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Multi-Tier Supply Chain Learning Networks: A Simulation Study Based on the Experience-Weighted Attraction (EWA) Model

Yu Gong [1], Xiaojiang Xu [2], Changping Zhao [3,4,*] and Tobias Schoenherr [5]

1 Southampton Business School, University of Southampton, Southampton SO16 7QB, UK; y.gong@soton.ac.uk
2 College of Finance and Statistics, Hunan University, Changsha 410082, China; m18342205102@163.com
3 Business School, Changshu Institute of Technology, Changshu 215506, China
4 Tianhua College, Shanghai Normal University, Shanghai 201815, China
5 Broad College of Business, Michigan State University, East Lansing, MI 48824, USA; schoenherr@broad.msu.edu
* Correspondence: zhao0037@sina.com

Abstract: Supply chain learning (SCL), which is reflected in organizational learning, referring to the learning between organizations in the supply chain, carries the promise to enable sustainable competitive advantages. Many large multinational companies, such as IKEA, Nestle, and Microsoft, have therefore integrated supply chain knowledge management and continuous learning into their corporate strategies. While there is evidence in extant research about a positive correlation between both the subjective attitude and learning ability of supply chain members and their performance improvement, areas where insight is still missing pertain to the relationship between supply chain members' subjective psychological factors, and their relationship network structures. This is a serious omission, since these dimensions likely play a key role in the dynamics underlying SCL. In order to alleviate this void, we consider a multi-tier SCL network and develop a model in which a supply chain member's attraction is weighted based on its previous learning experience. The game mechanism underlying SCL captured in this experience-weighted attraction (EWA) model is then tested using a simulation study of IKEA China's multi-tier supply chain network for its sustainable cotton initiative. The results suggest that learning costs can be reduced and learning spillover befits can be increased by the provision of rewards to network member companies and better communication. In addition, the perception of and preference for SCL by suppliers can be influenced by initiating sustainable advocacy and providing knowledge and technology training, as well as fostering a range of subjective factors we investigate in our study, such as the strategic attractiveness the decline ratio due to forgetting, the attractiveness improvement ratio due to preferences, and the response sensitivity to strategies. The findings offer insight into the influence mechanisms of the supply chain network structure and subjective attitude about SCL, which are especially applicable to large, multinational enterprises.

Keywords: experience-weighted attraction model (EWA); multi-tier; supply chain learning; supply chain network

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1. Introduction

The 21st century brought supply chain management (SCM) to the forefront of both industry and academia. Benefits of SCM are reflected in lower costs and higher efficiencies, making it a competitive priority for multinational companies. However, the COVID-19 pandemic and frequent geopolitical tensions have wreaked havoc with the smooth flow, operation and predictability of global supply networks. These rapid changes necessitate to learn about their supply networks and to acquire new knowledge resources, with the ultimate goal to enhance their innovation capabilities and market positions.

Within this context, supply chain learning (SCL) carries the promise as an effective approach for organizations to enable sustainable competitiveness advantage [1–4]. As such, many large multinational companies, such as IKEA China, Nestle, and Microsoft, have integrated supply chain knowledge management and SCL into their corporate strategies. SCL is reflected in organizational learning, and refers to the learning between organizations in the supply chain. The ability of organizational learning' to leverage a firm's supply chain partners' knowledge has been noted as being more efficient compared to other types of organizational learning approaches [5]. As such, SCL is an important way for enterprises to acquire knowledge and technology quickly, and thus improve competitiveness. The importance of SCL is reflected in 60 to 70% of large enterprises in the European and American markets having introduced formal knowledge management systems in their supply chains [6], highlighting the practical relevance and importance of SCL.

Literature is rich in studies investigating the positive impact of SCL. For example, Hernandez-Espallardo et al. (2010) tested the effectiveness of SCL for 219 Colombian apparel manufacturers [7], demonstrating that knowledge sharing and learning can significantly improve the overall performance of the supply chain, with an adequate governance of inter-firm relationships being a critical enabler for SCL. This has also been verified by the comparative advantages derived from Toyota's production network [8]. Organizational learning and knowledge sharing in the supply chain promotes innovation, thereby enabling performance improvements and the attainment of a supply chain's sustainable competitiveness [9–12]; this is especially the case when knowledge synergy across the supply chain is achieved [13–16]. The results are similar across industry supply chains.

Current research on the learning mechanism of multinational companies mainly focuses on the study of knowledge sharing mechanisms, which include objective factors such as the characteristics of knowledge, knowledge senders, knowledge recipients, and organizational contexts, as well as the methods of knowledge transfer [17]. It has not yet been determined how subjective psychological factors such as supply chain members' cognition and learning abilities influence supply chain learning and, in turn, supply chain performance, which is a serious omission in previous work. At the same time, while factors such as the openness of communication between networks, communication density, different corporate cultures, and the depth and breadth of network relationships can affect the flow, transfer, and development of knowledge [18], here research on supply chain learning from the perspective of the overall supply chain relationship network of multinational companies is lacking, This state of research leads us to the following research questions, which we aim to investigate in this study:

Q1: How will the subjective factors of supply chain members affect learning about the supply chain relationship network?
Q2: How can the effect of SCL be improved?

In aiming to answer these questions, we build on the four SCL types (captive, consortium, selective, and distributed) and the associated two fundamental dimensions of the SCL (SCL driver and SCL network) recently proposed by Silvestre et al. [19] for studying the network structure of SCL in this paper.

Most current articles on SCL focus on conceptual definitions and corporate performance improvement impact. We build on this work in this article and further explore the SCL mechanisms from the perspective of the cognitive level, the learning ability, and the learning network structure of supply chain member companies. At the same time, as sustainable supply chain management has become the focus of SCM research, we use a network game methodology in the form of the Experience-Weighted Attraction (EWA) model to study SCL mechanisms of multinational companies and propose targeted suggestions to improve the SCL of these multinational companies to maintain their sustainable competitive advantages. As part of our study, we improve the research method, which can be used to generally explain the mechanisms of SCL more comprehensively, serving as a ready tool to guide and help multinational companies to foster SCL, leveraging resources such as knowledge and technology to fully play their role among various supply chain member companies, to create value, and to maintain supply chain competitiveness.

After literature review, we then proceed with the presentation of the IKEA China case study, which serves as the context, within which we investigate SCL. This is then followed by a section constructing the complex supply network of IKEA China's SCL, establishing a network game model based on the Experience-Weighted Attraction (EWA) model considering realistic case conditions. The fifth section of this paper then presents the simulation method and details how it is used to simulate the network game model of IKEA China. The conclusions of the simulation are discussed in Section 6. A final section discusses the derived implications that can guide the implementation of SCL in multinational companies from a theoretical and practical perspective, serving as an important reference for academic research and business management.

2. Literature Review

2.1. Supply Chain Learning

Supply chain learning (SCL) is founded in organizational learning [20]. In this vein, Spekman et al. (2001) positioned learning as a key ingredient for the development of supply chain capabilities, with the supply chain being considered as "a tool for gathering knowledge and learning" [21]. Similarly, Bessant (2003) explored how SCL happens and identified three stages of SCL, consisting of a set-up phase, an operating phase, and a sustaining phase. The set-up phase is usually driven by the core company or a third-party and triggered by clear benefits and/or challenges that necessitate the intervention; the operating phase includes creating the network, defining the learning rules, maintaining the members, and decision-making; in the sustaining phase, a mechanism to maintain the long-term learning is identified [1].

Hernandez-Espallardo et al. (2010) developed a structural equation model to test data collected from 219 Colombian apparel manufacturers, with the results showing that knowledge sharing and learning have a positive impact on the performance of supply chain management, and that the competitiveness of the supply chain hinging on whether the relationships between enterprises are adequately managed [7]. The case of Toyota also illustrates that suppliers can learn faster after participating in a knowledge sharing network, which partially explains the relative productivity advantage enjoyed by Toyota and its suppliers [8]. In addition, a thematic analysis of blockchain-related agri-food business news and expert opinions from the Ovid database's Agricola section found that organizational adoption strategies determine the effectiveness of the implementation of technologies such as blockchain in agri-food supply chains [22]. A nuclear power incident in Sweden in 2006 also demonstrated the importance of organizational learning. Through interviews, seminars, and feedback from preliminary analysis, the specifics of organizational learning in this case were revealed, suggesting that there are other ways to enhance learning, thus further stressing the importance of the risk analysis and the impact of risk regulation [23]. Overall, it can be said that SCL can improve the collective performance of the system, which however is dependent on the learning ability of individual supply chain members, who are also responsible for their focal firm's performance [15].

Generally, the focal company, as the initiator of SCL, considers sustainability and stability of supply as a management strategy, with the focal company thus using its economic position to incentivize supply chain members to participate. These dynamics make SCL so diverse and complex [24]. For example, Gong et al. (2018) validated Bessant's three-stage model through multiple case studies and pointed out that focal companies need to orchestrate both internal and external supply chain resources, altering the supply chain network structure to effectively drive the development of SCL [2]. Jia et al. (2019) further proposed that focal companies or third-party organizations should play a leadership role in facilitating this learning process [25]. Furthermore, Gong et al. (2023) explored the complexity of multi-layered sustainable supply chain management (SSCM) from the perspective of social systems theory. Through case study analysis, the authors suggest that in order to cope with environmental complexity associated with multi-tier sustainable initiatives, focal companies tend to create both internal complexity and collaborative complexity through a variety of governance mechanisms, and that the increased environmental overlap and available collaborative complexity during the process can be fed back into the system to facilitate further creation of the requisite variety [26].

At the same time, the knowledge held by firms close to end markets often accurately describes the current needs of end customers, and through SCL, they can help the focal enterprise to more accurately position its products in the market and improve its ability to effectively perform its responsibilities. In turn, the knowledge that suppliers gain from the supply chain allows them to further understand specific needs and preferences [27]. While the roles of focal companies and suppliers in SCL are different, they both can benefit from participating in SCL. However, current research in SCL within the context of multinational corporations primarily focuses on the study of knowledge sharing mechanisms. In these studies, scholars have mainly explored the impact of factors such as the characteristics of knowledge, knowledge senders, knowledge recipients, and organizational contexts, as well as the methods of knowledge transfer and so on [17]. From the perspective of network structure, the learning mechanisms of multinational companies works through social networks among managers. An important foundation in promoting knowledge sharing is to establish a network of mutual trust, representing the basis for open and honest communication (cf., [18]). At the same time, as noted earlier, factors, such as the openness of communication between networks, communication density, different corporate cultures, and the depth and breadth of network relationships have the potential to affect the flow, transfer, and development of knowledge [18].

