Modelling and simulation of the balance of supply chain ecosystem

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ABSTRACT. *This paper explores the impact of the balance in supply chain ecosystem on the revenue of the supply chain. Specifically, the amount, quality, dissemination speed and decomposition speed of information in the ecosystem were subjected to dynamical analysis and numerical simulation, aiming to disclose their impacts on supply chain revenue. The impacts of individual factors were combined to simulate the effects of the balance in supply chain ecosystem on the said revenue. The results show that the supply chain revenue can be promoted by the balance of supply chain ecosystem, and the balance can be maintained by controlling the information amount, enhancing the information quality, and accelerating the information dissemination.*

RÉSUMÉ. *Ce document explore l'impact de l'équilibre de l'écosystème de la chaîne d'approvisionnement sur les revenus de la chaîne d'approvisionnement. Plus précisément, la quantité, la qualité, la vitesse de diffusion et la vitesse de décomposition de l'information dans l'écosystème ont été soumises à une analyse dynamique et à une simulation numérique, dans le but de révéler leurs impacts sur les revenus de la chaîne d'approvisionnement. Les impacts des facteurs individuels ont été combinés pour simuler les effets de l'équilibre dans l'écosystème de la chaîne d'approvisionnement sur les revenus en question. Les résultats montrent que les revenus de la chaîne d'approvisionnement peuvent être favorisés par l'équilibre de l'écosystème de la chaîne d'approvisionnement et que l'équilibre peut être maintenu en contrôlant la quantité de l'information, en améliorant la qualité de l'information et en accélérant la diffusion de l'information.*

KEYWORDS: *supply chain ecosystem, balance, information volume, information quality, information dissemination speed, information decomposition speed.*

MOTS-CLÉS: *écosystème de la chaîne d'approvisionnement, équilibre, volume de l'information, qualité de l'information, vitesse de diffusion de l'information, vitesse de décomposition de l'information.*

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1. Introduction

The supply chain is a functional network chain structure composed of nodes such as suppliers, manufacturers, distributors, retailers and customers (Santoso *et al.*, 2005; Nagurney *et al.*, 2002). In the supply chain network, information flow acts as a link to connect each node, affecting the logistics and capital flow. Information flow plays an irreplaceable role in supply chain management. Inventory information, order information, market information, and logistics information are all part of the information flow. Any mishandling of information will affect the normal operation of the supply chain system. Therefore, although the supply chain network structure is morphologically affected by material flow, it is essentially based on information flow. All enterprise nodes in the supply chain are constantly generating, transmitting, consuming, and decomposing information, thereby forming a topological structure network of information transmission. The information ecosystem of supply chain is an organic whole composed of the interaction and interplay between the information subject, the information ecological environment and the information in the supply chain environment (Vincent and Macleod, 2011; Tao, 2014). In the current supply chain information ecosystem, the problem of information ecological imbalance is very common. The disorderly production of information producers leads to the difficulty of information dissemination, the flooding of useless and distorted information hinders the information users from exploring useful information, and the weakness in information decomposition deepens the of the above problems. In order to promote the development of the supply chain information ecosystem in a balanced direction, it is necessary to explore the relationship between information production, transmission, consumption and decomposition, so that the various elements in the system can be reasonably distributed and the operational structure is more efficient.

The information ecological balance of supply chain is an indispensable part of constructing the ecological civilization society. As the most basic organizational form of enterprise information ecosystem, the dynamic balance of supply chain information ecological chain is the basic prerequisite for the harmony and stability of supply chain information ecosystem. Study on dynamic balance mechanism of information ecological chain of supply chain can clarify the motive and main characteristics of dynamic balance or imbalance of information ecological chain of supply chain, so as to provide theoretical guidance for maintaining or restoring balance.

A supply chain ecosystem consists of the elements of the supply chain and the entities that influence the goods, information and financial flows through the supply chain (Viswanadham and Samvedi, 2013; Chaplin-Kramer *et al.*, 2016). At present, in the research of network information ecosystem, Lou *et al.* (2013; 2014) systematically studied the dynamic balance of network information ecological chain, symbiosis and mutual benefit, increments of value, collaborative competition, and information circulation etc. From the perspective of supply chain, Fan (2011) proposed in terms of the information ecosystem balance to rebuild the supply chain business process through information integration platform and establish a dynamic alliance, in order to achieve the dynamic balance of the information ecosystem. Huo *et al.* (2016) empirically studied the relationship between the degree of information

standardization, information transmission ability and willingness to send, the willingness to receive information and the ability to receive, and the information transmission efficiency of the supply chain information ecological chain. Boehmke and Hazen (2017) proposed to build a supply chain information ecosystem through an open source ecosystem.

