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Research on Measurement and Evolutionary Mechanisms of Supply Chain Flexibility

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1. Introduction

With the continuously updating of technology and various of customer's requirement, there are various uncertainties in supply chain environment, from market situation, changeable customer's requirement, collaboration of supply chain partnership to various operation management internal supply chain, all of them exist kinds of uncertainties, which add the complexity of supply chain management. Flexibility has been considered as the ability to react uncertainty and a major determinant of competitiveness. In order to guide the supply chain to respond to environmental uncertainty and make accurate decisions for the construction and evolution of supply chain flexibility, fully and accurately measure the level of supply chain flexibility is the key.

The most literatures on the flexibility are concentrated in the context of manufacturing field and enterprise level. With the need of competition and the blurring boundaries of the firm, supply chain flexibility has been receiving increasing attention from both practitioners as well as researchers. Due to the multidimensional concept of flexibility and the complexity of supply chain, the research field of the connotation, basic motive force and generated mechanism of supply chain flexibility are still confusion. In order to response environmental uncertainty, deeply understand flexibility and analysis measurement and evolution of supply chain flexibility in changeable demand environment is a basic goal in supply chain management. Currently, researches on flexibility measurement are still not unified. There are many measuring methods focusing on one aspect of the flexibility elements but few articles comprehensively measuring supply chain flexibility from an overall perspective. Furthermore, almost no researchers draw attention to the issue of supply chain flexibility evolution.

This paper has launched a thorough study of the measurement and evolutionary mechanisms of supply chain flexibility, including building the dimension and measurement index system of supply chain flexibility, presenting integrated measurement method and offering the evolution framework and process, and studied on environmental uncertainty and matching models of supply chain flexibility, proposing a complete theory of supply chain flexibility evolution.

2. Research on content and generation mechanism of supply chain flexibility

2.1 Content and features of supply chain flexibility

In the past decade, driven by the volatile business environment, organizations seek flexibility and quick response to market demand [1]. Modern competition has been changed from competition between enterprises to that between supply chains. Under time-based supply chain competitive environment, supply chain flexibility has become a major topic, which becomes more and more important, discussed by practitioners and scholars [2]. However, because of the multi-dimensional nature of supply chain flexibility concept, today its definition is still not uniform.

Most literatures on the flexibility concentrate in manufacturing field. Vickery et al. (1999) relatively early researched flexibility from the perspective of supply chain, but simply defined flexibility as the reaction to internal and external environmental uncertainty and multifunction of the organization [3]. Gunasekaran et al. (2001) considered that under supply chain environment, supply chain flexibility can meet specific consumer needs through proper products or services, which may be obtained by some techniques [4]. However this understanding is too narrow, relying on technology alone can not build the supply chain flexibility, and in order to get the supply chain flexibility, we must study its formation mechanism in depth and build elements of flexibility.

Therefore the definition of supply chain flexibility is not only necessary to grasp the essence of the concept of flexibility, but also emphasize the characteristics of supply chain, so the concept of supply chain flexibility should accentuate the following:

First supply chain is a function network connecting all node enterprises and overall processes. The function network of supply chain reflects its integrity, which is the essential characteristic of the supply chain. Second, supply chain should be a value added process, which is not a simple sum of node enterprises, but customer demand oriented. Last, the strategic partnership of supply chain is extremely significant to flexibility. So we should focus on changing supply chain partners in case of flexible business environment and reconstruct supply chain system capability and information sharing capacity rapidly and cost-effectively [2].

As can be seen from the above definition, flexibility is an ability that can manage changing. Changing and uncertainty is a prerequisite for the existence of flexibility, therefore the definition flexibility includes several key elements, such as capacity, systems, change, uncertainty, etc. The combination of these elements reveals the essential features of flexibility. At the same time, flexibility is more than a single concept, but in terms of system. It is a feature of system and the flexibility of supply chain system is the object of this paper [5].

Based on the points of view above, consumer-oriented supply chain flexibility is defined, in this article, as the capacity to respond customer-orientedly reasonably and rapidly to internal and external environment and the robustness demonstrated, based on that supply chain is provided with organically integrated core competencies of partners. Supply chain studied in this paper is consumer-oriented supply chain. To facilitate, consumer-oriented supply chain flexibility, in this paper, will be referred to as supply chain flexibility.

(1) Dynamicity

Flexibility is a dynamic concept. Organizations would obtain continuous learning and innovative capacities when they possess flexibility, which can be reflected in the use of

external and internal resources of the organization to make timely response to environmental instability and from the quick adjustment according to projected environmental changes in a proper time [6]. Supply chain is provided with obvious dynamics in the course of its life cycle, including the dynamic cooperation mechanism of supply chain as a result of the formation of partnerships required by business management, the dynamic coordination mechanism and the dynamic contract system, etc. Therefore the dynamic characteristics of supply chain life cycle determine that supply chain flexibility also has dynamics [7].

The flexibility level of supply chain should be a function of environmental uncertainty and relevant to the needs of customers, while flexibility is a relative concept, environmental uncertainty and law of supply and demand cause that the formation and development of supply chain has dynamic characteristics. Consequently the supply chain flexibility should be possessed with dynamic sensitivity to respond to market demand and environmental uncertainty. It is in the state of dynamic equilibrium when the customers' needs and the level of environmental uncertainty are balanced with the level of system flexibility; when the flexibility requirement of customer demand or environmental uncertainty increases, it is necessary to improve flexibility to meet the needs of environmental uncertainty and respond to competition, at which time the original flexibility balance of the system is broken and start to evolve to a new equilibrium [8]. So the law of supply and demand and the degree of environmental uncertainty prompt supply chain to adjust the flexibility continuously and cause dynamic characteristics as a result.

(2) Multidimensional

The multidimensional nature of supply chain flexibility refers to the multi-component ability of supply chain shown when dealing with uncertainty. Precisely because of the multidimensional nature, it makes the research of flexibility various. For instance, many scholars study it from the economic point of view and some others from the perspective of time. There is a mutual constraint among all of these angles, which means a separate one can not fully understand the flexibility and multi-angle investigation must be adopted. An effective and comprehensive definition of supply chain flexibility dimension is of great value to measure the flexibility.

(3) Timeliness

Flexibility is the capacity that system can take fast response when faced with uncertainty. Timeliness of supply chain flexibility is mainly reflected from the quick adjustment of logistics, information flow and network structure of supply chain operations in response to environmental uncertainty and to meet the rapidly changing market demands. Timeliness is the key to effective implementation of supply chain flexibility [8], which requires that supply chain should be realtimely aware of the market changes and environmental uncertainty and take rapid reaction. Meanwhile, environmental changes also makes a certain level of supply chain flexibility effective only in a period of time, which leads that supply chain flexibility has to achieve the required level in a particular term.

(4) Robustness

Supply chain flexibility also has a crucial feature—robustness, which is a fundamental property of the system, an ability to maintain the function of system when facing the variation of internal structure and external environment and a common phenomenon accompanied by uncertainty problem. The core issue of supply chain flexibility is the formation of robust operation and robust strategy [9]. The robustness of the supply chain is

the capacity that system is still able to maintain its benefits and continuous operation even being interfered with uncertainties such as internal and external unexpected emergency [9]. It is the flexibility that becomes an embodiment of this ability. Supply chain flexibility is the ability to adapt to changes in market demand, which is usually manifested through the robustness indicated by the relationship between upstream and downstream business under uncertain environment [10].

(5) Scalability

In accordance with the definition that supply chain is a functional network chain to connect all nodes and the overall process of enterprises [11], we can see that this network chain structure of the supply chain has far exceeded the boundaries of a single enterprise and with the development of information technology and the needs of the market, the boundaries between the modern enterprises are becoming increasingly blurred. According to the needs of the business, supply chain can make continued outward extension, which is not only a geographical expansion but also includes the expansion of business scope and production capacity, by means of creating virtual enterprises, dynamic alliances and other forms [11]. This extension of the supply chain is also reflected in its flexibility, which means with the expansion of supply chain and the variation of circumstance, the structure of flexibility is updated correspondingly as a consequence. On the other hand, this has prompted scholars to look upon supply chain flexibility from a systemic perspective and grasp the structural flexibility embodied by supply chain and the evolution of it.

2.2 Elements and driving force of supply chain flexibility

Most current literatures are still focused on the enterprise when investigates the classification of flexibility elements--researching on classification of manufacture flexibility elements, only a few scholars discussed flexibility elements from the perspective of supply chain, but many of them followed the classification of manufacturing. Therefore, based on previous literatures, we define five types of supply chain flexibility from a customer-oriented point of view, which is divided into product flexibility, response flexibility, volume flexibility, new product flexibility and distribution flexibility [3].