Overall, extant research has defined the concept of SCL, provided evidence that inter-organizational learning can significantly promote the performance of supply chain management, and studied the knowledge sharing mechanisms between enterprises. Our review of the literature revealed that the roles of focal companies and suppliers in the supply chain network are different, necessitating a SCM perspective when analyzing. Focusing on SCL mechanisms is important to incentivize enterprises to participate in SCL, thereby enhancing the overall supply chain competitive advantage.

2.2. Complex Networks

A complex network is a system model that can be used to describe interconnected systems in the natural sciences, the social sciences, and engineering technology. Yang et al. [28] defines it as a network with some or all of the properties of self-organization, self-similarity, being an attractor, small world, and scale-free. The widespread existence of complex networks has led a large number of scientists to engage in research on the topological properties and dynamic properties of complex networks [28]. Well-known complex network models include the Erdos–Renyi (ER) random network model [29], the Strogatz–Watts (SW) small-world network model [30], and the Barabasi–Albert (BA) scale-free network model [31]. Since these network models were proposed, complex network research has developed vigorously and has been applied in many fields.

Game theory is used to study how a single individual seeks to maximize interests in the process of interacting with others. Due to factors such as information barriers, cognitive levels and structural deviations, and policy time lags, game individuals do not fully comply with the rational economic man assumption usually considered in traditional game theory during the decision-making process of the game, but make irrational choices. As such, the bounded rationality assumption in evolutionary game theory [32] can provide a more realistic explanation because its characteristics are more consistent with many real networks. Therefore, using game evolution on complex networks to study real problems has attracted the attention of scholars. For example, Nowak and May (1992) identified the positive effect of spatial structure on the cooperation, which provided a research method model for subsequent research [33,34]. Further, Tomassini et al. (2006) analyzed the hawk–dove game on small-world networks and found that cooperative behavior in small-world networks is related to the evolutionary rules, benefit assumption ratios, and network characteristics set in the game [35].

Through the above literature analysis, we suggest that it is feasible to study real-world networks by combining complex networks and evolutionary games. When doing so, different real networks can be studied according to their characteristics to construct different complex networks. In view of this, taking into account the close connection between various stakeholders in the supply chain network of multinational corporations, this paper also builds an SCL network based on the SCL structure proposed by Silvestre et al. [19] and designs an SCL model based on the case situation, followed by simulation analysis.

3. Method and Model Analysis

Different companies are associated with different learning network structures at different stages of their SCL, however, after SCL gradually stabilizes, a final closed network structure can be derived. Since that the supply chain network involves many nodes and the connections between the networks are complex and large-scale, individuals can always be connected with each other through the relationship of the supply chain, with enterprises at different levels having different roles and importance levels for SCL, this further increases the complexity of the network.

Tachizawa and Wong (2014) noted that in a sustainable multi-tier supply chain, focal companies adopt multiple governance mechanisms, which can include direct cooperation, indirect cooperation (through first-tier suppliers), and cooperation with third-parties (such as non-governmental organizations and industry associations), so as to manage the sustainability performance of supply chain members [36]. The adoption of multiple governance mechanisms was evidenced in the studies by Gong et al. (2018) and Jia et al. (2019), who conducted in-depth interviews with members of IKEA China's supply chain network, including senior managers from both IKEA China and its suppliers across multiple tiers [2,25]. Both studies found that a mix of the three supplier governance mechanisms was applied to implement the sustainable cotton initiative.

Specifically, in GONG et al.'s [2] study, an exploratory multiple case study approach was adopted and three MNCs' sustainable initiatives in China were examined. The data were primarily collected through 43 semi-structured interviews with managers of focal companies and their multi-tier suppliers. They extended their internally focused resource orchestration perspective (ROP) to the supply chain level and answered the theoretical question of how multinational corporations orchestrate internal and external resources to help their supply chains learn sustainability.

The study by Jia et al. [25] is also based on multiple case studies of these three multinational companies. In their research, they paid more attention to the leadership of focal companies in the supply chain. They proposed a framework based on the constructs of supply chain leadership, multi-tier supply chain governance, multi-tier supply chain structure and SCL and found that the combined effect of supply chain leadership and governance mechanisms affects both supply chain structure and SCL and MNCs change their supply chain structure to facilitate supply chain learning.

This article pays more attention to the perspective of supply chain network, and carries out an analysis of the SCL mechanism based on their multiple case studies on multi-layer SCL of multinational companies [2,25]. IKEA China, a Western multinational company operating in China, was chosen as the research object as Western multinational companies are much more mature than Chinese companies in terms of SCM and corporate social responsibility [37]. At the same time, multinational companies that adopt localized manufacturing and supply chain operation strategies are better able to maximize SCL [2]. IKEA China has a complete set of strict organizational systems and it determines the domestic sales and exports of products through scientific management, which provides the basis for its SCL. In addition, compared with Tetra Pak and Nestlé, which were also studied by Gong et al. [2], IKEA China's sustainable development plan—the cotton plan—has achieved a 100% sustainable procurement and has a higher degree of SCL, making the case analysis more insightful. According to IKEA China website, it is guided by the IKEA group, which hopes to integrate sustainable development into life through more than 4000 sustainable products. Sustainable development is an important strategic cornerstone of IKEA, which runs through IKEA's value chain, company operations, and cooperation and communication with various stakeholders. The group is not only interested in growing business, but also in how its business impacts the world. This way of balancing commercial interests and social responsibility is imperative for today's enterprises, which can win the trust and support of consumers and is the key to forming a competitive advantage in the supply chain.

The present research applies an EWA model to the SCL network of IKEA China with the objective to simulate the SCL game mechanism [2,25]. The simulation method is first used to test the game model, followed by an assessment of the influence mechanisms associated with the multi-tier supply chain network and related subjective psychological SCL factors.

Specifically, we utilize a statistical learning model to study the effect of subjective psychological factors on SCL and to then predict changes in SCL behavior of large companies. The model is tested using a simulation study of IKEA China's multi-tier supply chain network for its sustainable cotton initiative. While various learning models exist, including reinforcement learning models and belief learning models [38–41], we leverage the EWA model [42], which combines the reinforcement learning models and the belief learning models, taking into account the effects of experience reinforcement and strategic attraction, representing a more general learning model.

IKEA China's cotton-textile supply chain consists of six processes: cotton farming, ginning, spinning, weaving, dyeing, and cutting and stitching. These six processes are carried out at five levels in IKEA China's SCL network (as in Figure 1): the first level (L1) consists of the focal firm in the supply chain network, i.e., IKEA China, where the branding is implemented here.; the second level (L2) is comprised of the cutting and stitching supplier (a T1 supplier), which is a tier-one supplier that receives training directly from IKEA China; the third level (L3) consists of the dyeing supplier, which is contacted by the tier-one supplier (L3 is thus a T2 supplier); the fourth level (L4) includes the weaving and spinning suppliers (T3 and T4 suppliers) that interact with T1 and T2 suppliers; the fifth and last level (L5) is comprised of ginners and cotton farmers (T5 and T6 suppliers, respectively), with which IKEA China has direct contact and/or collaborates with in the form of third-party knowledge providers, such as the Better Cotton Initiative (BCI), which is a third-party non-governmental organization (NGO). Depending on the specialization of suppliers, the various activities in the supply chain (ginning, spinning, weaving, dyeing, cutting and stitching) may be covered in different combinations by suppliers.

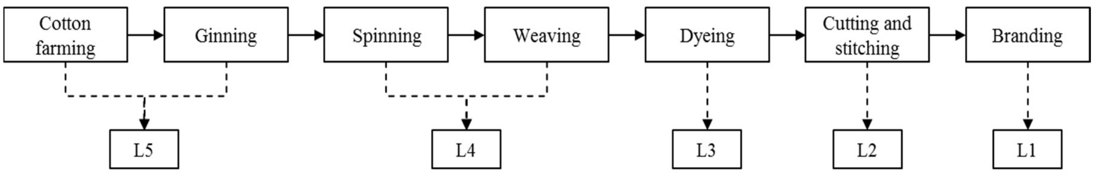

Figure 1. IKEA China's supply chain learning network.

As is evident from this structure, the cotton-textile supply chain is long and complex, encompassing vertically integrated suppliers at different levels. For example, while some suppliers cover all the processes from spinning to cutting and stitching, others only cover one or two processes. In an instance of very limited integration, Gong et al. (2018) for instance found that IKEA China directly provided training to T1 suppliers [2]. At the same time, T2 and some T3 suppliers were also indirectly involved through first-tier suppliers, for instance in the form of joint workshops. For T3 and T4 suppliers, IKEA China mainly adopted indirect or third-party cooperation methods through T1 or T2 suppliers to gain influence; for T5 and T6 suppliers, IKEA China adopted a direct approach in the early stages of network development, and a third-party cooperation approach in the later stages, so as to provide hands-on training. The implication is that in addition to directly managing raw material suppliers (T5 ginning and T6 cotton farming), IKEA China tends to fully delegate sustainable cotton purchases to T1 suppliers and third-party agencies. While cooperation with third-party organizations was one of the governance methods chosen by

IKEA China, the associated costs for cooperation and communication were mainly covered by IKEA China. We therefore consider third-party organizations as learning resources provided by IKEA China, the focal company, to maintain the SCL network.

Members on the same level of IKEA China's cotton supply chain can leverage industry communication platforms to learn and communicate with each other. For example, ITCS (Inter Testing & Consulting Services) is IKEA's own laboratory, which integrates product testing and supplier training to provide comprehensive and high-quality technical support services for IKEA suppliers. At the same time, IKEA China continuously coordinates with its suppliers to enable knowledge sharing and learning when it comes to sustainable management standards. There is a mutual understanding for collaborative learning among members at the same level, thereby forming a connected learning network. For simulation purpose, based on Gong et al. (2018) and Jia et al. (2019) [2,25], and further confirmation by IKEA China's sustainable cotton managers, the number of suppliers to IKEA China at the various levels described above were 1, 5, 5, 5, and 6 for L1 through L5, respectively.