It can be seen from the above literature that the study on the balance of the supply chain information ecosystem is still insufficient. Based on the above-mentioned literature, this paper intends to use the system dynamics to establish a mathematical model. Through numerical simulation, it also analyses the impact of information amount, information dissemination speed, information decomposition speed, and information quality etc. on the supply chain revenue in the supply chain ecosystem, and then discusses the related issues such as the balance of the supply chain information ecosystem etc.

2. Information ecosystem dynamics

The function and quantity of the information subject are properly configured. The function and quantity configuration of information subject is the important content of information ecological chain structure. Different types of information subjects in the information ecological chain have different information functions, and all kinds of information subjects can carry out information activities according to their respective information functions. The balanced information ecological chain must have all kinds of necessary functional information subjects, less functional niche overlap of core nodes, no redundant functional information subjects, and an appropriate proportion of different types of information subjects.

Information service supply and demand matching between upstream and downstream nodes. The fundamental purpose of information flow is to meet the information needs of downstream nodes through the information services of upstream and downstream nodes. Whether the supply and demand of information services can match between upstream and downstream nodes is an important sign of whether the information ecological chain can maintain a stable and balanced state.

The information technology level of upstream and downstream nodes is adaptive to each other. The mutual adaptation of information technology between upstream and downstream nodes of information ecological chain means that the construction and application level of computer infrastructure are the same as that of upstream node and downstream node. The higher the level of adaptability of information technology between upstream and downstream nodes, the higher the degree of coordination between nodes, the stronger the collaborative ability, and the more stable the information ecological chain.

The information system of upstream and downstream nodes is mutually recognized and harmonious. The information subjects in the information ecological chain all carry out information activities under certain institutional conditions. Under the state of balance, the information systems of upstream and downstream nodes should be mutually recognized and coexist in harmony.

Information technology and information system coordinate with each other. The information ecological chain needs to keep the coordination among information, information technology and information system, so as to ensure the structure and function of the chain in a relatively stable state for a long time.

3. Information ecosystem dynamics model of supply chain

The total amount of information in the supply chain information ecosystem changes with time. It's influenced by factors such as the number of nodes, the willingness to share information, and the speed of information decomposition etc. The more the number of nodes and the greater the willingness to share node information, the higher the information production rate. The information production rate and the information decomposition rate together determine the change in the total amount of supply chain information:

$$dm/dt = k_1 wx - v_d \tag{1}$$

where, m is the total amount of information in the supply chain information ecosystem, w is the willingness to share information in general, v_d is the speed of information decomposition, k_1 is the total amount of unique information resources that all nodes can share, and indicating the participation in information sharing in the supply chain ecosystem, and x is the proportion of nodes (for information sharing) in the total number of nodes in the supply chain ecosystem.

In formula (1), the information decomposition speed is a relatively stable value. In this paper, it is assumed to be a constant, and the information sharing willingness is affected by many factors such as the information processing cost in the information sharing process. It is a time-related parameter.:

$$dw/dt = \beta - p \tag{2}$$

where, p is the information processing cost, and β is the tolerance degree of the enterprise to the information processing cost. When the information processing cost p exceeds the tolerance threshold β, the willingness to share information will decrease.

The dissemination of information between supply chain nodes depends on the information ecological network. The information dissemination speed is affected by the network topology. In a regular linear network, the information dissemination of two nodes needs to pass through several intermediate nodes at a lower speed of information dissemination; conversely, in a fully connected network the information is transmitted at a relatively faster rate. Since the topology is relatively stable during the evolution of the supply chain ecosystem, in this paper, the constant c was used to describe the impact of topology structure on information propagation speed. The larger value c means that the higher information propagation speed in the network. The amount of information contact within the unit time in the supply chain information ecosystem is proportional to the total amount of information and the speed of information dissemination, namely:

$$e = cm \tag{3}$$

where, e is the total amount of information exposed to the node within the unit time.

The higher the speed of information dissemination in the network, the higher the information timeliness and the greater the unit value of information; the stronger the willingness to share information in the information ecosystem, the greater the value of information units. Information decomposition will also increase the quality of information to a certain extent. If the unit value (information quality) of information is u, then:

$$u = k_2 cwv_d \tag{4}$$

where, the coefficient k_2 is the action intensity of the information dissemination speed, the willingness to share, the information decomposition speed and other factors on the value of the information unit.

In the case that the amount of information required by the information user is constant, the more information that is contacted, the greater the probability of obtaining useful information, but the higher the cost of the corresponding information processing; the cost of information processing is proportional to the total amount of information exposure, and inversely proportional to the quality of information:

$$p = k_3 e/u \tag{5}$$

k_3 is a constant, indicating the action intensity of information exposures within the unit time, and information unit value etc. on the information processing cost.