Duclos et al (2003) have analyzed the elements of supply chain flexibility, including the flexibility of operation, market, logistics, supply, organization and information [1], and established the conceptual framework of supply chain flexibility [12]. Wang Lu (2008) divided flexibility into short-term and long-term from the perspective of time. Considering it from the short-term point of view, it refers to the capacity to take full advantage of existing resources and facilities aiming at adapting to changes. On the contrary, it reflects the ability that the company adopts new resources, new inventions and new methods and then integrates into the production of current system [6].

The classification of supply chain flexibility above mainly inherited that in firms and manufacture, and the concept was overlapped and the definition was vague among those elements of flexibility, which did not reflect the essential characteristics of supply chain. Therefore, aiming at the scope of this study, we concern about customer needs and adding value for them, focusing on the integration point. We divide the elements of supply chain flexibility into four categories, namely operation flexibility, logistics flexibility, robust network & reconstruction flexibility and information flexibility. The definitions of these four flexibilities are as shown bellow.

1. Information flexibility

In a dynamic changing environment, to make the supply chain flexible, it is essential to realize effective integration among various information systems of different segments of the supply chain in order to transfer information quickly and effectively between member enterprises in it and forming information flexibility consequently. Flexible information mainly consists of two flexibility elements: one is the mechanisms for information exchange with flexibility and the other is information systems with flexibility.

(a) Communication mechanism

The communication mechanism of flexibility is an essential part of supply chain flexibility and it is the general term for information dissemination, information transmission, feedback, information gathering, information processing, etc., collectively, reflecting the efficiency that supply chain deals with information. Furthermore, the capacity that let partner companies know when changing information mainly reflects in the timeliness of the information transmission, which indicates the speed of information processing and sharing. In order to improve the ability of supply chain to respond to changing requirements, we should minimize the policy failures due to the delays made by transmission of information as far as possible, which requires timely transmission of information [13].

(b) Information System flexibility

Information system flexibility, whose main parts are the various types of information systems used by the enterprises in supply chain, refers to the ability of information systems to respond to the internal and external changes of environment and the transmission capacity of information in supply chain [5]. This article defines the information system flexibility as the information transmitting and sharing ability of the cooperative information systems between supply chain nodes neglecting internal processes, which could be measured through the capacity that reusability, reconfigurability and scalability of information system.

2. Logistics flexibility

Flexibility is the capacity that by means of providing technical support and services to receive raw materials cost-effectively and deliver products when organizations supply materials or their customers change requirements [14]. Considering Time-based strategy, logistics flexibility is reflected in customer orientation, which means responding to custom demand rapidly by minimizing the loss of performance in order to ensure the reliability of logistics systems and customer service levels. In this article we define the logistics flexibility as the ability that supply chain in response to environmental uncertainty, adopting appropriate transportation and inventory strategies in a reasonable cost level, adjusting service needs quickly and improving storage space and logistics policies rationally. It can be divided into inventory and delivery flexibility. Effective inventory strategy is a significant way for supply chain to win market and improve performance; hence inventory flexibility can be measured by two indicators that the number of stock policies available and the capacity to adjust inventory level. Delivery flexibility reflects the ability to change the established way of distribution and the capacity to adjust established distribution.

3. Robust network and reconstruction flexibility

Robust network and reconstruction flexibility has two meanings: firstly, the stability and robustness reflected when the existing network structure in response to changes of external

environment; the second is the capacity to vary the combination of partnerships and establish flexibility relationships with partners [14]. This article defines the robust network and reconstruction flexibility as the anti-interference ability demonstrated by the existing structure of supply chain and the capacity to make structural adjustments that in accordance with changes in the external environment for the purpose of maintaining high performance, such as the robustness of the existing network structure, fast reconstruction, cultural integration and other capabilities. So the supply chain network must have long-term strategic alliance partnerships to achieve sustained competitiveness, but also offer short-term ability to local adjust in accordance with environmental requirements, which is robust network and reconstruction flexibility.

4. Operation flexibility

Operation flexibility refers to the capacity for each node enterprise of the supply chain to operate and deploy resources rapidly to respond to customer demand on product type, quantity and new products, including the variation and mix of products, yield changes, product innovation and also the ability coping with the changes of product life cycle [14]. This article defines the operation flexibility as the capacity to quickly allocate assets, change manufacturing process and dynamically adjust productivity highlighting the allocation of resources to produce manufactures (including new products) and provide services, which considers customer and market demand from the perspective of operating system. Hence it can be concreted into product flexibility, volume flexibility and resource flexibility. Thereinto, volume flexibility mainly reflects the ability that supply chain can meet customer needs and from a deeper level it indicates manufacturing flexibility of supply chain and the ability to adjust production plans in according with market demand. Beamon(1999) have quantified the volume flexibility, which pointed out that the demand that could be satisfied referred to the number of product D_t for any $D_t \in (D_{min}, D_{max})$that supply chain could provide. D_{min} is the minimum yield to ensure supply chain profit, D_{max} is the maximum number of production achieved by the existing scale of supply chain. Suppose that the customer demand D for any $D \sim N(\mu, \sigma_D^2)$ follows normal distribution, then the calculation formula [15] of volume flexibility G_D is:

$$G_D = P\left(\frac{D_{\min} - \bar{D}}{\sigma_D} \le D \le \frac{D_{\max} - \bar{D}}{\sigma_D}\right) = \Phi\left(\frac{D_{\max} - \bar{D}}{\sigma_D}\right) - \Phi\left(\frac{D_{\min} - \bar{D}}{\sigma_D}\right)$$

5. The driving source of flexibility

Under the dramatic changes in modern business and highly uncertain dynamic environment, supply chain must scan its dynamic circumstance in real-time and identify its degree of uncertainty. only through continuous capture and grasp opportunities and threats that may arise in dynamic environment of opportunities and threats that may arise, can we accurately define and describe the supply chain environment and realize the dynamic environmental monitoring and early warning in order to guide the formation of strategic decision-making of supply chain flexibility and enhance its ability to withstand environmental changes [16]. Jack G.A.J. van der Vorst and A.J.M.B.(2002) have identified the source of the uncertainty generated by supply chain reconstruction strategy and pointed out that uncertainty during decision-making process of supply chain is an important driving factor in the reconstruction of it [17]. As can be seen from some studies, environmental uncertainty is a fundamental driver of supply chain flexibility and it is only the presence of

environmental uncertainty that cause flexibility. The gap between the two determines the level of flexibility generation power.

In order to facilitate writing, all the uncertainty factors $\{x_{11}(t), x_{12}(t),\ldots,x_{32}(t)\}$ under uncertain environment in supply chain are written in $\{x_1(t), x_2(t),\ldots,x_n(t)\}$. The level perceived by a certain environmental uncertainty factor when supply chain at a certain time t is $f(x_i(t))= x_i(t)\times\alpha$, then the momentum generated by supply chain flexibility can be expressed by the following n-dimensional vector: $\vec{F}=[f_1,f_2,\cdots,f_i,\cdots,f_n]$. There into, $f_i=\frac{f(x_i(t))-f(x_i(0))}{f(x_i(0))}$ for any i = 1,2,…,n. Functions $f(x_i(t))$ and $f(x_i(0))$ refer respectively to the level value and the baseline or reference value perceived by ith environmental uncertainty factor of supply chain, hence, the momentum generated by supply chain flexibility can be expressed by vector:

$$\vec{F}=[\frac{f(x_1(t))-f(x_1(0))}{f(x_1(0))},\frac{f(x_2(t))-f(x_2(0))}{f(x_2(0))},\cdots,\frac{f(x_n(t))-f(x_n(0))}{f(x_n(0))}].$$

The value of the vector is

$$\left|\vec{F}\right|=\left\{\sum_{i=1}^{n}\left[\frac{f(x_i(t))-f(x_i(0))}{f(x_i(0))}\right]^2\right\}^{1/2}$$

Typically, the higher the value is, the stronger supply chain environmental uncertainty and the greater force generated by the flexibility are.

2.3 Factors and generation mechanism of supply chain flexibility

After analyzing that the environmental uncertainty is the source and impetus of the generation of supply chains, we can see that supply chain flexibility is a capacity which is not constructed without foundation but is subject to the dynamic capability of the core business, supply chain collaboration and other factors to cope with environmental uncertainty. The following will analyze the factors of supply chain flexibility from the aspects of motility and adaptability.

2.3.1 Motility factor analysis

As pointed out earlier, the operation of supply chain is consumer-oriented and core businesses play a key role, consequently they are also significant to the construction of flexibility, which is mainly reflected in their dynamic capability that becomes a motility factor of flexibility as well.

Supply chain is essentially a dynamic enterprise alliance, whose dynamicity determines that supply chain may face dissolving, updating and re-establishing at any time. This uncertainty is due to less competitive supply chain as a whole, profit instability, the distribution of benefits without balance or the incompatibility between a node enterprise and its upstream and downstream enterprises [18]. In a dynamic environment, core competence is definitely important, but if it can not update, then core capabilities will eventually become core rigidities [19], which means that core competencies can not

necessarily bring about a sustainable competitive advantage [20]. It is for sake of reconciling the contradiction between competence rigidity and environmental changes that the concept of dynamic capability comes into being [19].