In order to determine whether there is a learning relationship between two suppliers, we consider whether the suppliers are on the same level or on adjacent ones; if the suppliers are on the same level or adjacent ones, a learning relationship exists; otherwise, a learning relationship does not exist. Utilizing the UCINET 6 software yields the SCL network as depicted in Figure 2.

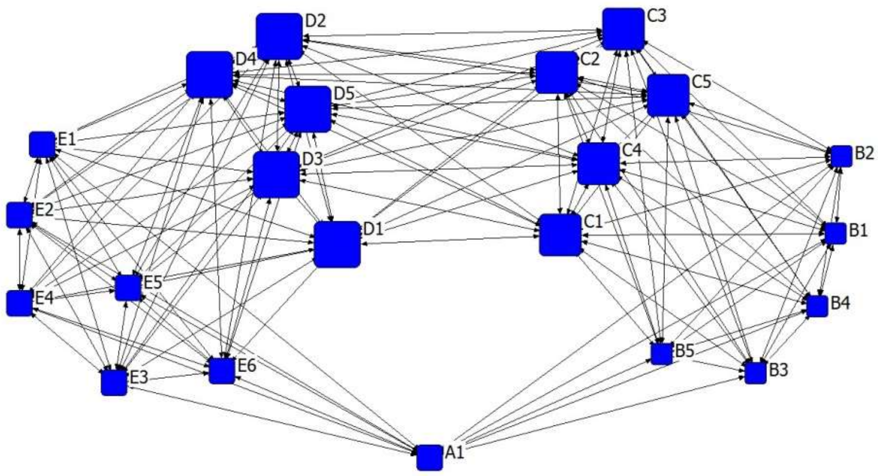

Figure 2. Complex network diagram of IKEA's SCL network.

The relationship matrix corresponding to Figure 2 is shown in Figure 3. The letters A, B, C, D, and E represent the IKEA supply chain levels from L1 to L5, respectively. There are 5 suppliers each at theL2, L3, and L4 links, and 6 atL5. We plotted their learning relationships in Figure 3 and determine the degree of the corresponding node enterprise in the supply chain as K_i = [11, 10, 10, 10, 10, 10, 14, 14, 14, 14, 14, 15, 15, 15, 15, 15, 15, 11, 11, 11, 11, 11, 11, 11].

	A1	B1	B2	B3	B4	B5	C1	C2	C3	C4	C5	D1	D2	D3	D4	D5	E1	E2	E3	E4	E5	E6
A1	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1
B1	1	0	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0
B2	1	1	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0
B3	1	1	1	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0
B4	1	1	1	1	0	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0
B5	1	1	1	1	1	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0
C1	0	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0
C2	0	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0
C3	0	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	0	0	0	0	0	0
C4	0	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0	0	0	0	0	0
C5	0	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	0	0	0	0	0	0
D1	0	0	0	0	0	0	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1
D2	0	0	0	0	0	0	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1
D3	0	0	0	0	0	0	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1
D4	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1
D5	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1
E1	1	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	1	1	1	1	1
E2	1	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	0	1	1	1	1
E3	1	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0	1	1	1
E4	1	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	1	1
E5	1	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	0	1
E6	1	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	0
Ki	11	10	10	10	10	10	14	14	14	14	14	15	15	15	15	15	11	11	11	11	11	11

Figure 3. Relationship matrix of network nodes.

4. Game Model of IKEA China's Supply Chain Learning Network

4.1. EWA Model

The EWA model is able to capture both reinforcement learning and belief learning. On the one hand, reinforcement learning theory suggests that game participants will adjust their behavior based on the experience formed by the reward of past actions, which means high-yield action strategies are selected and strengthened, while low-yield strategies are discarded—and since they are not applied any more, they cannot be strengthened. On the other hand, belief learning theory suggests that by observing the game history, participants discover the probability that other participants choose action strategies, form beliefs about other participants' action choices, and then choose their own optimal action strategy based on their beliefs. Belief learning conforms to statistical laws, which are governed by internal psychological laws. The EWA model, which combines these two learning theories and blends the reinforcement of experience with the beliefs of players, is a more general learning model.

In reality, when determining the SCL strategy, the member enterprises of the supply chain will make the selection of the current period based on the experience of the previous period. In order to reflect the actual situation more comprehensively and objectively, this paper constructs an SCL strategy selection model for supply chain member enterprises based on the basic idea of the EWA learning model, and the equation can be expressed by Equation (1):

$$A_i^j(t) = \frac{\varphi N(t-1) \times A_i^j(t-1) + \left[\delta + (1-\delta) \times I(s_i^j, s_i(t))\right] \times \Pi_i(s_i^j, s_{-i}(t))}{N(t)} \quad (1)$$

where t is the period of the game. s_i^j is the j-th strategy of player i in period t, the strategy set of other players is denoted as $s_{-i}(t)$. $\Pi_i(s_i^j, s_{-i}(t))$ is the income of node i. $A_i^j(t)$ is the attractiveness of strategy j to node i. $N(t)$ is the experience weight, which indicates the influence of a participant's game history on the attractiveness of the current strategy. $A_i^j(t)$ and $N(t))$ are updated after each experience period. The parameter δ represents the weight that the learner subjectively gives to the benefits of the unselected strategy, δ ∈ [0, 1]. It is affected by the perceived reliability of the abandoned strategy's benefits, which is a psychological estimation variable.

The parameter φ represents the coefficient indicating the decline of strategic attractiveness. In the process of the SCL game, enterprises partially abandon their experience due to forgetting or the competitive environment changing, resulting in the attenuation of the attraction in the previous period and a decrease in the effectiveness of the strategy. The parameter φ measures the extent of the decrease.

The initial value of the experience weight is $N(0)$, and is updated according to $N(t) = \varphi(1-\kappa)N(t-1)+1$. Its limitation is $N(t) \leq \frac{1}{1-\varphi(1-\kappa)}$, so $N(t)$ is weakly increasing. The initial value of attraction is $A_i^j(0)$, which is updated according to Equation (2):

$$A_i^j(t) = \frac{\varphi N(t-1) \times A_i^j(t-1) + \left[\delta + (1-\delta) \times I(s_i^j, s_i(t))\right] \times \Pi_i(s_i^j, s_{-i}(t))}{\varphi(1-\kappa)N(t-1)+1} \tag{2}$$

where κ is the learning growth rate of strategic attractiveness, indicating the learning ability to learn from past gaming experiences. Due to the cumulative increase in the strategy's attractiveness in the reinforcement learning model, and the slow growth of attractiveness in the belief learning model, this model uses κ to represent the impact of different models on the increase in strategy attractiveness in the game learning process. The lower the attraction growth rate, the closer κ is to 0, and the higher the growth rate of the attraction, the closer κ is to 1. $I(s_i^j, s_i(t))$ is an indicator function, which is equal to 1 when s_i^j is the same as $s_i(t)$, and 0 in other cases, as shown in Equation (3):

$$I\left(s_i^j, s_i(t)\right) = \begin{cases} 1 & \text{if } s_i^j = s_i(t) \\ 0 & \text{if } s_i^j \neq s_i(t) \end{cases} \tag{3}$$

The weighted payment term $\left[\delta + (1-\delta) \times I(s_i^j, s_i(t))\right] \times \Pi_i(s_i^j, s_{-i}(t))$ in Equation (2) can be expressed as

$$\left[\delta + (1-\delta) \times I(s_i^j, s_i(t))\right] \times \Pi_i(s_i^j, s_{-i}(t)) = \begin{cases} \Pi_i\left(s_i^j, s_{-i}(t)\right) \text{ if strategy j is adopted} \\ \delta\Pi_i\left(s_i^j, s_{-i}(t)\right) \text{ if strategy j is not adopted} \end{cases} \tag{4}$$

The attractiveness of the strategy $A_i^j(t)$ determines the probability of the strategy being selected. The greater the attractiveness of the strategy, the more likely it is to be selected. Since the learning process conforms to the law of measurement statistics, an index model can be used to express the strategy's attractiveness. The selection probability can be expressed by Equation (5):

$$P_i^j(t+1) = \frac{e^{\lambda A_i^j(t)}}{\sum_{k=1}^{m_i} e^{\lambda A_i^k(t)}} \tag{5}$$

where m_i represents the strategy set of i, and λ represents the sensitivity of the supply chain member companies to strategic attraction, which is affected by the member companies' motivation, psychological perception, and other factors.

4.2. Payment of the Supply Chain Learning Network Game Model

Member companies in the multi-tier supply chain network share knowledge and information through learning. The sharing of knowledge and information is conducive to improving the work and innovation capabilities of supply chain employees; these capabilities are reflected in the supply chain's production efficiency and operating performance through the learning curve effect. Further, companies in a supply chain can be said to possess the characteristics of economic people, pursuing profits and avoiding risks [43]. As such, based on the research of Christoph et al. (2019) [44], the following assumptions can be made:

(1) The production costs of member companies in the supply chain network conform to the learning curve. It is assumed that the production cost of a node company is X, and its value range is $X > 0$. X_q represents the cost of producing the q-th product, X_1 is the initial production cost, and considering the impact of SCL on the learning curve, the cost function of node i for product production is as follows:

$$X_q = X_1 \times (Q^{-a})^{s_i^j} \times (Q^{-d})^{s_{-i}^j} \times Q^{-b} \tag{6}$$

where $(Q^{-a})^{s_i^j}$ and $(Q^{-d})^{s_{-i}^j}$ indicate that when a company chooses SCL, the sharing of expertise and technology within the supply chain leads to a continuous decline in the costs, related to, for instance, production, management, and transactions. Specifically, $(Q^{-a})^{s_i^j}$ represents the cost reduction effect brought by a nodal i enterprise after implementing SCL, and $(Q^{-d})^{s_{-i}^j}$ represents the cost reduction effect brought by a nodal $-$i enterprise after implementing SCL. These effects accelerate the decline of the learning curve. Compared with the case where SCL is not performed, the latter produces the same number of final products, and its marginal cost decreases faster, which is likely to foster a supply chain's competitive advantage [45,46]. In addition, when $s_i^j = 1$ and $s_{-i}^j = 1$, the marginal production cost is

$$X_q = X_{11} = X_1 \times Q^{-a-\mathrm{d}} \times Q^{-b} \tag{7}$$

Further, when $s_i^j = 1$ and $s_{-i}^j = 0$, the marginal production cost is

$$X_q = X_{10} = X_1 \times Q^{-a} \times Q^{-b} \tag{8}$$

Moreover, when $s_i^j = 0$ and $s_{-i}^j = 1$, the marginal production cost is

$$X_q = X_{01} = X_1 \times Q^{-\mathrm{d}} \times Q^{-b} \tag{9}$$

Also, when $s_i^j = 0$ and $s_{-i}^j = 0$, the marginal production cost is

$$X_q = X_{00} = X_1 \times Q^{-b} \tag{10}$$

(2) Enterprises in a supply chain generally participate in the production of the final product. In the short-term, the market price of the final product is fixed at P and the market demand is Q. The contribution rate of a single company i to the product in the supply chain is $\mathrm{v_i}$.

