, and there is the possibility of triggering a risk crisis, but the system is still in an orderly state. During the outbreak period, most members of the green vegetables supply chain are affected by risks due to business dealings with infected members. The crisis will suddenly break out and the system will fall into a disordered stage. During the recovery period, most members successfully survived the crisis through early warning and emergency management, and they were immune to similar crises. The green vegetables supply chain was re-operated and the system appeared in a new orderly state.

Fifth is the similarity of spreading key points. Whether the spread of the virus harms the entire society, the key point is the society's ability to respond to the virus. Among them, medical institutions play a decisive role due to their own advantages. Medical institutions have played a decisive role in suppressing the spread of the virus through vaccination, isolation and treatment of virus-infected persons, restriction of social communication for suspected virus carriers, and promotion of virus-related protective measures. In the green vegetables supply chain, it plays a key role in restraining the spread of risks due to its advantages in capital scale and information acquisition. For one thing, the core green vegetable suppliers can effectively improve the anti-risk ability of the entire supply chain by integrating upstream production and processing resources, while establishing a unified and efficient warehousing, distribution and sales network downstream. For another, when there is a green vegetable supply risk, the core green vegetable supplier will initiate a predetermined emergency plan to help upstream and downstream members stabilize the production and market of green vegetables through measures such as storage deployment and production recovery and improve their early warning and emergency response capabilities to ensure the stability of the entire green vegetable supply chain.

In summary, the spread of risks in the green vegetable supply chain network is highly similar to the spread of viruses. Therefore, the SIR model has high applicability in the research of risk communication in the green vegetable supply chain.

3.2. Model Hypothesis

a. Each node i represents a member of the green vegetable supply chain, the degree d(i) of the node represents the size of the member, and d(c) represents the size of the core green vegetable supplier. The edges between nodes represent the business transactions between members, and the weight of the edges (w_{ij}) is expressed as the amount of business. The stage P of each node i at any time t is the susceptible state (expressed by P(i, t)=0), and the infection period (expressed by P(i, t)=1), immune status (expressed by P(i, t)=2).

b. Define node scale factor $x_i(i) = d(i) / d(c)$ .It can be seen from the definition that the core green vegetable supplier node scale coefficient is 1, and the other member node scale coefficients are all less than 1.

It is assumed that the scale coefficient $x_1(i)$ of the node is positively correlated with the node’s net risk warning capability α_0(i) and the node's net risk recovery capability β_0(i) (Net risk warning capability and net risk recovery capability are defined as the risk warning capability and risk recovery capability of node members when there is no supply chain management.).

c. Assuming that the path of risk spread pathway is direct business exchanges between members (nodes with connected edges), the spread probability is related to the business volume and node status. And the risks between nodes that do not have direct business transactions will not spread to each other. α_{ij} represents the infection probability of the

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infected node j to the susceptible node i, α_{ij} is positively correlated with the transactions w_{ij} between the nodes, and the susceptible node i affected by all connected infected nodes is $\alpha(i)=1-\prod(1-\alpha_{ij})$.

d. The probability of susceptible node i being infected is related to the following three factors, namely the node's net risk warning capability $\alpha_0(i)$, supply chain management's increased value of the node's risk warning capability $\alpha_h(i)$, and the impact of connecting infected nodes on it $\alpha(i)$. The calculation formula is as follows

$$x_2(i)=[1-\alpha_0(i)][1-\alpha_h(i)]\alpha(i)$$
$$=[1-\alpha_0(i)][1-\alpha_h(i)][1-\prod(1-\alpha_{ij})]$$

e. Infected members can recover from the risk of infection after a period of time. The recovery probability $x_3(i)$ of infected node i is related to the following two factors, namely the node's net risk recovery ability $\beta_0(i)$ and the value of supply chain management to the node's risk recovery ability $\beta_0(i)$.The calculation formula is as follows

$$x_3(i)=1-[1-\beta_0(i)][1-\beta_h(i)]$$

f. The loss y(i) suffered by the infected member i is proportional to the degree d(i) of its node and the final infection time T(i, t). And define the risk loss degree is y(i) = d(i)×T(i, t).