Dynamic capability is not a one-dimensional concept, He Xiaogang(2006) divided the dimension of dynamic capacity by means of empirical research into five areas [20]. Li Xingwang(2006) started with the functional origin of dynamic capacity, which considered that it can be identified from the aspects environment, strategy / tactics, products, resource structure and competitive advantage [21].

After the analysis above, the dynamic capacity is defined as the capacity of resource integration and reconstruction that core business can constantly create new needs and new value which is composed by knowledge, resources, processes and other elements. It can be measured by the following three aspects, namely, environmental insights and customer-oriented value, the configuration and integration capability of value chain and learning ability. Achieving the capture of information in use of learning ability to respond to environmental changes, which is the premise of dynamic capabilities; realizing product/service customization by focusing on customer-oriented value, which is the foundation of dynamic capabilities; Achieving the variation of operational capability through integration and reconstruction ability, which is the means to comply dynamic capabilities [22].

2.3.2 Adaptive factor analysis

Supply chain flexibility is a dynamic supply network in rapid response to environmental changes built around the core business by a number of suppliers, acquirers and other entities. It emphasizes the overall business integration and effective coordination control of each node and its activities to ensure that logistics, information flow and capital flow would run smoothly and all available resources would be utilized and configured sufficiently. Under the competitive circumstance based on time and flexibility, the response rate of end-user's demand is a key factor in the success of the supply chain. In order to obtain flexibility, enterprises must build a seamless supply chain, which makes interoperability play an important role in ensuring the orderly operation of supply chain [23].

As for supply chain flexibility, supply chain collaboration is a crucial factor, coordinating all aspects of its operation and effectively adjusting the level of flexibility to match environmental uncertainty to achieve rapid response to demand. Since the adoption of efficacious collaboration in information flow and logistics can be beneficial to compress the response time of supply chain and enhance overall competitiveness [24], so we see it as an adaptive factor.

Cai Shuqin(2007) divided the collaboration from a practical perspective into management coordination, technical cooperation, and man-machine cooperation. The author thought that supply chain collaboration should be the unity of the three types. Organizations utilize advanced information technology by means of contracts or combination, strengthening mutual coordination and collaboration through rapid and accurate transmission of information to share with each other in order to organize and arrange production and business activities more coordinately within the enterprise and access to the maximum benefit of supply chain under the premise of achieving the common goal [25].

After the analysis above, we consider that supply chain collaboration is mainly reflected in three aspects, the collaboration of management, business and information.

2.3.3 Generating process of supply chain flexibility

The flexible construction of supply chain is a systematic project, improving the level of flexibility from the overall point of view [26]. As for the research target and the characteristics of the flexibility analyzed above, the construction process is mainly divided into four stages, namely, identifying needs and environmental uncertainty for setting goals, determining the value-added process and selecting partners, organizational design and program implementation, performance measurement and dynamic evolution, which is shown in Figure1.

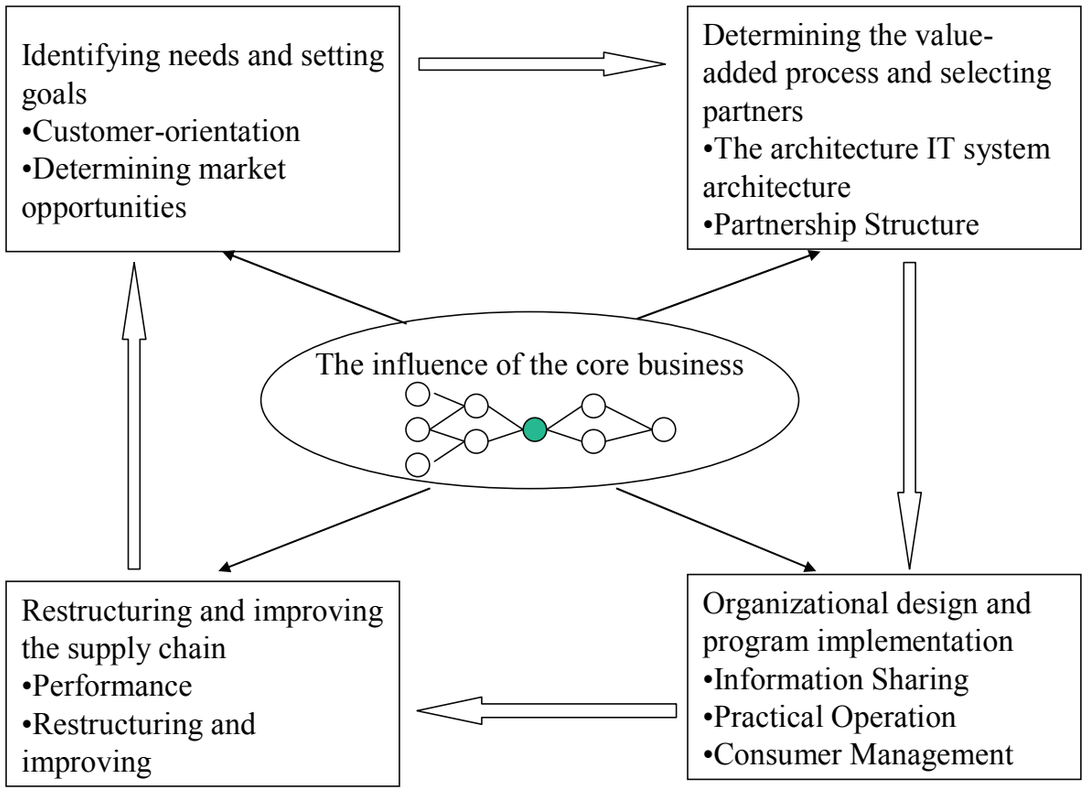

Fig. 1. Construction of demand-driven supply chain

As it is shown in the chart above, in the first stage, core businesses should analyze demand and market opportunity and assess environmental uncertainty. on this basis, they should decide whether to respond to the opportunities and establish strategic goals. The following two aspects must be grasped: (1) to accurately identify and understand the specific needs of consumers, because providing consumers with satisfactory products and services is the purpose to set up the supply chain; (2) to identify and assess the extent and content of environmental uncertainty after understanding consumer needs sufficiently, which is prerequisite for building supply chain flexibility. In the second phase, the core business should firstly identify the value-added term of production according to the objectives established, which is the basis for the formation of supply chain. As the result of determining specific value chain, they can choose the right partner and build a corresponding network structure, so as to reduce non-value-added process more effectively at the same time increase the anti-jamming capability and robustness of supply chain. The

following two major aspects must be concentrated at this stage: (1) value chain configuration, which indicates that accurate identification of the value-added process is the foundation to build supply chain and improve operational performance; (2) the construction of robust network, which means to design specific organizational forms for node enterprises and construct robust network based on the value chain model, the participate way of partners, the type of business in supply chain and other factors analyzed by the core business. In the third stage, it is mainly acquired to design the elements of flexibility, including operation flexibility, logistics flexibility and other elements, adopting related techniques, methods and procedures in accordance with the level of environmental uncertainty identified and the network structure built. These are the details in response to environmental uncertainty from a business point of view, but in the specific implementation process of flexibility, whether it is synergistic between systems determines the validity of supply chain, which includes the collaboration of management, information and business. In the fourth stage, it is mainly about measuring supply chain flexibility, analyzing the matching status between the level of flexibility and environmental uncertainty and then adjusting the flexibility to some extent if necessary. By judging the matching level, the core enterprises can understand the evolving direction of supply chain flexibility.

2.3.4 Generation mechanism of supply chain flexibility

The consumer-oriented supply chain flexibility is generated around the core business. Driven by its requirement information, other nodes take capital flow, service flow and logistics as medium through functional division and cooperation, which is in order to obtain the continuously value-added robust network of the entire supply chain [11]. Consequently, the core business plays a significant role in the formation of supply chain.

Based on the analysis above, as it is shown Figure 2, we can understand the effect of core businesses on the formation of consumer-oriented supply chain flexibility. The figure reflected that the supply chain system consisting of the core business, channel enterprises and market is targeted at the customer demand, which means it is closely run around the requirement and focus on variable needs of consumers. The market demand, which is identified by the core enterprise, is the driving source of supply chain. The core enterprise rapidly and effectively integrates the internal and external resources from the perspective of adding value and pass the demand along to the relevant members of the supply chain through valid information sharing, which can meet consumer needs efficiently, rapidly and low-costly.