(3) Assuming that the node enterprises have a similar risk appetite, they have two strategies to choose from: learning and not learning; remember that the jth strategy of participant i is s_i^j, The strategy set of participant i in period t and other participants (denoted as $-i$) are $s_i(t)$ and $s_{-i}(t)$, respectively.

(4) Combining Assumptions 1, 2, and 3, we can obtain the gains π of a single-node enterprise. The difference between the total revenue and the total cost of the final product in the supply chain is distributed according to the contribution rate, and the gains π can be expressed as

$$\pi_{\mathrm{i}}(s_i(t), s_{-i}(t)) = \mathrm{v}_i \times (PQ - \int_0^Q X_q dx) \tag{11}$$

Under different learning strategies, the payoffs for node companies are as follows:

(a) When the central node i chooses to learn, and the neighbor node −i also chooses to learn, the payment income for nodes i and $-i$ is

$$\pi_{i11} = \mathrm{v}_i \times (PQ - \int_0^Q X_{11} dx) \tag{12}$$

$$\pi_{-i11} = \mathrm{v}_{-i} \times (PQ - \int_0^Q X_{11} dx) \tag{13}$$

(b) When the central node i chooses to learn, and the neighbor node −i chooses not to learn, the payment income is

$$\pi_{i10} = \mathrm{v}_i \times (PQ - \int_0^Q X_{10} dx) \tag{14}$$

$$\pi_{-i10} = \mathrm{v}_{-i} \times (PQ - \int_0^Q X_{10} dx) \tag{15}$$

(c) When the central node i chooses not to learn, and the neighbor node −i chooses to learn, the payment income is

$$\pi_{i01} = \mathrm{v}_i \times (PQ - \int_0^Q X_{01} dx) \tag{16}$$

$$\pi_{-i01} = \mathrm{v}_{-i} \times (PQ - \int_0^Q X_{01} dx) \tag{17}$$

(d) When the central node i chooses not to learn, and the neighbor node −i chooses not to learn, either, the payment income is

$$\pi_{i00} = \mathrm{v}_i \times (PQ - \int_0^Q X_{00} dx) \tag{18}$$

$$\pi_{-i00} = \mathrm{v}_{-i} \times (PQ - \int_0^Q X_{00} dx) \tag{19}$$

The payment matrix for a single game between the enterprise and their neighbors on the supply network is shown in Table 1.

Table 1. Single-game payment matrix.

Single Game of Nodes *i*, $-i$		**Strategy of Node $-i$**	
		Learn	**Do Not Learn**
Strategy of node i	Learn	π_{i11}; π_{-i11}	π_{i10}; π_{-i01}
	Do not Learn	π_{i01}; π_{-i10}	π_{i00}; π_{-i00}

The inter-firm learning of a company's supply chain network is a dynamic process. Each supplier chooses the strategy of the next game according to the income obtained by the strategy it chooses in the game. The experience of the previous game will form a belief and affect the next game decision. We use $\Pi_i(s_i(t), s_{-i}(t))$ to represent the expected return of enterprise i.

4.3. Network Game Model for SCL

In the learning network diagram shown in Figure 2, each node represents a company within the SCL network. Based on the conclusions of the field interviews reported in Gong et al. (2018) and Jia et al. (2019) [2,25], the following assumptions are made:

(1) The node enterprises in the learning network will imitate their neighbors with a higher probability than non-adjacent neighbors [47,48]; the strategy set of each node

enterprise i is s_i^j = {0,1}; 1 indicates that a learning strategy is pursued, and 0 indicates that no learning strategy is pursued. Similarly, we can obtain $s_{-i}^j = \{0, 1\}$;

(2) The adjacency matrix A is used to represent the learning network of the supply chain. If there is an edge between node i and node −i, A_{-ii} is 1, otherwise it is 0. IKEA China's supply chain network is shown in Figure 3;

(3) In the SCL network, node companies can only communicate with their neighbor nodes and is mainly influenced by them [49], so the game relationship only exists between neighbor nodes;

(4) Whatever the network structure is, incentives in general exhibit a facilitative effect on cooperative behavior [8]; therefore, it can be assumed that in order to motivate the learning behavior of network nodes, the core company (IKEA China in our illustration) that chooses the learning strategy will economically reward the nodes that also choose the learning strategy in the network. Let r denote the reward given by the company (i.e., the core company) to other enterprise nodes in the supply chain. The total reward amount paid by the company is $\sum_{2}^{Z} s_i^j \cdot$r, where Z represents the total number of enterprise nodes in the supply chain of a company, and the incentive received by a single enterprise node in the supply chain is $s_i^j \cdot$r;

(5) Due to information asymmetry, corporate relations, knowledge stickiness, and differences in the ability to transfer knowledge between different enterprises, obstacles will appear in the learning process. As such, enterprises incur costs to reduce or eliminate these obstacles [50,51]. The ratio of these costs to the benefit is represented by u_i; $0 < u_i < 1$. The learning cost of the node enterprise can then be expressed as $s_i^j u_i \times \sum s_{-i}^j A_{-ii}(\pi_{i11} + \text{r})$, with $(\pi_{i11} + \text{r})$ being the current income obtained when node *i* chooses to learn in this round of the game;

(6) Learning has a knowledge spillover effect, which is also applied in our context of a company's supply chain [52]. As such, IKEA China is at the core of the SCL network, and thus can fully absorb the knowledge experience of each node company, hence garnering the largest knowledge spillover benefit. There is a positive correlation between the spillover effect and the number of node companies that choose to participate in the learning. We use *f* to denote the spillover gains obtained by the company from a single learning supplier. The spillover gains obtained by IKEA China from the entire supply chain network are thus $\sum_{2}^{Z} s_i^j \cdot f$, where $\sum_{2}^{Z} s_i^j$ is the number of all companies that choose to cooperate in the supply chain.

The gains functions of a focal company and its multi-tier suppliers in the SCL game are thus as follows:

(1) Gains function of the focal company: When node i is a focal company, node i plays a leading role in the SCL network; this is generally the case for large enterprises like IKEA China. At this time, the payoff that node i can obtain in the game is composed of three parts: the immediate income obtained by participating in SCL, the supply chain knowledge spillover income, and the incentives paid to other cooperative nodes:

$$U_{i(t+1)} = \sum_{-i \in \text{NBR}} \sum_{s_i} \Pi_i(s_i, s_{-i}) P_{(s_{-i})} + s_i^j \sum_{2}^{Z} s_{-i}^j f - s_i^j \sum_{2}^{Z} s_{-i}^j r \tag{20}$$

This means that in the t + 1th round of the game, the gains that a focal company can obtain under the two strategies is

$$U_{i(t+1)} = \begin{cases} \sum_{-i \in \text{NBR}} \sum_{s_i} \Pi_i(s_i, s_{-i}) P_{(s_{-i})} + \sum_{2}^{Z} s_{-i}^j f - \sum_{2}^{Z} s_{-i}^j r & s_i^j = 1 \\ \sum_{-i \in \text{NBR}} \sum_{s_i} \Pi_i(s_i,\ s_{-i}) P_{(s_{-i})} s_i^j = 0 \end{cases} \tag{21}$$

(2) Gains function of suppliers: When node i is a supplier company, the gains that node i can obtain in the game consist of three parts—immediate benefits gained by participating in SCL, hidden costs to acquire new knowledge, such as costs for overcoming barriers between corporate cultural differences, and incentives received from the focal company:

$$U_{i(t+1)} = \sum_{-i\in \mathrm{NBR}} \sum_{s_i} \Pi_i(s_i, s_{-i}) P_{(s_{-i})} + s_i^{t+1} r_i - s_i^{t+1} u_i \times \sum_{-i=1}^{Z} s_{-i}^j A_{-ii}(\pi_{i11} + r) \quad (22)$$

This means that in the t + 1th round of the game, the gains that suppliers can obtain under the two strategies are

$$U_{i(t+1)} = \begin{cases} \sum\limits_{-i\in \mathrm{NBR}} \sum\limits_{s_i} \Pi_i(s_i,\ s_{-i}) P_{(s_{-i})} + r_i - u_i \times \sum\limits_{-i=1}^{Z} s_{-i}^j A_{-ii}(\pi_{i11} + r) s_i^j = 1 \\ \sum\limits_{-i\in \mathrm{NBR}} \sum\limits_{s_i} \Pi_i(s_i, s_{-i}) P_{(s_{-i})} s_i^j = 0 \end{cases} \quad (23)$$

where $P_{(s_{-i})}$ is the probability of the −ith node making the strategy selection in the t + 1th period, which is given by Equation (5) in the EWA model. Table 2 provides a summary of the parameters in the above equations.

Table 2. Parameters in Equations (1) to (23).