3.3. Evolution Rules

According to the hypothesis, the state P(i, t) of the node i at time t is related to the state P(i,t-1) of the node at time t-1 and the infection time T(i,t-1).

a. If P(i, t-1) = 0, that is, the state of node i at time t = 1 is susceptible, then the node has a $x_2(i)$ probability of being infected at time t. If it is infected at this node, then P(I, t) = 1. If it is not infected, then P(I, t) = 0. Moreover, regardless of whether the node is infected at time t or not, the infection time at this time is 0, that is, T(i, t)=0.

b. If P(i, t -1) = 1, that is, the state of node i at time t -1 is infected, then the state of the node at time t is also relevant to the node's infection time T(i, t-1). First, if T(i, t -1) <T, it means that the node i is infected at time t -1, but the infection time is less than T, so the node is still infected at time t, and the infection time increases by 1, that is, P(i, t) = 1, T(i, t) = T(i, t-1) +1. Second, if T(i, t-1) ≥ T, it means that after the node has experienced the infection period of T time period, the node has a $x_3(i)$ probability of recovery at time t, and it changes from the infected state to the immune state. If it is not recovered, then the node is still in the infected state at this time, and the infection time increases by 1, that is, P(i, t) = 1, T(i, t) = T(i,t-1) + 1. If recovered, the node is in immune state at this time, and the infection time remains unchanged, that is, P(i, t) = 2, T(i, t) = T(i, t-1). Third, if P(i, t -1) = 2, that is, the state of node i at time t -1 is already immune, then the state of the node after time t -1 is immune, that is, P(i , t) = 2, T(i, t) = T(i, t-1).

4. SIMULATION ANALYSIS

4.1. Simulation Process

4.1.1Sample Chosen

This study takes China Nanjing Green Vegetable Non-staple Food Group Co., Ltd. as the research sample, and the simulation model data is collected from the website and the research. China Nanjing Green Vegetable and Non-staple Food Group Co., Ltd. has a registered capital of 141 million yuan and a total of 20 directly affiliated or investment holding subsidiaries. On the one hand, the 9 core subsidiaries of the group are used as supply bases to establish a complete

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supplier system to ensure product quality. On the other hand, through the establishment of direct stores, specialty stores, franchised stores, wholesale markets, group buying networks and online sales, a green vegetable sales system covering Nanjing has been established. By the end of 2019, 7 distribution centers and 173 service distribution outlets have been established in Nanjing.

Abstract the market system constructed by Nanjing Green Vegetable and Non-staple Food Group Co., Ltd. into a supply chain network. Assume that the node weight corresponding to each distribution network is 1; the node weight of the distribution center is the sum of the node weights of the distribution network in the area; the node weight of the enterprise is the sum of the node weights of the distribution center. It can be obtained that the weight of the enterprise's node is the number of distribution network, that is, d(c) = 173. Assume that the sum of the node weights of the suppliers is equal to the core enterprise node weights, that is, ∑d(i) = d(c). The node weight d(i) of the supplier is directly proportional to the actual sales of the enterprise, and it is the business volume of the supplier and the core company, that is, d(i) = w_{ij} .

4.1.2Data Processing

According to the hypothesis, the net risk warning capability and net risk recovery factors of enterprise i are positively correlated with its scale factors and the probability of risk transmission between enterprises is positively correlated with its business volume.

$$\alpha_0(\mathrm{i}) = \begin{cases} 0.3 & x_i(i) \le 0.05 \\ 0.4 & 0.05 < x_1(i) \le 0.1 \\ 0.5 & x_1(i) > 0.1 \end{cases} \qquad \beta_0(\mathrm{i}) = \begin{cases} 0.1 & x_1(i) \le 0.01 \\ 0.2 & 0.01 < x_1(i) \le 0.05 \\ 0.3 & 0.05 < x_1(i) \le 0.1 \\ 0.4 & x_1(i) > 0.1 \end{cases}$$

$$\alpha_{ij} = \begin{cases} 0.2 & w_{ij} < 30 \\ 0.3 & 30 \le w_{ij} < 60 \\ 0.4 & w_{ij} \ge 60 \end{cases}$$

Then the node weight d(i) of each supplier, the business volume of the core enterprise, the node scale coefficient, the node's net warning capacity, the node's net recovery capacity, and the risk infection probability are demonstrated in Table 1.

Table 1. Results of data processing of each supplier

Supplier	d(i)	w_{ij}	x_1(i)	α_0(i)	β_0(i)	α_{ij}
S1	17	17	0.098	0.4	0.3	0.2
S2	56	56	0.324	0.5	0.4	0.3
S3	9	9	0.052	0.4	0.3	0.2
S4	25	25	0.145	0.5	0.4	0.2
S5	11	11	0.064	0.4	0.3	0.2
S6	31	31	0.179	0.5	0.4	0.3
S7	5	5	0.029	0.3	0.2	0.2
S8	16	16	0.092	0.4	0.3	0.2
S9	3	3	0.017	0.3	0.2	0.2
Total	173	173	1.000			

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Three suppliers S2, S4, and S9 with different scale factors were selected as risk sources, and Matlab was used to simulate simulations. The time span was t =0 to t =30, and the simulation was performed 120 times. The simulation results were averaged.