Consumer-oriented supply chain management is willing to solve the following two problems: firstly, how to accurately identify the real needs of consumers; secondly, how to integrate the internal and external resources quickly and effectively and improve supply chain flexibility to meet individual demand. To illustrate, the effect of the core business on the formation of consumer-oriented supply chain flexibility is mainly reflected in that, first of all, it is identification center of consumer demand. Second, it is the reconstruction center of organizations. The third one is that it is the information exchange center and finally a distribution and dispatch center of logistic.

Therefore, the formation mechanism of supply chain flexibility is the factors that impact the flexibility and the interaction between them. Studying on the formation mechanism of supply chain flexibility will help us to understand the action principle of supply chain so as to find the key flexibility or weakness and improve response capability to customers [27]. Based on the foregoing analysis, we construct the framework of the mechanism of supply chain flexibility, which is shown in Figure 3.

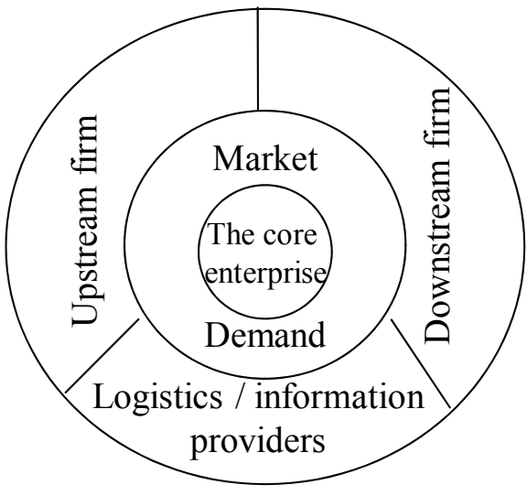

Fig. 2. The position of core enterprises in the consumer-oriented supply chain

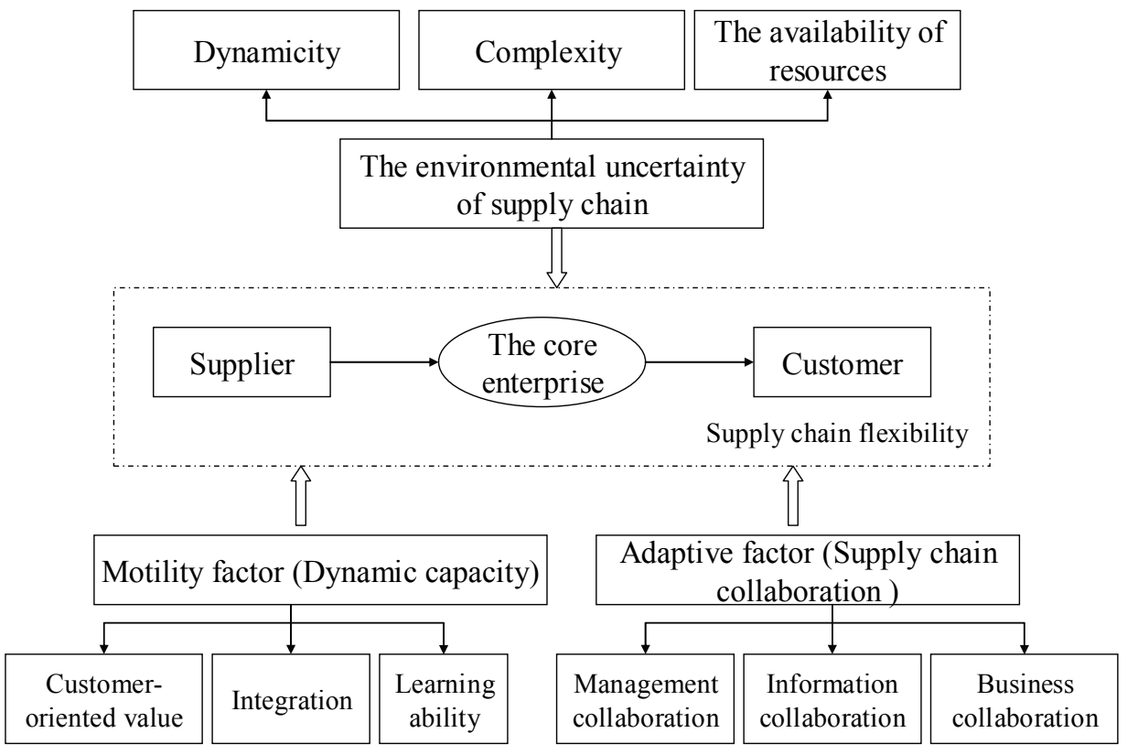

Fig. 3. Generation mechanism diagram of supply chain flexibility

The framework above gives the causes and conditions of the formation and development of supply chain flexibility. Environmental uncertainty provides supply chain flexibility with driving force. It is because of the dynamic, complexity and non-availability of resource that supply chain environment gets uncertainty, which driving enterprises to acquire flexibility in response to changing circumstance. As for the construction of supply chain flexibility, since the supply chain is a complex system, the formation of flexibility is not deliberate,

which requires the co-activation of organizations. The important factors include two aspects, one is the motility factor that is helpful for supply chain flexibility to evolve and innovate, namely, the dynamic capability of core enterprises, including environmental insights and customer-oriented value, value chain configuration and integration and learning ability. Another is the adaptive factor to ensure supply chain flexibility to respond effectively and adapt to environmental uncertainty, namely, supply chain collaboration, including the collaboration of management, information and business. Environmental uncertainty is the basis for generating supply chain flexibility and dynamic capability and supply chain collaboration is an important factor to implement and enhance the flexibility, which is targeted at a market-oriented supply chain, in order to provide circumstances and conditions for the generation and evolution of it. Only in the common effect of these three aspects, can supply chain flexibility be rapidly constructed, evolve and adjust appropriately and dynamically according to environmental changes, thereby enhance the performance of supply chain.

3. Environmental uncertainty measurement of supply chain flexibility

Currently, researches on flexibility measurement are still not unified. There are many measuring methods focusing on one aspect of the flexibility elements [10] [28] but few articles comprehensively measuring supply chain flexibility from an overall perspective [29]. Accurately measuring the level of supply chain flexibility is the foundation of the evolution of it, and only on a certain approach to comprehensively investigate the level of supply chain flexibility, can we make corresponding decisions through evolution models.

3.1 Construction of supply chain flexibility dimensions

In order to guide the supply chain to respond to environmental uncertainty and make accurate decisions for the construction and evolution of supply chain flexibility, fully and accurately measure the level of supply chain flexibility is the key. We can analyze the capacity how the existing supply chain responds to environmental uncertainty by an effective measurement, identify the crux of the problem and chart the course of the evolution of supply chain flexibility [8]. The main reason why flexibility is difficult to understand and measure lies in two aspects: On the one hand, flexibility is an inherent expressive ability of the system, not as cost, quality, or other production targets which can be calculated by external manifestations or a certain formula. On the other hand, flexibility is attached to the system; due to the complexity of supply chain it is rather difficult to understand [30]. Therefore, it is necessary to accurately grasp the meaning and development rules of flexibility and construct a reasonable flexibility dimension, and it is the basis of effectively measuring and evaluating the level of supply chain flexibility.

Flexibility is a multidimensional concept [14], flexibility dimension refers to the aspects we can analyze the flexibility of the system from. It is of great significance for understanding and measuring flexibility to anatomize its in depth. Scholars have studied flexibility from different angles. Early researchers [31] [32-35] tended to understand it from three aspects that time, range and cost. Later than that, Upton(1994,1995) described it depending on range, mobility and uniformity [32] [37]. Koste(1999) extended its dimensions to four aspects on that basis, those were range-number, range-heterogeneity, mobility and uniformity [38] [39] [40] [41]. After that, Koste (2004) combined those four dimensions into two, namely range and accessibility [42].

Based on the analysis above, this article would synthesize the features of flexibility and the view of these scholars, and build the supply chain flexibility in two dimensions, namely scope and adaptability. The definition of scope--which reflects the range of available policy options in order to meet the dynamic market demand in supply chain, videlicet, the number of different states and diversity--is consistent with that defined by Slack and Upton. Organizations can increase the range of strategies or through an efficient application of them to achieve greater flexibility, so scope is a necessary dimension of flexibility [43]. The other dimension is adaptability which reflects the resorting capacity of facilities in given scope. The concept of adaptability which is defined as the conversion capability of system that can rapidly, low-costly and efficiently transform from one state into another is more generalized in this article. The dimension of adaptation is more accurate than the concept mobility defined by earlier researchers, because it expresses the conversion capability and difficulty level maintaining a certain level of performance in given scope, and it exercises due caution on cost and efficiency not just the conversion itself [43].

3.2 Construction of supply chain flexibility evaluating index system

Index system as the evaluating standard of supply chain flexibility, how reasonable it designed would affect the evaluation results of supply chain flexibility, so taking the characteristics of supply chain flexibility and the emphasis of this article into account, we should follow these three principles, namely, systematicity, Scientific justification and focus when design it.