Parameter	Definition
t	The period of the game
A_{-ii}	Network connection relationship between node *i* and −*I*, which is either 1 or 0
s_i^{t+1}, s_{-i}^{t+1}	The strategy adopted by nodes *i* and −*i* in the t + 1th period
$\Pi_i(s_i^j, s_{-i}(t))$	The income of node *i*
$A_i^j(\mathrm{t})$	The attractiveness of strategy *j* to node *i*
$N(t)$	Experience weight, which indicates the influence of a participant's game history on the attractiveness of the current strategy
$P_i^j(t+1)$	The probability of the strategy *j* being selected by node *I* in the t + 1th period
m_i	The strategy set of node *i*
λ	The sensitivity of the supply chain member companies to strategic attraction
δ	The weight assigned to the benefits of the unselected strategy
φ	The coefficient of decline in the attractiveness of the strategy due to forgetting, competition changes or other reasons
κ	Learning growth rate of strategic attractiveness, indicating the company's ability to learn from past gaming experiences
f	SCL spillover gains obtained by the focal company from a single supplier selection
r	Rewards paid by the focal company to other enterprises in the supply chain
u_i	The learning cost rate that node i will pay to eliminate learning barriers when choosing to learn

4.4. Model Analysis

Under the assumption of the same risk appetite, strategy j has the same attractiveness to different game participants, which can be expressed as follows:

$$A_{-i}^j(t) = A_i^j(t) \quad (24)$$

Substituting this into the probability Equation (5), we obtain the probability that player −i adopts strategy j:

$$P_{-i}(t+1) = P_i^j(t+1) = \frac{e^{\lambda A_i^j(t)}}{\sum_{k=1}^{m_i} e^{\lambda A_i^k(t)}} \quad (25)$$

Assume that in the early stage of the SCL network game, supplier companies do not participate in the learning, which means when t = 0, the probability that the game player

$-\mathrm{i}$ chooses the learning strategy ($\mathrm{s}^{\mathrm{j}}_{-\mathrm{i}} = 1$) is $\mathrm{P}_{-\mathrm{i}}(\mathrm{t}+1) = \mathrm{P}^{\mathrm{j}}_{\mathrm{i}}(\mathrm{t}+1) = \frac{\mathrm{e}^{\lambda \mathrm{A}^{\mathrm{j}}_{\mathrm{i}}(\mathrm{t})}}{\sum_{\mathrm{k}=1}^{\mathrm{m_i}} \mathrm{e}^{\lambda \mathrm{A}^{\mathrm{k}}_{\mathrm{i}}(\mathrm{t})}} = 0$. After that, the node enterprise will continuously adjust its strategy according to the income situation. When the gains of choosing not to learn are greater than the learning gains, the node enterprise will not adopt SCL, otherwise it will continue to use SCL.

Substituting the initial return matrix into the total return formula, the equilibrium conditions of the node enterprise i in the t + 1th game round are obtained as follows:

(1) When the node enterprise i is the focal company,

$$U_{i(t+1)} = \begin{cases} Z_{t+1}\pi_{i11}P_{-i}(t+1) + (Z - Z_{t+1})\pi_{i10}(1 - P_{-i}(t+1)) + \sum\limits_{2}^{Z} \mathrm{s}^{j}_{-i} f - \sum\limits_{2}^{Z} \mathrm{s}^{j}_{-i} r & s^{j}_{i} = 1 \\ Z_{t+1}\pi_{i01}P_{-i}(t+1) + (Z - Z_{t+1})\pi_{i00}(1 - P_{-i}(t+1)) & s^{j}_{i} = 0 \end{cases} \tag{26}$$

In this equation, $\mathrm{Z_{t+1}}$ represents the number of enterprises participating in SCL in the t + 1th game round, and $\mathrm{P}_{-\mathrm{i}}(\mathrm{t}+1)$ represents the probability that node $-\mathrm{i}$ adopts the learning strategy with node i.

The equilibrium condition for node i's selection learning strategy is that the gains of learning $\geq$ the gains of not learning, as shown in Formula (27):

$$\begin{aligned} &Z_{t+1}\pi_{i11}P_{-i}(t+1) + (Z - Z_{t+1})\pi_{i10}(1 - P_{-i}(t+1)) + \sum_{2}^{Z} \mathrm{s}^{j}_{-i} f - \sum_{2}^{Z} \mathrm{s}^{j}_{-i} r \\ &\geq Z_{t+1}\pi_{i01}P_{-i}(t+1) + (Z - Z_{t+1})\pi_{i00}(1 - P_{-i}(t+1)) \end{aligned} \tag{27}$$

Formula (27) is simplified to obtain the conditions for enterprise i to choose a learning strategy, as shown in Formula (28):

$$\begin{aligned} &Z_{t+1}\pi_{i11}P_{-i}(t+1) + (Z - Z_{t+1})\pi_{i10}(1 - P_{-i}(t+1)) + \sum_{2}^{Z} \mathrm{s}^{j}_{-i} f - \sum_{2}^{Z} \mathrm{s}^{j}_{-i} r - Z_{t+1}\pi_{i01}P_{-i}(t+1) \\ &+(Z - Z_{t+1})\pi_{i00}(1 - P_{-i}(t+1)) \geq 0 \end{aligned} \tag{28}$$

From Equation (28), it can be derived that the behavior of a focal company in a game round is directly related to the incentives given to other cooperative nodes to participate in SCL, the spillover benefits obtained in the supply chain, and the benefits obtained by choosing not to engage in SCL. The greater the incentives for other suppliers to participate in SCL, the less likely that (28) is to be established, and the less likely it is for a focal company to choose a learning strategy; the greater the benefit of knowledge spillovers in the supply chain network, the greater the payoffs that a focal company can gain from SCL, the easier it is to formulate (28), and the more likely it is that a focal company will choose to learn. At the same time, the probability of supplier nodes choosing to learn also affects the choice of strategies for the focal company.

(2) When the node enterprise i is one of the suppliers,

$$U_{i(t+1)} = \begin{cases} Z_{t+1}\pi_{i11}P_{-i}(t+1) + (Z - Z_{t+1})\pi_{i10}(1 - P_{-i}(t+1)) + r_i - u_i \cdot \sum\limits_{-i=1}^{Z} s^{j}_{-i} A_{-ii}(\pi_{i11} + r) & s^{j}_{i} = 1 \\ Z_{t+1}\pi_{i01}P_{-i}(t+1) + (Z - Z_{t+1})\pi_{i00}(1 - P_{-i}(t+1)) & s^{j}_{i} = 0 \end{cases} \tag{29}$$

The equilibrium condition for node i's selection learning strategy is that the gains of learning $\geq$ the gains of not learning, as shown in Equation (30):

$$\begin{aligned} &Z_{t+1}\pi_{i11}P_{-i}(t+1) + (Z - Z_{t+1})\pi_{i10}(1 - P_{-i}(t+1)) + r_i - u_i \\ &\cdot \sum_{-i=1}^{Z} s^{j}_{-i} A_{-ii}(\pi_{i11} + r) \\ &\geq Z_{t+1}\pi_{i01}P_{-i}(t+1) + (Z - Z_{t+1})\pi_{i00}(1 - P_{-i}(t+1)) \end{aligned} \tag{30}$$

Formula (30) is simplified to obtain the conditions for enterprise i to choose a learning strategy, as shown in Equation (31):

$$Z_{t+1}\pi_{i11}P_{-i}(t+1)+(Z-Z_{t+1})\pi_{i10}(1-P_{-i}(t+1))+r_i-u_i\cdot\sum_{-i=1}^{Z}s_{-i}^{j}A_{-ii}(\pi_{i11}+r)-Z_{t+1}\pi_{i01}P_{-i}(t+1) +(Z-Z_{t+1})\pi_{i00}(1-P_{-i}(t+1))\ \geq 0 \quad (31)$$

According to Equation (31), the decision to engage in a game round by other suppliers in the focal company's SCL network is directly related to the immediate benefits of participating in SCL, the rewards obtained from the focal company, and the hidden costs to be paid when choosing the learning strategies. The greater the immediate benefits of participating in SCL, the greater the probability of (31) being established, and the greater the probability node enterprise i will choose a learning strategy; the greater the rewards received from a focal company, the greater the node's gains from SCL, the easier Formula (31) is to establish, and the more likely the supplier company will choose to learn. At the same time, the company's weak knowledge transfer ability, learning obstacles caused by cultural differences, and knowledge stickiness can lead to hidden costs for suppliers when participating in SCL, which will reduce the probability that suppliers choose to engage in SCL.

5. Model Simulation of the SCL Mechanism

Using MATLAB R2016a software to simulate the model, the simulation flowchart is summarized in Figure 4:

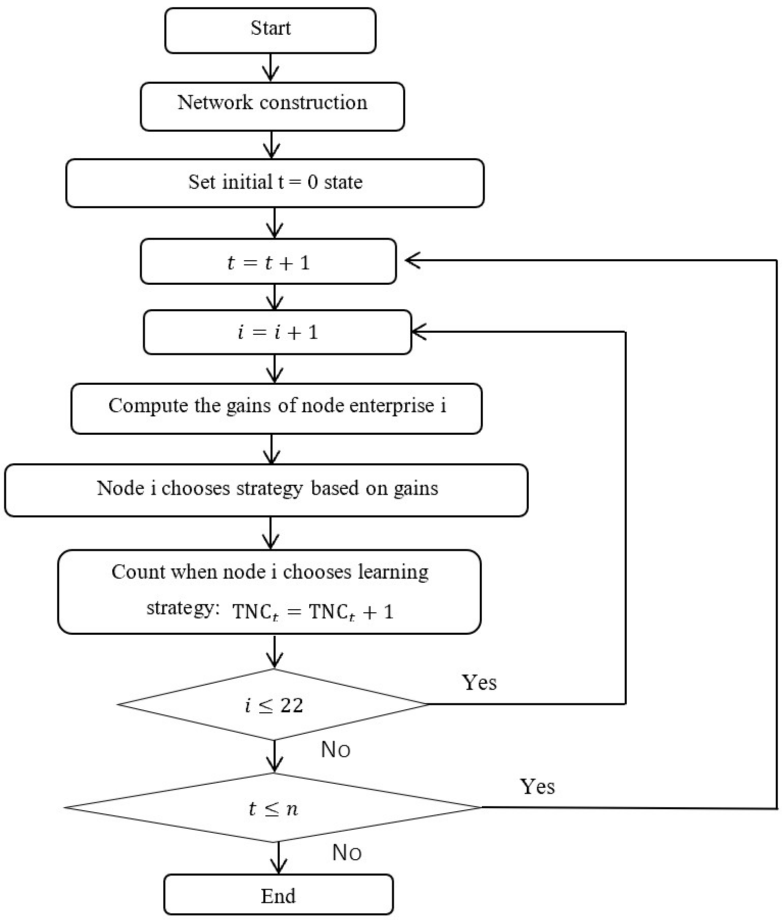

Figure 4. Model simulation flowchart.