The income of node is positively correlated with the amount of information and information quality that it is exposed to, but when the amount of information obtained is closer to the actual information demand, the increase of incomes in node is smaller than the amount of information it's exposed to. In this paper, the logarithmic function was used to describe the phenomenon that the information income decreases with the increase of information quantity and information quality. Assuming that the information income is represented by the symbol h, then:

$$h = log(1 + k_4 eu) \tag{6}$$

where, k_4 is a constant, which indicates the influence of factors such as information exposures per unit time and information unit value etc. on information income.

The net income π of nodes in the supply chain information ecosystem is the difference between information income and information processing cost, i.e.:

$$\pi = h - p \tag{7}$$

Based on formula (1)-(5), the evolved dynamic equation of supply chain information ecosystem is given as:

$$\begin{cases} \frac{dm}{dt} = k_1 wx - v_d \\ \frac{dw}{dt} = \beta - k_3 m/(k_2 w v_d) \end{cases} \tag{8}$$

By formula (4)-(7), it's calculated as:

$$\pi = log(1 + k_2 k_4 c^2 m w v_d) - \frac{k_3 m}{k_2 w v_d} \tag{9}$$

Given a set of initial values and parameter values, the total amount of information and the willingness to share information can be obtained according to formula (8). On this basis, the change rule of nodes incomes in the supply chain information ecosystem can be obtained according to formula (9).

4. Numerical simulation analysis of supply chain information ecosystem

To simulate the influence of information amplification, information decomposition speed and information dissemination speed on the balance of supply chain information ecosystem, three sets of simulation analysis were carried out in this paper. In the first set of simulation analysis, all coefficients k were to 1, and $x = 1$, $v_d = 1$, $\beta = 1$, and $c = 1$. Figure 1 shows the numerical simulation results, in which the total amount of information represented by the blue curve increases sharply, and the supply chain gains increases initially with the amount of information; when the amount of information reaches a certain level, the benefit/gains of the supply chain will decrease due to the cost increase in extracting useful information, and then the willingness to share information has also declined accordingly.

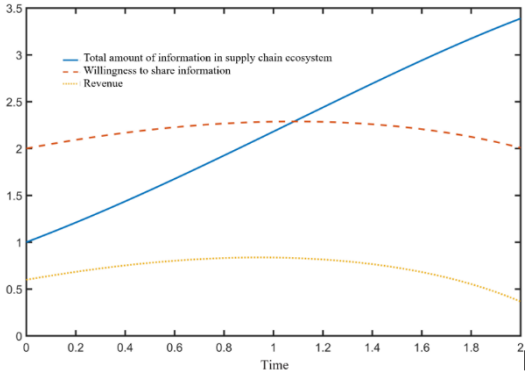

Figure 1. Simulation results when all k parameters are 1

In the second set of numerical simulation, the information analysis speed was increased, and other parameters were unchanged. Figure 2 shows the results. Compared with Figure 1, it can be seen that when the information decomposition

speed is accelerated, the increase rate of the total information amount in the supply chain ecosystem is slowed down to a certain extent, which promotes the supply chain revenue.

In the third set of numerical simulation, the information propagation speed was reduced, and other parameters were unchanged. Figure 3 shows the results. Compared with the results of Figure 1 and 2, when the information dissemination speed is reduced, the supply chain revenue will decrease. The reduction of information dissemination speed will reduce the timeliness of information obtained by information users, thereby reducing the use value of information and affecting the total revenue of the supply chain.

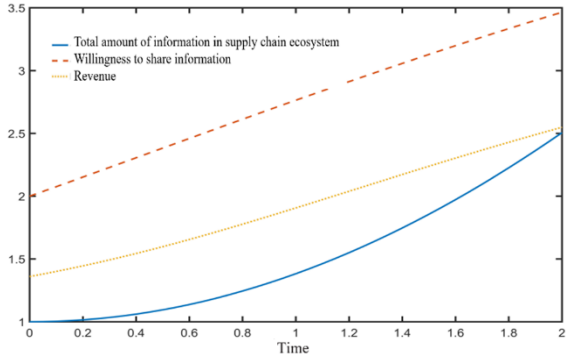

Figure 2. Numerical simulation results when increasing information decomposition speed

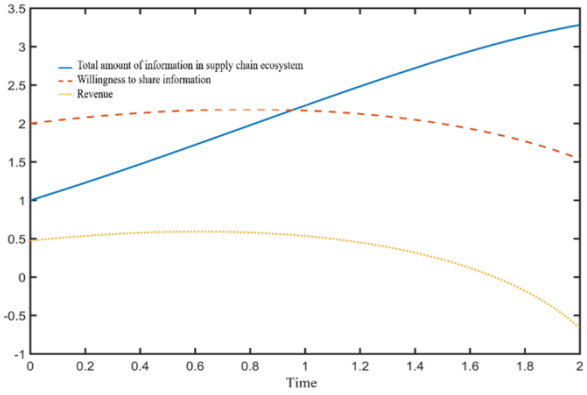

Figure 3. Numerical simulation results when reducing information dissemination speed