To construct the index system scientifically and reasonably, we should take the complexity of supply chain and the multidimensionality of flexibility into consideration, because supply chain is an overall function network chain into which it links suppliers, manufacturers, distributors and end users through logistics, capital flow and information flow driven by consumer demand. Supply chain has independent economic entities which hold their own goals and play different roles with multi-participation in the operation of each other, while it is in a changing external environment, so the supply chain itself is a complex system. The multi-dimensional flexibility and its various properties have increased the difficulty and complexity of supply chain flexibility.

Therefore, in accordance with the construction principles and two kinds of flexibility dimension previously proposed, we analyze four elements of supply chain flexibility--operation flexibility, logistics flexibility, information flexibility and Robust network and reconstruction flexibility respectively from the dimension of scope and adaptation to build the index system. This indicator system is more comprehensive, which integrated reflects the characteristics of flexibility especially the feature under supply chain function network. As it is shown in Table 1, we can understand the detail obviously.

3.3 Comprehensive measurement of supply chain flexibility with series features

Supply chain flexibility is a complex open system, and that complexity is produced by the interaction between the environment and system. At the same time flexibility is a relative concept, so it is necessary to start with the relationship above in order to understand it in depth. For the purpose of measuring the environmental uncertainty and the matching level of supply chain flexibility effectively, accurate quantification of flexibility is the very first thing to do.

	One grade index	Dimensions	Two grade index
Supply Chain Flexibility	Operation flexibility	Scope	The range and number of products available [44]
			The number of application skills of generalist staff [44]
		Adaptability	The capacity to improve existing products [45]
			The ability to change the number of products [44]
	Logistics flexibility	Scope	The number of stock strategy options [44]
			The number of alternative distribution channels [44]
		Adaptability	The ability to adjust inventory quantity [44]
			The capacity to adjust the established shipping method [44]
	Information flexibility	Scope	The frequency of informal information exchange [46]
			The quality and accuracy of information exchange [46]
			The capacity to let partners know quickly in case of changing information [46]
		Adaptability	The ability of reconfiguration or reuse
			Scalable capacity
	Robust network and reconstruction flexibility	Scope	Time to form a stable partnership / selecting time of supplier / time of reconstruction
			Stability and robustness of existing supply chain
			The number of suppliers available
		Adaptability	The ability of cultural integration
			The ability to change suppliers' delivery requirements [44]

Table 1. Index system for measuring supply chain flexibility

As to the measurement of the supply chain flexibility, most existing literatures only discuss one side of a certain element of supply chain flexibility, such as Beamon(1999) who investigated it from the perspective of quantity flexibility, transport flexibility, combination flexibility and new product flexibility [15]. These scholars neglected the network features of supply chain and the flexibility of operation as well as the relationship between supply

chain partners [47]. The measuring approaches of existing studies also has limitations, which means most methods concentrate on static analysis, however supply chain flexibility is a dynamic, complex system. Consequently, it is essential to introduce time parameters into measurement models for the sake of quickly and accurately responding to environmental uncertainty. In previous studies, measurement indicators were mainly viewed as constant weights, ignoring the dynamic nature of supply chain flexibility, making a strong one-sidedness of its evaluation. To solve this problem, we introduce the time parameter to measure integrated flexibility level within or at a certain period of time, thus to achieve just in time management and decision-making. For comprehensive measurement, identifying the weight and creating models is the key issue. Previous researchers mostly used AHP to determine weights [48] [49], but the premise of this method is judgment matrix consistency. Psychological experiments show that when the number of elements being compared is more than 9, it would be difficult for the judgment matrix to ensure its consistency [50]. Thus this paper, no consistency test method for determining the weights would be adopted but time parameters would be introduced

Therefore, we build an integrated quantitative model of flexibility with a balanced of 'function' and 'coordination' of all flexibility elements:

$$y = \lambda_1 y^{(1)} + \lambda_2 y^{(2)} = \lambda_1 \sum_{j=1}^{m} w_j^{(1)} x_j + \lambda_2 \prod_{j=1}^{m} x_j^{w_j^{(2)}}$$

Indicators λ_1, $\lambda_2 (\lambda_1 \geq 0, \lambda_2 \geq 0, \lambda_1 + \lambda_2 = 1)$ in the formula above are known scale factors which respectively refer to the percentages the factors 'function' and 'coordination' take in integrated results. Indicators $w_j^{(1)}$, $w_j^{(2)}$ refer to the weights of each flexibility element x_j in 'function' valuation and 'coordination' measurement. When measuring, firstly do the measurement at single index layer, then to measure step by step up, consequently, the measurement of supply chain flexibility would be finished. Concrete steps are as follows:

(1) Dimensionless treatment of index system

We use extreme value approach to Nondimensionalize factors, that is,

$$x_{ij}^* = \frac{x_{ij} - \min\limits_i (x_{ij})}{\max\limits_i (x_{ij}) - \min\limits_i (x_{ij})}, \; x_{ij}^* \in [0,1].$$

We discuss the flexibility level of several supply chain systems s_i ($i = 1,2,\cdots,n$) at different times t_k ($k = 1,2,\cdots,N$), and the supply chain system at each flexibility level has number m valuation indicators $x_1, x_2, \cdots, x_m$, forming time series data $\{x_{ij}(t_k)\}$ as it is shown in Table 2.

	t_1	t_2	…	t_N
	x_1 x_2 … x_m	x_1 x_2 … x_m	…	x_1 x_2 … x_m
S_1	$x_{11}(t_1)$ $x_{12}(t_1)$… $x_{1m}(t_1)$	$x_{11}(t_2)$ $x_{12}(t_2)$ … $x_{1m}(t_2)$	…	$x_{11}(t_N)$ $x_{12}(t_N)$ … $x_{1m}(t_N)$
S_2	$x_{21}(t_1)$ $x_{22}(t_1)$ … $x_{2m}(t_1)$	$x_{21}(t_2)$ $x_{22}(t_2)$ … $x_{2m}(t_2)$	…	$x_{21}(t_N)$ $x_{22}(t_N)$ … $x_{2m}(t_N)$
⋮	…	…	…	…
S_n	$x_{n1}(t_1)$ $x_{n2}(t_1)$ … $x_{nm}(t_1)$	$x_{n1}(t_2)$ $x_{n2}(t_2)$ … $x_{nm}(t_2)$	…	$x_{n1}(t_N)$ $x_{n2}(t_N)$ … $x_{nm}(t_N)$

Table 2. Time series data

(2) Determination of weight $w_j^{(1)}$

Indicator $w_j^{(1)}$ is the weight of each indicator in 'function' valuation. Function valuation primarily concentrates on the contribution of a certain function of the system made by each indicator. Because that adopting addition rules, comprehensive result is so insensitive to index movement, hence the purpose of determining weights is to reflect the distinction between each measured object as a whole as far as possible, namely, the overall difference between systems $s_1, s_2, \cdots, s_n$ and time series data matrix $\{x_{ij}(t_k)\}$. To make the largest overall difference between systems, the total sum of squares of indicator $y_i^{(1)}(t_k) = \sum_{j=1}^{m} w_j^{(1)} x_{ij}(t_k)$, videlicet, indicator $\sigma^2 = \sum_{k=1}^{N}\sum_{i=1}^{n}(y_i(t_k) - \overline{y})^2$ must be the largest, namely,

$$A_k = \begin{bmatrix} x_{11}(t_k) & \cdots & x_{1m}(t_k) \\ \cdots & \cdots & \cdots \\ x_{n1}(t_k) & \cdots & x_{nm}(t_k) \end{bmatrix}, k = 1, 2, \cdots, N .$$

Then calculate each indicator $H_k = A_k^T A_k (k = 1, 2, \cdots, N)$, weight $w^{(1)}(t_k)$ is the priority vector corresponded to the maximized eigenvalue $\lambda_{\max}(H_k)$ of matrix H_k, which means get maximum value of σ^2.

(3) Determination of weight $w_j^{(2)}$

Indicator $w_j^{(2)}$ is the weight of each indicator in 'coordination' measurement. Researchers used to adopt AHP to determine weight. However, using this method, it is difficult to ensure the consistency of adjustment matrix when dealing with large volume of indicators. Therefore, we adopt order relation approach without consistency test in this article.

Suppose that during a period of time $t \in [t_0, T]$, valuation index $x_1, x_2, \cdots, x_m$ has order relationship $x_1^* \succ x_2^* \succ \cdots \succ x_m^*$ for a certain standard, for which parameter x_1^* refers to i th index after arranging $\{x_j^*\}$ according to the order relationship '$\succ$'. If the length of interval $[t_0, T]$ is relatively lager, it is not stable between indicators $x_1^*, x_2^*, \cdots, x_m^*$. Considering about that, we separate the interval $[t_0, T]$ into number p(p≥2) subintervals, and in each of them, order relations between indicators $x_1^*, x_2^*, \cdots, x_m^*$ can be considered stable.