5.1. The Impact of the Attractiveness Decline Ratio φ on a Focal Company's SCL

Assume that the supplier's response sensitivity to the strategic attractiveness is 0.03, the reward r paid by the focal company to a single supplier participating in SCL in the supply network is 0.4, the cost rate u for the supplier to overcome the obstacle of learning is 0.01, and IKEA China's SCL spillover benefit f from a single selected supplier is 0.8. Under the initial conditions, the attractiveness of strategy $A_i^j(0)$ is 2, the experience weight $N(0)$ is 0, and the probability of the player choosing the two strategies obeys the uniform distribution probability P(0) = 0.5; that is, the number of initial partners is 11. The empirical estimation of the parameters of the EWA model in the general case can be obtained as follows: Participating players give the unselected strategy's return a weight of δ = 0.5, the previous attractiveness decline ratio coefficient is $\varphi \in (0.8, 1)$. Among them, the value of δ is fixed. Most of the variables here are probabilities, with values ranging from 0 to 1. Since our research is a simulation and we do not have actual data, we have selected data within a reasonable range and can better reflect the simulation effect for presentation [53–55]. In fact, using other values within the reasonable range, the result trend is still the same, which can also support our research. Assume that the learning growth rate of strategic attractiveness κ is 0.5, and the value of the previous attractiveness decline ratio φ is as follows: $\varphi = 0.8$; $\varphi = 0.85$; $\varphi = 0.9$; $\varphi = 0.98$. The simulation results are shown in Figure 5.

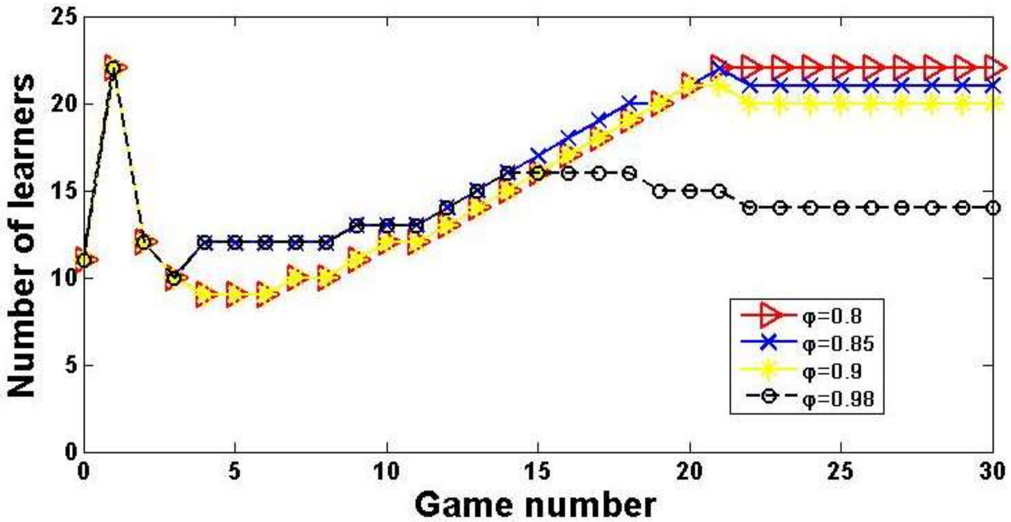

Figure 5. Effect of the previous attractiveness decline ratio φ in the EWA learning model on the number of partners in the focal company's SCL network game.

In Figure 5, the decline rate of attractiveness φ has an inhibitory effect on a focal company's SCL. The larger the decline rate, the lower the number of suppliers who choose a learning strategy. When φ = 0.98, the number of cooperative companies in the network increased from the 3rd game with some fluctuations until the 22nd game, reaching the equilibrium point of 13. When φ = 0.9, the number of enterprises participating in SCL in the network started to rise from the 3rd game, converged to 20 at the 22nd game, and then remained stable. When φ = 0.85, the change trajectory is roughly the same as the previous changes, but stabilizes at a higher point (21). When φ = 0.8, the number of partners in the network finally stabilizes at 22, which means that each company in the network chooses cooperation strategies and participates in SCL. As such, φ indicates that supply network node enterprises are affected by psychological factors, such as the pressure to learn, emotional excitement, and forgetting, weakening their preferences for the selected strategy.

5.2. The Impact of the Learning Growth Rate of Strategic Attractiveness κ on the Focal Company's SCL

The related variables of the initial conditions are assumed to be the same as in the previous Section 5.1. The value of the previous attractiveness decline ratio φ is 0.9, and the learning growth rate of strategic attractiveness is $\kappa \in (0, \varphi)$. It is assumed that the values of κ are as follows: $\kappa = 0.3$; $\kappa = 0.5$; $\kappa = 0.7$; $\kappa = 0.9$. The result is shown in Figure 6.

In Figure 6, the learning ability from strategic attractiveness κ continues to increase as more companies choose to participate in SCL. When κ = 0.3, the number of companies participating in SCL in the network starts to fluctuate from the 4th game, and converges to 12 at the 22nd game; when κ = 0.5, the number of companies that choose to learn increases from the 4th game, and stabilizes at 20; when κ = 0.7 and when κ = 0.9, the number of learners in the network stabilizes at 22, which is when all companies in the focal firm's supply chain choose to participate in SCL.

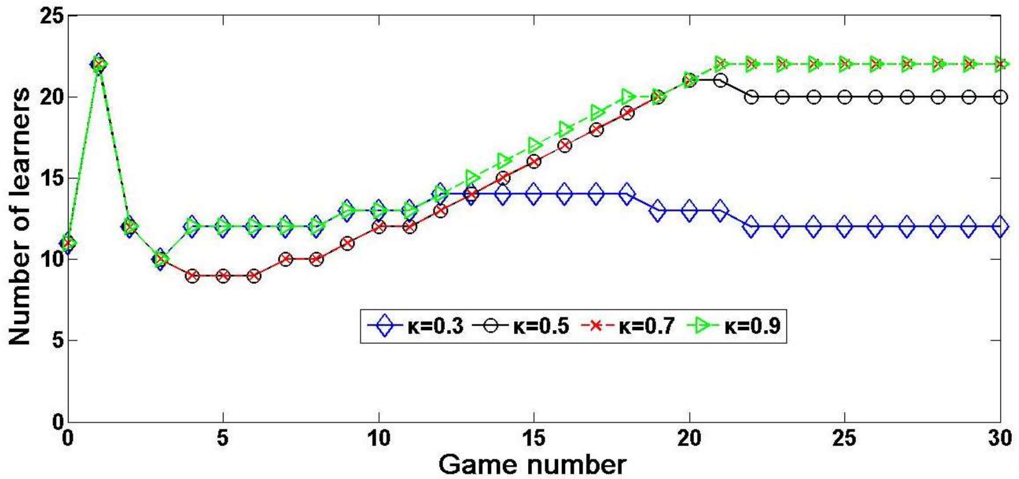

Figure 6. Effect of the learning growth rate of strategic attractiveness κ in the EWA learning model on the number of learners.

5.3. The Impact of the Strategic Attractiveness' Response Sensitivity λ on the Focal Company's SCL

When the other variables are assumed to be constant and the same as in the previous case (Section 5.1), and the values of the strategic attractiveness' response sensitivity λ are 0.1, 0.05, and 0.01, the simulation results as shown in Figure 7 are obtained.

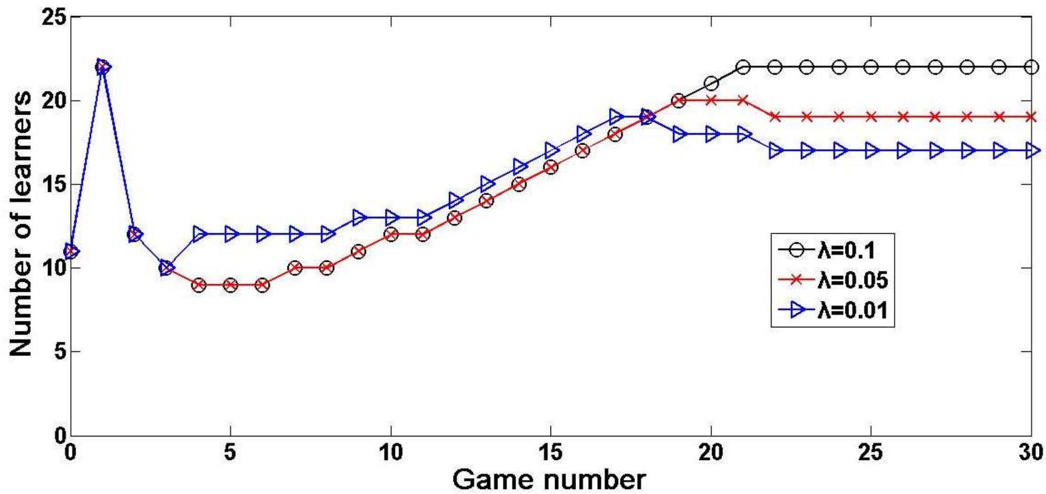

Figure 7. Effect of the strategic attractiveness' response sensitivity λ on the number of learners.

In Figure 7, we observe that the larger the value of λ, the more enterprises choose a learning strategy after the game equilibrium has stabilized. When λ is 0.01, after a short-term fluctuation, the number of companies choosing to learn stabilizes at 18. When the value of λ is 0.05, the number of companies that choose a learning strategy fluctuates in the first two games and starts to increase from the third game, stabilizing at 19. When λ is 0.1, the number of companies that choose a learning strategy in the supply chain gradually increases from the third game and stabilizes at 22, indicating that all companies participate in the focal firm's SCL network. Therefore, the strategic attractiveness' response sensitivity has a positive relationship with the choice of learning strategy. The larger it is, the more it can promote the learning of the supply chain network.

5.4. The Impact of Spillover Income f on SCL

With the initial values for other variables being the same as in the previous case (Section 5.1), we consider a spillover income f of 0.2, 0.4, and 0.8. This means that the spillover benefits obtained by the focal company from a single supplier participating in SCL are greater than, equal to, or less than the incentives given to a single cooperative supplier, respectively. The simulation results are shown in Figure 8.