4. Conclusions

From the above analysis, the balance of the supply chain ecosystem shall affect the total revenue of the supply chain. When the amount of information in the system is larger, despite the higher probability that the information user acquires useful information, the relevant information processing cost is higher. Excessive amount of information can also cause a decline in the quality of information, which in turn has a negative impact on supply chain revenue. In order to maintain the balance of the supply chain ecosystem, more emphasis should be put on the role of information decomposition, which can strengthen the function of information decomposers for quickly deleting useless and inaccurate information and then ensure the normal operation of the information ecosystem.

In addition, the speed of information dissemination will have a greater impact on the revenue of the supply chain. At a lower speed of information dissemination, it is difficult for information users to obtain timely information, and the use value of the information will decrease. To ensure the speed of information dissemination in the ecosystem, the topology structure of the supply chain network should be optimized to avoid the generation of linear structures. By controlling the amount of information, enhancing the quality of information, and accelerating the speed of information dissemination, the balance of the supply chain ecosystem can be maintained and then the overall benefits of the supply chain can be promoted.

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References

Boehmke B. C., Hazen B. T. (2017). The future of supply chain information systems: The open source ecosystem. *Global Journal of Flexible Systems Management*, Vol. 18, No. 2, pp. 163-168. https://doi.org/10.1007/s40171-017-0152-x

Chaplin-Kramer R., Jonell M., Guerry A., Lambin E. F., Morgan A. J., Pennington D. (2016). Ecosystem service information to benefit sustainability standards for commodity supply chains. *Annals of the New York Academy of Sciences*, Vol. 1355, No. 1, pp. 77-97. https://doi.org/10.1111/nyas.12961

Fan X. N. (2011). Study on imbalance and countermeasures of information ecosystem in supply chain. *Intelligence Science*, Vol. 29, No. 6, pp. 847-851.

Huo M. K., Zhang X. X., Li S. (2016). Empirical study on factors influencing the efficiency of information transmission in information ecological chain of supply chain. *Journal of*

Intelligence, Vol. 35, No. 2, pp. 188-194. https://doi.org/10.3969/j.issn.1002-1965.2016.02.033

Lou C. Q., Bi D. Y., Zhang M. M. (2014). Study on operation mechanism of network information ecological chain: Dynamic balancing mechanism. *Information Science*, Vol. 32, No. 1, pp. 8-13.

Lou C. Q., Gui X. M., Yang G. (2013). Study on operation mechanism of network information ecological chain: Cooperative competition mechanism. *Information Science*, Vol. 31, No. 8, pp. 6-12.

Lou C. Q., Yang Y., Gui X. M. (2013). Research on operation mechanism of network information ecological chain: Information circulation mechanism. *Information Science*, Vol. 31, No. 6, pp. 3-9.

Lou C. Q., Yang Y., Gui X. M. (2013). Study on operation mechanism of network information ecological chain: Value increment mechanism. *Information Science*, Vol. 31, No. 9, pp. 3-9.

Lou C. Q., Zhang M. M., Pang L. (2013). Study on operation mechanism of network information ecological chain: Symbiosis and mutual benefit mechanism. *Information Science*, Vol. 31, No. 10, pp. 3-9.

Nagurney A., Dong J., Zhang D. (2002). A supply chain network equilibrium model. *Transportation Research Part E*, Vol. 38, No. 5, pp. 281-303. https://doi.org/10.1016/S1366-5545(01)00020-5

Santoso T., Ahmed S., Goetschalckx M., Shapiro A. (2005). A stochastic programming approach for supply chain network design under uncertainty. *European Journal of Operational Research*, Vol. 167, No. 1, pp. 96-115. https://doi.org/10.1016/j.ejor.2004.01.046

Tao Y. (2014). Glbal supply chain and information network. *American Behavioral Scientist*, Vol. 58, No. 10, pp. 1345-1360.

Vincent C., Macleod B. (2011). The application of structural holes theory to supply chain network information flow analysis. *Information Technology Journal*, Vol. 10, No. 1, pp. 146-151.

Viswanadham N., Samvedi A. (2013). Supplier selection based on supply chain ecosystem, performance and risk criteria. I*nternational Journal of Production Research*, Vol. 51, No. 21, pp. 6484-6498. https://doi.org/10.1080/00207543.2013.825056