Firstly, identify the ratio $w_{j-1}^*(t_k) \big/ w_j^*(t_k) = d_j(t_k)$ between indicators x_{j-1}^* and x_j^* at a certain time $t = t_k$ for any $j = 2, 3, \cdots, m (w_j^*(t_k) > 0)$, and the assignment of $d_j(t_k)$ can be consulted in Table 3.

$d_j(t_k)$	Demonstration
1.0	x_{j-1} and x_j have the same importance
1.2	x_{j-1} is slightly important than x_j
1.4	x_{j-1} is obviously important than x_j
1.6	x_{j-1} is highly important than x_j
1.8	x_{j-1} is extremely important than x_j

Table 3. Assignment reference of $d_j(t_k)$

So the weights of indicator x_m^* and x_j^* at time t_k is

$$w_m^*(t_k) = (1 + \sum_{r=2}^{m} \prod_{j=r}^{m} d_j(t_k))^{-1} \text{ and } w_{j-1}^*(t_k) = d_j(t_k) w_j^*(t_k),$$

For any $j = 2, \cdots, m-1, m$ and $k = 1, 2, \cdots, N$.

4. Comprehensive measurement of supply chain flexibility

According to the index system constructed, collect data for different time points in terms of the table above. Applying the comprehensive measurement model and the method for determining index weight, we could measure the flexibility level of several supply chain systems under the premise of keeping each function of flexibility elements and the coordinated the overall flexibility in mind.

4. Evolution process and matching models of supply chain flexibility under uncertain environment

Context above constructed supply chain flexibility evolution model and comprehensive measurement method from a theoretical point of view, which is the foundation of the evolution of supply chain flexibility. Now, we analyze how the supply chain flexibility evolutes and what the specific processes and methods are from a practical perspective.

4.1 Analysis of supply chain flexibility evolution process under uncertain environment

To make the supply chain adapt to environmental changes, we must monitor environment instantaneously and regulate flexibility appropriately, which involves the evolution of flexibility. According to the foregoing analysis that the fundamental drivers of the development of flexibility, we can see that environmental uncertainty should be the basis for the evolution of flexibility, and we should adjust the flexibility appropriately in light of the requirements of it to environmental uncertainty. So it will involve the matching of supply chain flexibility under uncertain environment.

The matching we talk about mainly refers to whether the level of flexibility that environment uncertainty requires is consistent with the level of reality and potential supply chain flexibility. If not match, it is necessary to accordingly evolve and adjust supply chain flexibility using its dynamic capability and interoperability, which is the basis for decision-making of supply chain flexibility. Therefore, the ultimate goal of flexibility evolution should be to enable the supply chain to adapt to as well as match the environment [51], which also laid a good foundation for supply chain to face changes in future. Figure 4 provides the matching processes of supply chain flexibility under uncertain environment from the practical point of view.

The flow chart in Figure 4 has clearly explained how the supply chain flexibility evolves and matches. Firstly, core business recognizes market demand. Then recognize the main value adding processes and construct supply chain based on whether it responds to demand. After that, analyze the environment uncertainty from the perspective its three dimensions and factors related in order to determine the requirement of supply chain flexibility. Lastly, dissect the reality and potential flexibility of supply chain according to the actual situation and potential resources and decide whether the requirement is appropriately matched with reality flexibility. There are two possibilities: If the reality flexibility is greater than the

requirement, the supply chain does not have to take any steps to respond to environmental changes; on the contrary, we should judge how the potential flexibility matches with the requirement. If the potential flexibility is larger than that required by environment, supply chain can adopt strategy combinations or limitedly use external resources without changing the main structure to deal with the problem, which makes supply chain collaboration play an important role. If it is the opposite, it means that the level of supply chain flexibility can not reach that required by environmental uncertainty even under he effect of supply chain collaboration, then the core business should consider building new strategies or reconstructing the supply chain, in the process of which the dynamic capability in the supply chain play a key role.

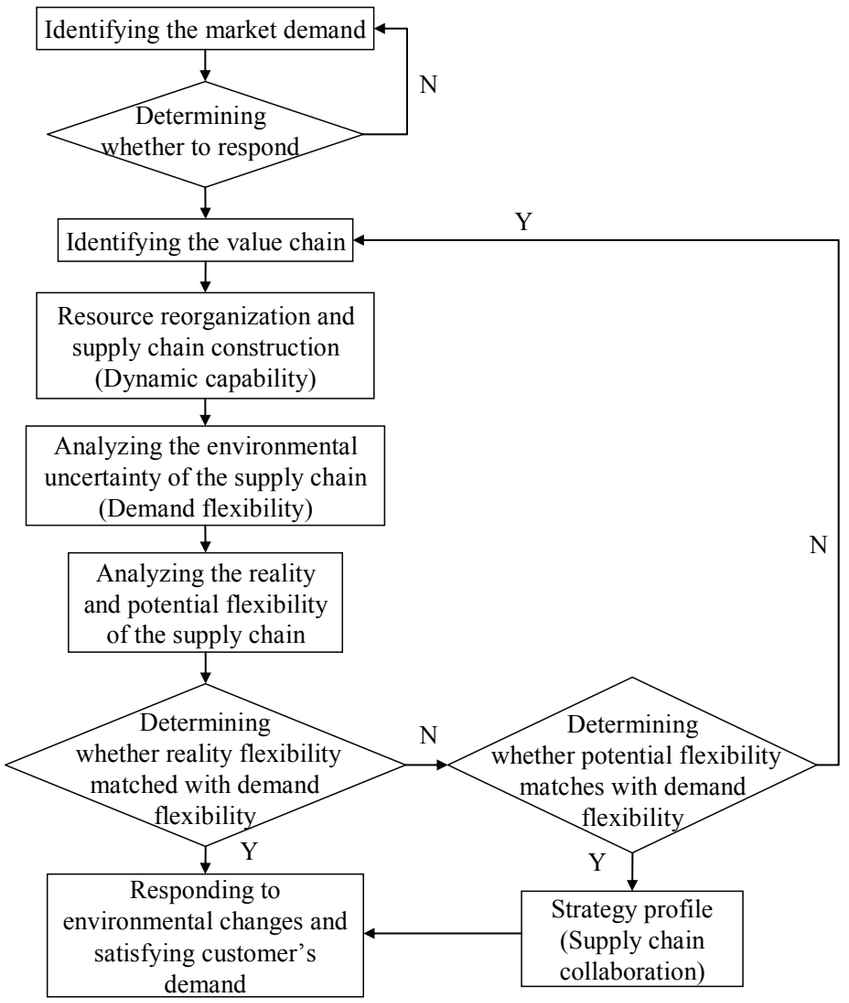

Fig. 4. The matching and evolution flow chart of supply chain flexibility under uncertain environment

There are two main aspects to consider about in the matching problem between supply chain flexibility and environmental uncertainty. Global matching that whether supply chain is able to cope with environmental uncertainty from an overall perspective—the state how reality flexibility matches with the requirement comes the first; Secondly it is component

matching, namely the matching situation between each element and environmental uncertainty. Both play a different role. Global matching observes the whole picture, offering the current system flexibility from a integrated perspective, which gives decision-makers an overall awareness. The disadvantage is that we have no idea about the specific circumstances of each element, only after component matching can we determine which one is not flexible to respond to environmental uncertainty. The organic combination of the two can form the supply chain flexible strategies to help managers make decisions, the following will talks about flexibility matching issues.

4.2 Matching models of supply chain demand flexibility and reality flexibility

According to the evolution process, we should firstly match reality flexibility to that required by environmental uncertainty. In order to give a general understanding, we will analyze it from two aspects—global matching and component matching. As the consequence of matching, if reality flexibility is larger than the requirement, it means that the actual state of supply chain is able to cope with uncertain environment and we don't have to take any actions, which reflects the buffering capacity of supply chain flexibility; If it is the opposite, further analysis will be needed to reveal the matching state between demand flexibility and potential flexibility.

4.2.1 Global matching

Reality flexibility refers to the practical level determined by supply chain constructed aiming at a particular consumer demand in the light of actual situation according to each environmental uncertainty factor. Demand flexibility represents the level that each flexibility element should possess under the condition that environmental uncertainty is observed by supply chain. Both of them are filled in Table 4.

Parameter E stands for environmental uncertainty and according to the preceding analysis of its dimensions and factors, we set them to be the rows of the table. Furthermore, we set parameter e_{ij} to stand for individual element of environmental uncertainty and the attention meter of each of them is indicator a_{ij}. In terms of the classification of supply chain flexibility elements, we use letters to represent every element and its corresponding index. To illustrate, letter O stands for operation flexibility and there are four of them--{O_1,O_2,O_3,O_4}; letter L represents logistics flexibility and the four indexes are {L_1,L_2,L_3 ,L_4}; letter I and letter N respectively refers to information flexibility and robust network & reconstruction flexibility, and so forth. At last, determine the actual status of each index depending on individual environmental uncertainty factor with variable x_{ij}^{ij} indicated corresponding to the left in each cell. As for the right, variable $\overline{x}_{ij}^{ij}$ stands for demand flexibility. Thereinto, subscript ij represents the code of flexibility elements corresponded and superscript ij refers to the code of related factors of environmental uncertainty.