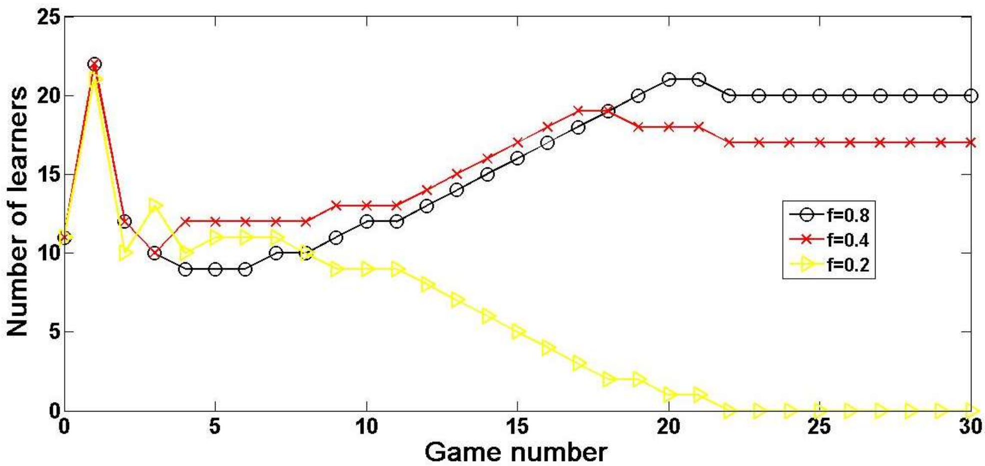

Figure 8. Effect of different spillover profits on the number of partners f in the focal company's SCL network.

As can be seen, as the value of f increases, the number of learners in a steady state tends to increase. When the value of f is 0.2, the number of learners fluctuates in the first few games, and shows a downward trend starting with the fifth game, decreasing to 0 in the 22nd game; when the value of f is 0.4, the number of learners still increases in the first few games and stabilizes at 17 in the 22nd game; when f is 0.8, the number of learners increases from the 4th game and converges to 20 in the 22nd game. Therefore, the larger the learning spillover effect of the supply chain network, the more companies participate in SCL, and the more it can promote the learning of the entire network.

5.5. The Impact of the Learning Cost Rate u on SCL

With the initial values for other variables being the same as in the previous case (Section 5.1), we consider the cost rate u used by the supplier to overcome the obstacle of learning as being 0.001, 0.005, 0.01, and 0.1. The corresponding simulation results are shown in Figure 9.

As can be seen, as the learning cost rate u increases, the number of learners continues to oscillate downward until it reaches a lower stability point. When the learning cost rate is 0.001, the number of learners quickly reaches 22, and all member companies choose a learning strategy. However, at the 21st and 22nd game, there was a small decrease, eventually stabilizing at 20. When the cost rate is 0.005, there are fluctuations early on, but the curve still stabilized at 20. When the cost rate is 0.01, the number of learners gradually increases in the first 21 games, with the curve then coinciding with other curves at Point 20. When the cost rate is 0.1, the trend of the curve is similar to that of the 0.01 cost rate, but the number of learning enterprises at the equilibrium is less than the former, being stable at 18. We can thus conclude that as the learning cost rate increases, the number of companies choosing a learning strategy in the network decreases. The higher the learning cost, the greater the obstacles for an overall learning effect on the supply chain network.

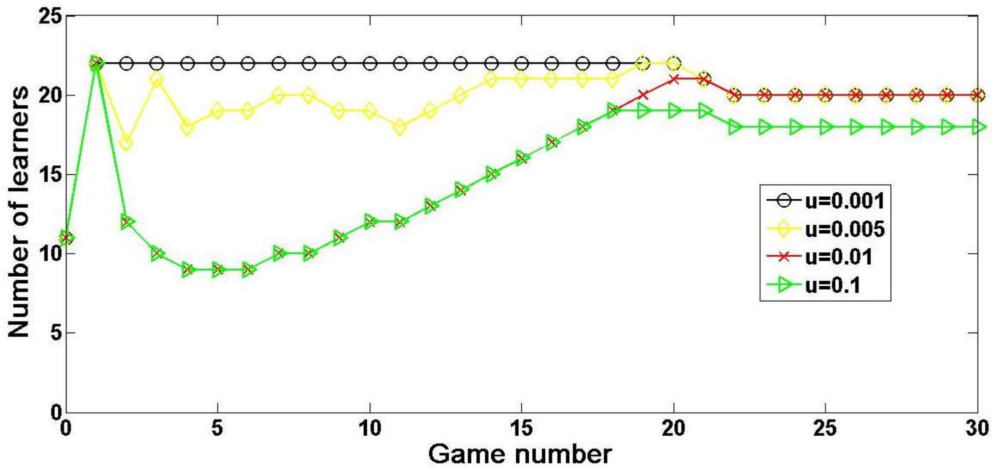

Figure 9. Effect of different learning cost rates u on the number of learners.

5.6. The Impact of Rewards r on SCL

With the initial values for other variables being the same as in the previous case (Section 5.1), we consider reward values r of 0.2, 0.4, 0.8, and 1. The corresponding simulation results are shown in Figure 10.

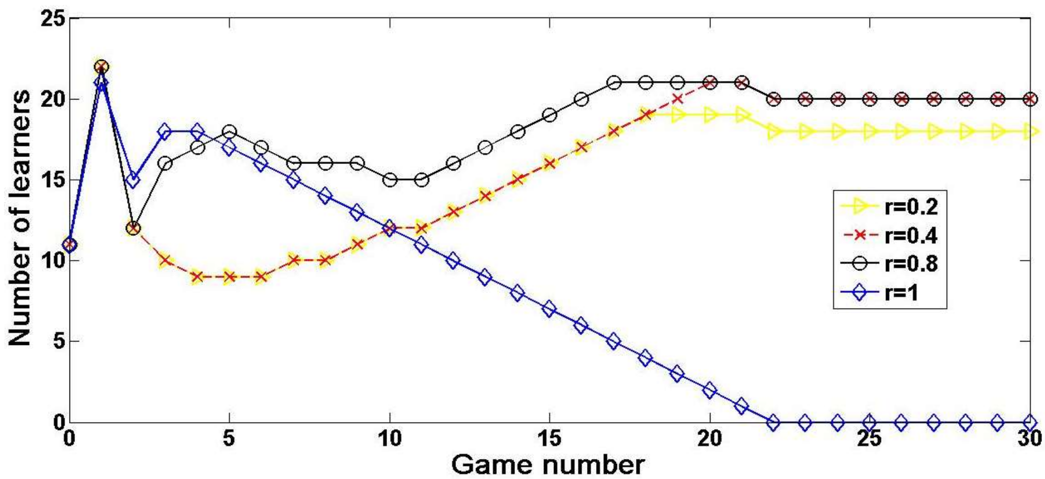

Figure 10. Effect of different rewards r on the number of learners.

As can be seen, as the amount of rewards r increases, the number of learners continues to increase. When r = 0.2, the number of companies choosing a learning strategy gradually increased from the fourth game, converging to 18 after a short period of shock. When r = 0.4, the number of learners also gradually converges upwards until 20 in the 23rd game. When r is 0.8, the curve is above the first two, indicating that the number of learners is higher, eventually stabilizing at 20. When r is 1, the number of learners decreases rapidly after the first few games, and then decreases to 0 in the 22nd game. It can be seen that when r does not exceed f, the larger the r, the more companies choose the learning strategy. As such, the reward strategies of focal companies promote the learning effect of the entire supply chain network.

6. Discussion

SCL is a way to exchange and share knowledge, technology, and resource advantages throughout the supply chain. It can create more learning value to a certain extent, enhance the sustainable supply chain management effect of the focal company in the chain, and maintain the competitive advantage of each supplier in the chain in the market. The relevant factors in SCL can be used to analyze the supply chain learning mechanism.

Based on the above analysis in a specific case, we derive insight into the following dynamics pertaining to SCL.

(1) Subjective psychological factors affect the strategic choices of companies in the SCL network. The simulation results of the learning game model, based on IKEA China's supply chain network, show that the equilibrium of the supply chain network learning game is affected by the decline ratio of strategic attractiveness φ and the ability to learn from previous experience κ, which capture aspects such as memory capacity and learning capacity. These results confirm that the learning experience from the spillover of SCL can improve the performance of supply chain management over time [56]. While the path to improvement may be complex, our study provides evidence for the applicability of the learning curve, as real data from IKEA China's SCL network were utilized;

(2) The sensitivity of the supplier's response to strategic attractiveness λ is affected by factors such as learning motivation and psychological perception. Learning motivation is related to the common interests among suppliers [1], the supplier's business mission, the company's incentives for learning, and competitive pressure. Psychological perception is affected by the ability of suppliers to receive information, the sensitivity of employees, and the elasticity of learning benefits for member companies;

(3) The spillover effect f has a positive impact on SCL networks. The spillover effect is related to the atmosphere of knowledge sharing, knowledge innovation, technological progress, and the number of member companies in the supply chain network. The larger the number of companies that choose a learning strategy in the network, the greater the spillover effect. Further, the more focal companies are willing to adopt incentives and management measures to regulate the SCL network, the better the overall learning effect of the network;

(4) The learning cost rate of enterprises u in the supply chain network represents an obstacle to the overall learning effect of the network. The learning cost rate of member companies is related to the corporate culture, work routines, information transparency of the network, and the stickiness of knowledge. Differences in corporate culture and highly regulated corporate work environments can limit knowledge sharing between supply chains [57]. Focal companies in a supply chain can increase training and promotion of SCL for suppliers through third-party organizations to enhance the awareness and potential of SCL in the supply chain, reduce differences in corporate cultures, promote looser supervision to facilitate learning, and exchange knowledge and technology in the supply chain. The higher the transparency of information and the more symmetrical the information, the easier it is for supply chain companies to perceive trust and fairness, and the greater the motivation for member companies to invest in learning, the better the learning effect [58]. The stickiness of knowledge is related to the knowledge accumulation and innovation capabilities of supply chain member companies. Supply chain networks can increase employees' knowledge accumulation through measures such as increasing training and optimized learning incentives, thereby reducing the cost to participate in SCL;