4.2. Simulation Results

According to model assumptions, through supply chain management, core green vegetable suppliers can improve the risk warning capabilities $\alpha_h(i)$ and risk recovery capabilities $\beta_h(i)$ of node members. The higher the degree of supply chain integration, the greater the risk warning and risk recovery capabilities of node members. Assume that Y(s) represents the sum of the risk loss of all suppliers when node s is the risk source, that is, $Y(s) = \sum_{i=1}^{5} y(i)$, and y(i) is the risk loss of node i. Suppose that F(s) represents the sum of losses of other suppliers when the risk source is node s, that is, F(s) = Y(s)-y(s) =-y(s), F(s) can also be expressed as the externality of risk infection.

Respectively select $\alpha_h(i) = \beta_h(i) = 0$, $\alpha_h(i) = \beta_h(i) = 0.2$, $\alpha_h(i) = \beta_h(i) = 0.4$, $\alpha_h(i) = \beta_h(i) = 0.6$, $\alpha_h(i) = \beta_h(i) = 0.8$, $\alpha_h(i) = \beta_h(i) =1.0$ to simulate and the results can be demonstrated in Table 2 and Table 3.

It can be seen from Table 2 that the risk losses y (S2), y (S4), and y (S9) of each risk source are reduced with the improvement of the supply chain management capabilities of core green vegetable suppliers, and the risk losses of large risk sources relatively bigger. When the core green vegetable supplier's supply chain management capability is 0, the risk loss of each risk source is y (S2) = 127, y (S4) = 78, and y (S9) = 34. When the core enterprise's supply chain management capability is 1, the risk loss of each risk source is y(S2) = 84, y(S4) = 57, and y(S9) = 26, a decrease of 34.68%, 26.92%, and 23.53% respectively. The low supply chain management capabilities of core green vegetable suppliers, the loosen entire green vegetable supply chain structure, the lack of effective management of upstream and downstream resources of core enterprises, the noneffective connection of upstream purchasing platform and downstream sales platform, and the information platform is not perfect are the main factors. A certain upstream supplier is exposed to risks (operational difficulties, financial crisis), which will quickly affect the downstream green vegetable sales of the supplier, causing the supplier to suffer huge losses.

The core green vegetable suppliers have high supply chain management capabilities, the entire green vegetable supply chain is highly integrated, and the purchasing platform, sales platform, and information platform operate efficiently, which can synchronize the logistics, capital flow and information flow of green vegetables. Therefore, even a certain upstream supplier is affected by risks, the risk loss of it can also be reduced to a large extent with the help of the management platform of the core enterprise.

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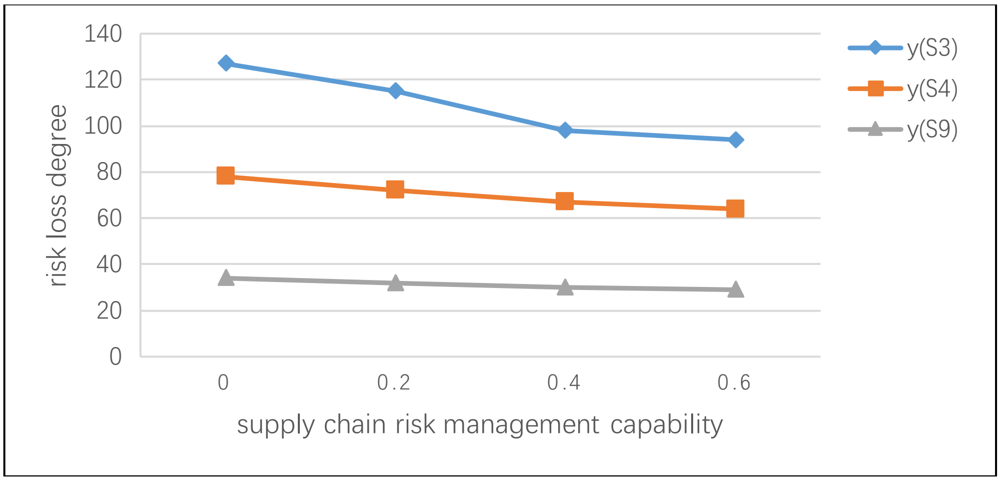