We assign the reality flexibility of each element of value $\sum \alpha_{ij} x_{fn}^{ij}$ and the demand flexibility of value $\sum \alpha_{ij} \overline{x}_{fn}^{ij}$. Depending on the comprehensive measurement we discussed above, respectively calculate the level of reality and demand flexibility, namely variable F and E. Matching function is assumed to be equation $r = \frac{F}{E}$.

If $r > 1$, which states $F > E$, it shows that the reality flexibility is larger than the demand one and we set warning coefficient φ_1 here. If inequality $1 < \frac{F}{E} < 1 + \varphi_1$ is right, there is no

Environmental uncertainty(E) / Supply chain flexibility (F)		Dynamic (E_1)		Complexity (E_2)		Resource availability(E_3)	
		e_{11}	e_{12}	e_{21}	e_{22}	e_{31}	e_{32}
		α_{11}	α_{12}	α_{21}	α_{22}	α_{31}	α_{32}
Operation flexibility(O)	O_1	$x_{O1}^{11}\ \bar{x}_{O1}^{11}$	$x_{O1}^{12}\ \bar{x}_{O1}^{12}$	$x_{O1}^{21}\ \bar{x}_{O1}^{21}$	$x_{O1}^{22}\ \bar{x}_{O1}^{22}$	$x_{O1}^{31}\ \bar{x}_{O1}^{31}$	$x_{O1}^{32}\ \bar{x}_{O1}^{32}$
	…	…	…	…	…	…	…
	O_4	$x_{O4}^{11}\ \bar{x}_{O4}^{11}$	$x_{O4}^{12}\ \bar{x}_{O4}^{12}$	$x_{O4}^{21}\ \bar{x}_{O4}^{21}$	$x_{O4}^{22}\ \bar{x}_{O4}^{22}$	$x_{O4}^{31}\ \bar{x}_{O4}^{31}$	$x_{O4}^{32}\ \bar{x}_{O4}^{32}$
Logistics flexibility(L)	L_1	$x_{L1}^{11}\ \bar{x}_{L1}^{11}$	$x_{O1}^{12}\ \bar{x}_{O1}^{12}$	$x_{O1}^{21}\ \bar{x}_{O1}^{21}$	$x_{O1}^{22}\ \bar{x}_{O1}^{22}$	$x_{O1}^{31}\ \bar{x}_{O1}^{31}$	$x_{O1}^{32}\ \bar{x}_{O1}^{32}$
	…	…	…	…	…	…	…
	L_4	$x_{L4}^{11}\ \bar{x}_{L4}^{11}$	$x_{L4}^{12}\ \bar{x}_{L4}^{12}$	$x_{L4}^{21}\ \bar{x}_{L4}^{21}$	$x_{L4}^{22}\ \bar{x}_{L4}^{22}$	$x_{L4}^{31}\ \bar{x}_{L4}^{31}$	$x_{L4}^{32}\ \bar{x}_{L4}^{32}$
Information flexibility(I)	I_1	…	…	…	…	…	…
	…	…	…	…	…	…	…
	I_5	…	…	…	…	…	…
Robust network and reconstruction flexibility(N)	N_1	…	…	…	…	…	…
	…	…	…	…	…	…	…
	N_5	$x_{N5}^{11}\ \bar{x}_{N5}^{11}$	$x_{N5}^{12}\ \bar{x}_{N5}^{12}$	$x_{N5}^{21}\ \bar{x}_{N5}^{21}$	$x_{N5}^{22}\ \bar{x}_{N5}^{22}$	$x_{N5}^{31}\ \bar{x}_{N5}^{31}$	$x_{N5}^{32}\ \bar{x}_{N5}^{32}$

Table 4. Data sources of demand flexibility and reality flexibility

necessity for supply chain to take any steps to respond environmental changes. On the contrary, if inequality $\frac{F}{E} > 1 + \varphi_1$ is valid, it means the level of reality flexibility is too high and we can use the existing resources to address environmental uncertainty by the most economical way through appropriate adjustment.

If $r < 1$, which states $F < E$, it shows that the reality flexibility is less than the demand one and we set warning coefficient φ_2 here. If inequality $1 - \varphi_2 < \frac{F}{E} < 1$ is right, it demonstrates that the gap between reality and demand flexibilities is within an acceptable range, and we can adjust it locally through the analysis of the matching status of specific components. On the other hand, if $\frac{F}{E} < 1 - \varphi_2$, it indicates that the gap between demand and reality flexibilities is over acceptable range, which means we need further analysis of the matching states between potential and demand ones.

4.2.2 Component matching

Depending on preceding analysis, each flexibility element has two dimensions, namely range(R) and adaptability (A), which constructs a two-dimensional space, as it is shown in Figure 5. Assuming the reality flexibility of an individual element is f_n, we can obtain its rectangular coordinate $f_n(f_n^R, f_n^A)$ in accordance with the index constructed from two dimensions, by this time the demand flexibility of the element is e_n and its rectangular coordinate is $e_n(e_n^R, e_n^A)$. Transform the rectangular coordinate into polar coordinate, namely $f_n(\rho_f, \theta_f)$, $e_n(\rho_e, \theta_e)$, and component matching function is assumed to be equation $\phi = \frac{\rho_f}{\rho_e}$.

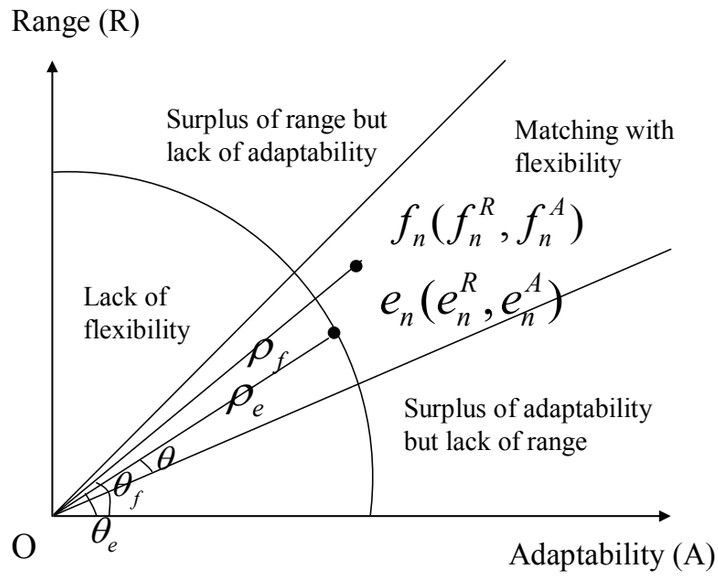

Fig. 5. Reality flexibility elements matching with demand ones

As shown in Figure 5, if $\phi < 1$, which states $\rho_f < \rho_e$, it indicates that the reality flexibility of a certain element is less than the demand one, that is to say the reality flexibility falls within the circle whose origin is O and radius is ρ_e, and it is necessary to be adjusted.

If $\phi > 1$, which states $\rho_f > \rho_e$, it indicates that the reality flexibility of a certain element is larger than the demand one, but it does not mean that the two dimensions of the flexibility are balanced and we need warning coefficient θ here. If $\theta_e - \theta < \theta_f < \theta_e + \theta$, namely reality falls within the area whose center axis is ρ_e and included angle is 2θ, it means the reality flexibility of a certain element is matched with the demand one. If inequality $\theta_f > \theta_e + \theta$ is valid, it indicates a lack of adaptability but an excess of range. However, it is the opposite situation when $\theta_f < \theta_e - \theta$. Both of the two cases above need local adjustment to ensure the most economical way when coping with the changes of environment.

During the feedback evolution process of supply chain flexibility and its dynamic environment, the flexibility continuously adjust itself through its dynamic capabilities and interoperability, hoping to achieve the optimal position in supply chain flexibility space, that is the required flexibility level depending on uncertain environment. Therefore, it is the existence of dynamic circumstance that drives supply chain to construct and continuously evolve flexibility. Based on the anatomize above we can see that the matching between reality and demand flexibility is a process which starts with the overall situation, grasps the details, adjusts locally and balances dimensions, aiming at allocating resources through the most reasonable way to address environmental uncertainty. Moreover, when the matching result indicates that there is gap or deviation between the reality flexibility and the demand one, we should construct and adjust the supply chain appropriately and here we can define the momentum function of its flexibility evolution as $\gamma = \sqrt{(r-1)^2 + \sum_{i=1}^{4}(\phi_i - 1)^2}$, thereinto, variables r and ϕ_i are the consequences of global and component matching respectively, variable i for any $i \in [1,4]$ refers to the supply chain flexibility elements. The larger value variable γ is, the greater momentum of supply chain flexibility evolution and the stronger tendency are.