(5) The reward amount r has a positive impact on the learning of the SCL network. Generally, a focal company is at the core and serves as the leader of a supply chain network. It generally has the highest knowledge accumulation, technological innovation, and regulatory capabilities for sustainable development, and can benefit the most from SCL networks. The overall learning of the supply chain network will improve the competitiveness and sustainable development of the entire supply chain network, which will in turn create new competitive advantages for focal companies. Focal companies improve the enthusiasm of network members by setting up a learning platform, bearing part of the learning costs for supply chain network members, and giving "rebate" rewards and other incentives to participating companies. In fact, IKEA China adopted incentives in the implementation of SCL to reduce "free-riding" in the network and promote supplier interest. The actual situation compiled by Jia et al. (2019) based on first-hand data is similar to our simulation results, which confirms

the rationality of our model and also confirms the benefits of paying economic incentives [2,25]. In maintaining the SCL network, as a core leader, focal companies need to carefully set the reward amount, so as to maximize the participation of suppliers while at the same time not giving away too much of the benefits;

(6) Case analysis was employed to map the IKEA China SCL network, which makes the structure of the network not universal. From the analysis of the learning game model, the number of network members and the degree of the node supplier companies directly affect the game returns of the focal companies and its suppliers. The larger the number of network members, the more common information sharing is among suppliers, the more platforms and approaches for learning, the greater the learning benefit of a single game, and the more companies in the supply chain network that choose to participate in learning, the more likely that the network will have a learning agglomeration effect, and the better the overall learning effect of the network. Focal companies can optimize the learning effect of the entire network by adjusting the structure of the supply chain network.

In general, the decline ratio of strategic attractiveness φ, the learning growth ratio of strategic attractiveness κ, the response sensitivity of member companies λ, the spillover effect of SCL f, and the learning cost rate of supply chain network member companies u, and the rewards given by focal companies to supply chain network member companies r are all factors which affect SCL. Based on the above discussion, the dynamics inherent to SCL are captured in Figure 11.

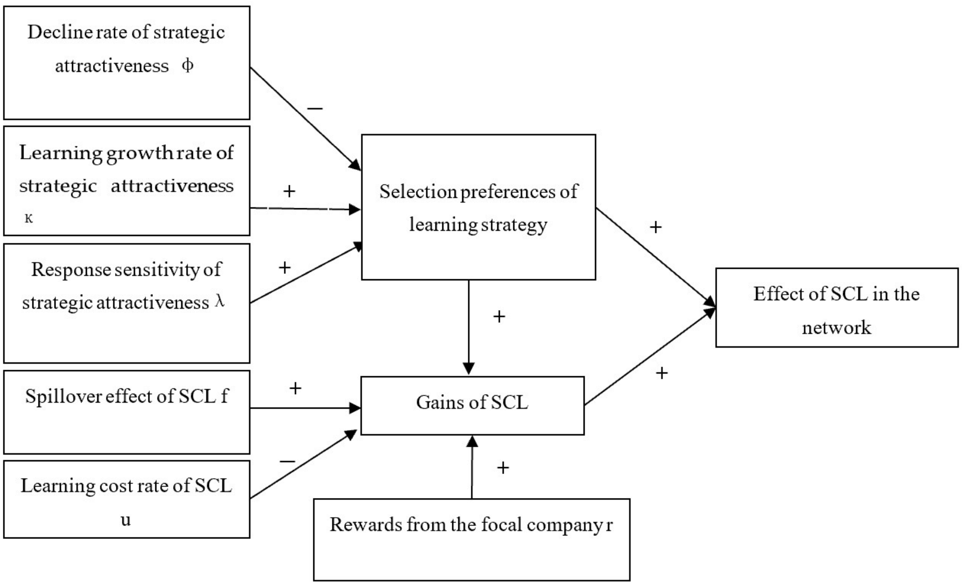

Figure 11. Learning dynamics in the supply chain network. (Notes: "−" represents a negative effect, and "+" represents a positive effect. The two effects both are brought from the left to the right).

Objective economic factors, such as the learning costs u, rewards for network member companies r, and learning spillover effects f, and the aggregation effect of the three, have a direct impact on the effect of SCL in the network. Among them, f and r have a positive effect on SCL income, and u has a negative effect on SCL income. The more gains of the SCL generated by the joint influence of the three, the more willing member companies in the supply chain network are to choose learning strategies, which will further produce significant agglomeration effects.

The subjective factors of supply chain network enterprises, such as the strategic attractiveness decline ratio due to forgetting φ, the attractiveness improvement ratio due to preferences κ, and the response sensitivity to strategies λ, have indirect and direct effects on network learning. Therefore, in the planning stages for an SCL network, focal companies need to consider the subjective and objective incentive policies, not only to improve the atmosphere of the SCL network, but also to attract suppliers to actively join the learning network by improving economic benefits. Among them, φ has a negative effect on strategy selection, and κ and λ have a positive effect on strategy attractiveness. The effect of the combination of the three directly affects the effect of SCL. At the same time, the effect of the combination of the three will affect the gains of SCL, which then affects the effect of SCL.

7. Conclusions

In answering the research questions set out at the beginning of this paper, we have made the following contributions to SCL theory.

First, SCL is a relatively new and emerging concept in supply chain management research. We contributed to this nascent domain by studying a real-world company, IKEA China. Our research established a model of SCL on the supply chain network. The model took into account the supply chain structure, the supply chain leadership of the focal company, the internal and external resources in the supply chain such as spillover benefits brought by training, and individual subjective factors. IKEA China, which has more complete data and a high degree of sustainable development among the three cases, is used for case study in this article and the data used also collected through semi-structured interviews with managers of focal companies and their multi-tier suppliers. Through the game simulation between the focal company and its suppliers, we found evidence for the leadership of the focal company in the complex network of SCL. To the best of our knowledge, this study may be the first to build a model based on a real-world case to validate supply chain leadership in SCL, and also confirms the theory of supply chain leadership affecting SCL, which proposed by Jia et al. (2019) [25].

Second, this research extends existing research on SCL mechanisms. We based our research on objective factors such as the characteristics of knowledge, knowledge senders, knowledge recipients, and organizational contexts, as reviewed by Szulanski et al. [17], in addition, specific subjective factors such as the cognitive level, learning ability, and other subjective psychological factors associated with SCL. We found that the equilibrium of the supply chain network learning game is affected by current learning gains, the ability to learn from past experiences, immediate gains, and learning experience, as well as memory ability as well as the psychological perception of welfare. However, the subjective factors we currently consider are not detailed enough and subsequent specific research is needed to make up for the associated shortcomings.

In addition to the theoretical contributions, this research has significant relevance to practice. Our research study is among one of the first to use practical examples to explore SCL by choosing a typical subnetwork of a focal, multinational company to represent its SCL network. The study of SCL mechanisms can promote the compatibility of supply chain knowledge resources among chain enterprises, which in turn further promotes the coordination and complementation of knowledge resources among chain enterprises, so that knowledge and technology can be virtuously circulated among each supply chain member enterprise and develop this supply chain in the long run.

While this may make the findings not necessarily generalizable to smaller firms, it is our hope that they can provide at least some initial direction, especially also if they serve as a supplier to a large focal company. The contribution to smaller firms in the supply chain is that they can learn how to use the learning network for their knowledge innovation in the SCL mechanism as a supplier, and at the same time turn it into productivity in the shortest time to improve efficiency and reduce cost.

As we discussed in the introduction, SCL benefits both the focal firm and the suppliers. For the focal company, the case study based on IKEA China can propose a general model of supply chain management that can be used to guide and help the focal company lead SCL, allowing resources such as knowledge and technology to be fully utilized across supply chain member companies to create value and maintain its corporate competitiveness. Jia et al. (2019) mentioned the leadership position of the focal company in supply chain learning and gave suggestions for the focal company to proactively coordinate internal and external resources to facilitate SCL [25]. Through the previous factor analysis, this article provides a more specific direction for the measures that the focal company can take proactively. Our research results provide the following suggestions.

First, increase rewards to network member companies and strengthen communication between companies to reduce learning costs and increase learning spillover benefits. Both the actual situation at IKEA China and our simulation results confirm the benefits of paying economic incentives [2,25]. Specifically, the focal company can create an atmosphere of free sharing of knowledge within the supply chain and actively share and exchange knowledge and technology from a leadership position. At the same time, it can provide certain incentives for other suppliers, such as strengthening business contacts, relaxing the payment recovery period, providing a positive and stable learning environment, and enhancing the learning driving effect and incentive effect. Since some measures require certain financial support, the focal company needs to take measures based on its development stage, benefits, and costs. Under the current economic downturn, there may be certain difficulties. Overall, these measures can further promote the achievement of SCL to a certain extent, strengthen the spillover effects brought about by supply chain learning, and promote the development of sustainable competitive advantages.

Second, the perception of and preference for SCL by suppliers can be influenced by initiating sustainable advocacy and providing knowledge and technology training, as well as fostering the range of subjective factors noted in our study. Multinational companies can give full play to their leadership position and help other suppliers to enhance their understanding of SCL through training, publicity, or rule formulation, strengthen the company's psychological perception of SCL, and strengthen its learning motivation. The learning motivation of an individual enterprise is nothing more than to help it carry out its daily work and gain benefits for future development. Focal companies can combine incentive measures and adopt certain economic means to strengthen the company's learning motivation. In fact, third-party organizations have participated at different stages of the SCL network, taking on different roles [2,25]. Multinational companies can also introduce external training institutions for learning and training to promote the absorption of knowledge and technology and improve SCL efficiency.

This article conducts an in-depth study on the SCL mechanism of multinational companies by using game simulation after building a network, and affirms the importance of relevant factors in the SCL of multinational companies, finds the learning game equilibrium under different conditions and provides a reference direction for the implementation of SCL for multinational companies. However, SCL is a process that changes dynamically within the network and will produce different results as the market and times change. In addition, a company's decision-making is affected by many factors, such as its economic structure position in the supply chain. Therefore, future research is encouraged to look at behavioral economics theories to adapt the model developed herein, in addition to considering the different economic structures of companies and their status in the supply chain. As such, the constraints on variables can be relaxed in an effort to foster SCL mechanisms, realize sustainable supply chain management performance, and enhance the competitive market advantage of focal companies and their supply chains.

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