Figure 2. Impact of supply chain risk management capability on risk sources

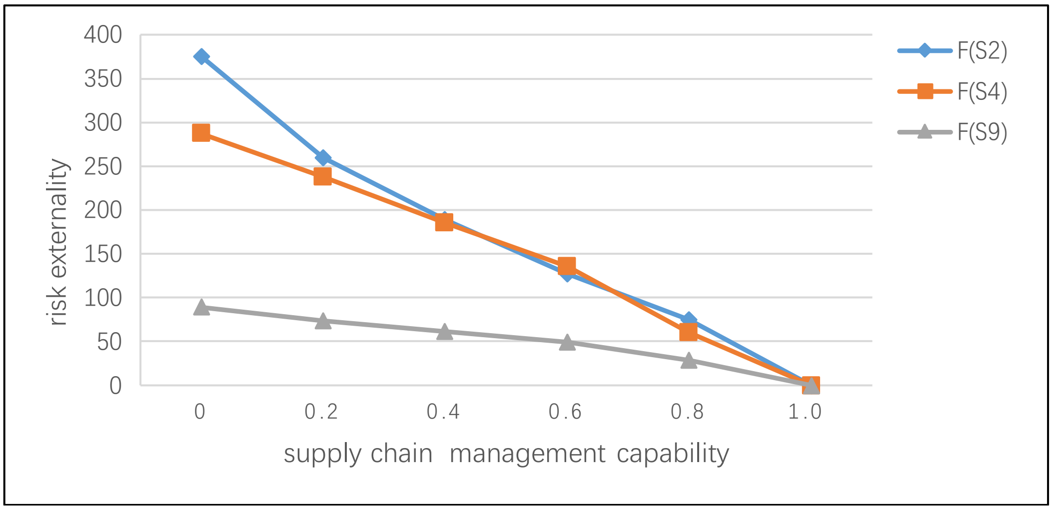

Figure 3. Impact of core enterprise supply chain management capability on external risk

From Figure 3, we can come to the conclusion that the stronger the supply chain management capability of the core green vegetable supplier, the lower the risk of external (Here the external risk means the sum of risk losses of the suppliers expect the risk sources in the process of risk spreading.). The externality of risk sources with large nodes is relatively large. When the core green vegetable supplier's supply chain management capability is 0, the externalities of each risk source are F (S2) = 375, F (S4) = 287, F (S9) = 89. When the core green vegetable supplier's supply chain management capability is 1, the externality of each risk source is 0. The core green vegetable supplier at the core of the supply chain has established a purchasing center in the upstream, and has established a strict product access system to ensure the quality of green vegetables. The suppliers have also established a professional and service-oriented marketing team on the consumer side and a market brand to ensure the market competitiveness of products. In this way, even if a certain upstream supplier has a risk problem, it will not affect the product sales of other suppliers with the help of the core green vegetable supplier's supply chain management platform. Thus they can stabilize the green vegetable consumer market, reduce the sum loss of the supply chain and increase the ability of supply chain to anti risk. Comparing Figure 2 and Figure 3, we can see that, compare to the risk loss of the risk source, the externality of risk is more sensitive to the supply chain management capabilities of core green vegetable suppliers. When the core green vegetable supplier's management capability changes from 0 to 1, the loss of the risk source is reduced by about 25%, and the external

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performance of the risk is reduced by 100%. Especially when the core company’s supply chain management capability is 1, the risk has not spread. The only source of loss in the entire green vegetable supply chain is the risk source which indicates that the stronger the supply chain management capability of the core green vegetable supplier, the green vegetable supply chain, the degree of integration is also higher, and high-strength supply chain integration can effectively inhibit the spread of risks.

5. CONCLUSION

To sum up, network cooperation has become the first choice for business operations. However, due to the special structure of the green vegetable network organization, the interest chain between vegetable suppliers also breeds a hotbed of risk transmission, and the contractual nature of the network economy makes transactions between suppliers prone to problems such as information asymmetry and information distortion, resulting in supplier networks facing various risks. This paper uses the SIR model to describe the risk transmission process of the core green vegetable suppliers, and verifies the SIR simulation results through model derivation. Case analysis shows that the integration of green vegetable supply chain is an important way to redistribute green vegetable production and circulation resources, and the integration of green vegetable supply chain. And core green vegetable suppliers can more effectively control the occurrence, spread and spread of green vegetable safety risks. Building a risk aversion supply chain can change the weak integration situation of the green vegetable supply chain.

This paper also has some concrete shortcomings. For example, the risk transmission of the green vegetable supply chain is simply determined as the SIR model, while not considering other transmission models. In order to be convenient to analyze, the author also does not consider temporary immunity. Due to the temporary immune habit, some local areas in the network will oscillate as the risk transmission in a large number of concentrated areas will produce some immune areas. Therefore, the research results of this article have certain limitations, which also point out the direction that needs to be further explored in the future.

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