4.3 Matching models of supply chain demand flexibility and potential flexibility

After the comparison of the demand flexibility required by environmental uncertainty and the reality one, if the former is greater than the later, it is necessary to further contrast the potential flexibility with the demand one, which determines the choice of supply chain flexibility strategy, that is, if the demand flexibility is less than the potential one, supply chain can finitely capture the boundary elements according to its own situation without shifting its main structure to choose or mix strategies in order to address environmental changes. Supply chain collaboration at this time plays an important role. If the demand flexibility is greater than the potential one, then the supply chain must reorganize the resources or reconstruct the structure through its dynamic ability to respond to environmental changes.

Strategies \ Indicators		Levels of flexibility elements			
		O_1	O_2	…	N_5
Potential flexibility	1	$x_{1,O1}$	$x_{1,O2}$	…	$x_{1,N5}$
	2	$x_{2,O1}$	$x_{2,O2}$	…	$x_{2,N5}$
	…	…	…	…	…
	m	$x_{m,O1}$	$x_{m,O1}$	…	$x_{m,N5}$
Demand flexibility	Optimal values	$x_{e,O1}$	$x_{e,O1}$	…	$x_{e,N5}$

Table 5. Flexibility levels and optimal values of each supply chain flexibility element under m kinds of strategies

The demand flexibility here is defined as before, that is the flexibility level of supply chain depending on the degree of environmental uncertainty. The potential flexibility refers to the capacity that supply chain maximally uses of available resources under the existing main structure to form strategy combinations. We can use m kinds of strategies to represent their potential flexibility. Demand flexibility can be considered to be the optimal status of flexibility that supply chain should have under the condition that each element observes the level of environmental uncertainty. Specific data is shown in Table 5.

All indicators of the four elements of supply chain $\{O_1, O_2, \ldots, N_5\}$ can form m kinds of strategies according to different levels of environmental uncertainty during a period of time. The index values corresponded by all policies have formed the potential flexibility of the supply chain. We use variable F_H to represent it and $F_H=\{F_{H1}, F_{H2}, \ldots, F_{Hm}\}$. Thereinto, variable $F_{Hi}=\{x_{i,O1}, x_{i,O2}, \ldots, x_{i,N5}\}$, which means the whole index value of ith strategy. The optimal flexibility values that each indicator identified in the light of environmental uncertainty should have during a certain period form demand flexibility which is represented by F_E, and $F_E=\{x_{e,O1}, x_{e,O2}, \ldots, x_{e,N5}\}$. Based on all of these, we define matching function as

$$\varphi_i = \frac{1}{n}\sum_{j=O_1}^{N_5} \frac{\delta_{\min} + \tau \cdot \delta_{\max}}{\delta_{ij} + \tau \cdot \delta_{\max}} .$$

Thereinto, variable n refers to the number of indicators and variable τ for any $0<\tau<1$ is a parameter of the model. As to equation $\delta_{ij} = \left| x_{i,j} - x_{e,j} \right|$, it stands for the deviation between the ith strategy under the jth index and the value of demand flexibility for any i = 1, 2, …, m and j = O_1, O_2, …, N_5. We define $\delta_{\max} = \max\left\{\delta_{ij}\right\}$ as the maximum value for δ_{ij} and

$\delta_{\min} = \min\{\delta_{ij}\}$ as the minimum value for δ_{ij}. So the matching function is also can be written as:

$$\varphi_i = \frac{1}{n}\sum_{j=O_1}^{N_5} \frac{\delta_{\min} + \tau \cdot \delta_{\max}}{\delta_{ij} + \tau \cdot \delta_{\max}} = \frac{1}{n}\sum_{j=O_1}^{N_5} \frac{\min\{|x_{i,j} - x_{e,j}|\} + \tau \cdot \max\{|x_{i,j} - x_{e,j}|\}}{\{|x_{i,j} - x_{e,j}|\} + \tau \cdot \max\{|x_{i,j} - x_{e,j}|\}}.$$

Matching function φ_i for any $\varphi_i \in [0,1]$ represents the level how close potential flexibility possessed by ith strategy and demand flexibility of the supply chain to each other, which reflects the resilience of supply chain to respond to variable resources in the environment. The closer φ_i is to 1, the stronger resilience between the potential flexibility and the demand one. Therefore, when analyzing matching status, we should choose the strategy corresponded by the maximum value of matching function φ_i among all the strategies in acceptable range. We can assume warning coefficient $\psi \in (0,1)$, and if $\varphi_i \geq \psi$, it means that the potential flexibility is matched with the demand one, that is, the supply chain can deal with environmental uncertainty by means of strategy combinations or a selection of a set of strategies without changing the main structure of it, during which process the coordination among organizations in supply chain plays the key role--through the effective collaboration between enterprises in supply chain, limited use of certain resources can form a suitable strategy to respond to environmental changes. On the other hand, if $\varphi_i < \psi$, it indicates that the potential flexibility is not matched with the demand one, which means it can not cope with environmental changes. Then it is essential to use the dynamic ability of supply chain to reconstruct itself or reorganize resources for the sake of forming innovative flexibility to respond to environmental changes.

To synthesize the analysis above, we can select strategies and make decisions by means of judging the matching status between the level how uncertain the environment is and the potential and demand flexibilities, providing a theoretical basis of rationally allocating flexibility of supply chain.

5. Conclusion and recommendation

This article targeted at increasing environmental uncertainty faced with modern supply chain, which discussed about the characteristics of supply chain flexibility, evolution mechanisms, matching models and some other topics in this area. It is mainly shown as the following two aspects.

First, based on the analyzed content and characteristics of supply chain flexibility, we researched on the fundamental drivers and the essence of environmental uncertainty and then constructed its dimensions, namely, complexity, dynamicity and resource availability. On that basis, we analyzed the factors of supply chain environmental uncertainty which is the fundamental driven source of its flexibility. Furthermore, we investigated the impact of flexibility factors from two perspectives, motility and adaptability, in accordance with the characteristics of flexibility, which is the foundation of supply chain flexibility's generation and evolution. As to the formation mechanisms of supply chain flexibility, using previous studies for reference, we divided the various elements of supply chain flexibility into operation flexibility, information flexibility, logistics flexibility and robust network and reconstruction flexibility. Besides, we comprehensively analyzed the formation process of supply chain flexibility and the function and generation mechanism of core enterprises.

Secondly, in accordance with the characteristics of flexibility dynamicity, we made further exploration of the measurement and evolution of supply chain flexibility based on its generation mechanism. In this paper, we analyzed the evolution theory of supply chain flexibility from the point of view of theoretical framework, measurement methods and practical process. First of all, we constructed the dimension and comprehensive index system of it according to previous studies. Then on this basis, we made further investigation of its evolution mechanism, which discussed the principles and strategies of the evolution process and gave the evolutionary framework from the theoretical perspective. In the end, based on the theories and methods, we provided the specific process and matching models of supply chain flexibility under uncertain environment. With the help of matching models and judgment criteria, managers can make the appropriate adjustment, which can contribute to supply chain decisions.

Summing up the above, there are some recommendations in order to construct supply chain flexibility and improve performance:

1. To identify environmental uncertainty accurately
2. To enhance the communication and cooperation between enterprises in supply chain
3. To enhance the adaptability and coordination of supply chain resources
4. Raise awareness of flexibility

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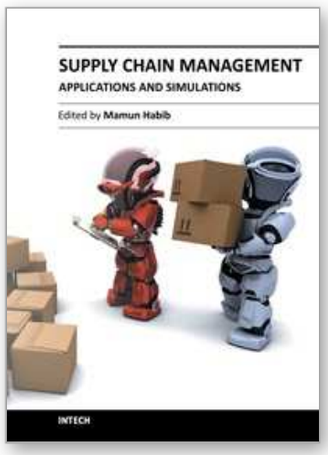

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Supply Chain Management (SCM) has been widely researched in numerous application domains during the last decade. Despite the popularity of SCM research and applications, considerable confusion remains as to its meaning. There are several attempts made by researchers and practitioners to appropriately define SCM. Amidst fierce competition in all industries, SCM has gradually been embraced as a proven managerial approach to achieving sustainable profits and growth. This book "Supply Chain Management - Applications and Simulations" is comprised of twelve chapters and has been divided into four sections. Section I contains the introductory chapter that represents theory and evolution of Supply Chain Management. This chapter highlights chronological prospective of SCM in terms of time frame in different areas of manufacturing and service industries. Section II comprised five chapters those are related to strategic and tactical issues in SCM. Section III encompasses four chapters that are relevant to project and technology issues in Supply Chain. Section IV consists of two chapters which are pertinent to risk managements in supply chain.

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