Energy Levels and Co-evolution of Product Innovation in Supply Chain Clusters

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Abstract. In the last decade supply chain clusters phenomenon has emerged as a new approach in product innovation studies. This article makes three contributions to the approach by addressing some open issues. The first contribution is to explicitly incorporate the energy levels in the analysis. Hence, the unit of analysis is widened from sectoral systems of innovation to socio-technical systems. Hence, the unit of analysis is widened from sectoral systems of innovation to socio-technical systems. The second contribution is to suggest an analytical distinction between different evolution method, actors involved in them, and the institutions which guide actor's perceptions and activities. Thirdly, the article opens up the black box of institutions, making them an integral part of supply chain. The article provides a coherent conceptual multi-level perspective, using insights from sociology, institutional theory and innovation studies. The perspective is particularly useful to analyze long-term dynamics supply chain clusters phenomenon, shifts from one energy level to another and the co-evolution of product innovation.

Keywords: Supply Chain Cluster, Wave-particle Duality, Quantum Jump, Co-evolution.

1 Introduction

Imitation or counterfeiting by bypassing the multi-year investment, enterprises can rapidly imitate products, using the reputation of original brand and marketing strategy to reap huge profits, it has become a strategic business model of the rapid development of enterprises [1]. Counterfeit Intelligence Bureau forecasted that global trade in 2008 accounted for 5% to 7% of counterfeiting products, the value of up to $600 billion. Counterfeiting products in Chinese market share are far more than the global average level, and local protectionism results in its large presence [2-3]. It cannot be denied that the short-term effects of counterfeiting is obvious, Chongqing Lijian Motorcycle Manufacture Co. for example, Honda motorcycle brand was imitated the "Hongda", but there are firms abusing the dominant market imitation strategy to pursue profits, or by lowering the product quality and technical content to reduce costs to ensure its survival in the highly competitive market environment, then result in the disruption of the normal order of market competition, and standardized-competitive conduct is

M. Zaman et al. (Eds.): CETS 2010, CCIS 113, pp. 140–158, 2010.

overwhelmed, product technical level is low, and the relative industrial upgrading is slow, with the inevitable impact on the country to promote innovative process.

Ecological/green-based product has become the construction key of a resource-saving and environment-friendly society. For example, the provision of pollutant emission standards indicate, enterprises which damage the natural environment will be punished, but the individual enterprise's environmental governing cost is high and its effect is limited, so we must from the whole supply chain environmental governing perspective to manage product innovation behaviors. In addition, Chinese counterfeiting products sold in the process of the world will face anti-dumping, patent protection and other multi-block, i.e., innovative enterprises usually have a variety of leading technologies and protected patents, with the international market standardization requirements and trade protection remounting, the counterfeiting product is difficult to occupy the global market and its security issues are concerned [3]. So, only through independent innovation, enterprises can gain the initiative competition in the global market. The modern enterprises in a supply chain or supply chain cluster need to actively build innovative networks, such as Dell's success is mainly due to its high efficiency throughout the value chain "network" efficiency [4]. The choice of product innovation in a supply chain and independent innovative model has become the core of the entire value chain as well as entering the world market, such as ZARA through continuous strengthening, consolidating, reengineering to reach the timely innovative capabilities to satisfy the customer demand and product innovation [5-6]. At the same time, innovation may also lead to destructive results [7-8]. Therefore, different energy-level control ability of product innovation cannot be ignored, i.e., the imbalance of innovation capacity and control ability is the reason that enterprise from the bloom to doom, as well as the loss of the root cause of vitality.

The idea of using the supply chain concept as a normative model to improve firm behavior and thus ultimately industrial innovation through the development of supply chain cluster (SCC) or integrated supply chains has been discussed since the late 1990s [9], a SCC is a geographically concentrated, self-flourishing ecosystem, including production systems. Shippers, logistics service providers, IT vendors, infrastructure providers, regulatory agencies, research institutions, consultants and other logistics-related organizations that leverage on the inter-dependencies between them, provide efficient and effective logistics solutions and create innovative new solutions. Reference [10] analyzed that simultaneous development of the SCC is possible with planning and aggressive marketing to attract multi-national companies in manufacturing and third-party logistics providers. This is important since they bring with their global experiences and also gain economies of scale. Additionally, while the supply chain process integrates all activities from product innovation to sales of a product, the integration of the service phase, physically, informationally and organizationally, with the rest of the supply chain is an emerging trend. So, a SCC is a geographically concentrated, self-flourishing ecosystem, including Shippers, Suppliers, Logistics Service Providers, IT Vendors, Infrastructure Providers of land, sea and air logistics facilities, Financial Institutions, Regulatory Agencies, Research Institutions, Consultants and other logistics-related organizations that leverages on the interdependencies between them, provide highly efficient and effective logistics

solutions and create innovative new solutions. It is easy to see, a SCC almost covers all activities of society, such as “a small society”. Therefore, using by such system can improve competitiveness through linkages and integration within a cluster, as well as between industrial clusters. A SCC system consists in one or more parallel single supply chains in the agglomeration location, not only presents all enterprises in one single supply chain cooperate with one another internally, but cooperation and coordination exists across different supply chains externally too [11]. Reference [10] showed India should proactively attract investments by following the SCC paradigm where all the stakeholders in the supply chain such as manufacturers, logistics providers, financial institutions, and so on are collocated in the region creating a value chain of excellence which is difficult to replicate. New technologies adoption in a cluster often has the nature of increasing returns , because of some reasons, new technologies are usually the dominant position with the virtue of pre-emptive to lower unit costs, reach learning effects and coordinated effects, then result in popularity in the market, thereby to achieve self-reinforcing virtuous cycle in the cluster; on the contrary, one better technology because of delay introduced into market, it might be trapped in a vicious cycle, or even "Lock-in" in some invalid state. Reference [12] argued that the self-reinforcing phenomenon for the technicalogical evolution to extended to the institutional change aspects, which established the path-dependent theory of the institutional changes. The core content of the theory is that path dependence has the objective rule, the operation mechanism can be summarized in the given conditions, activating mechanism, setup state, out of lock-in and so on process. From product innovation development, energy level of product innovation has an evolution process as well as human beings recognition on the environment and the evolution of the supply chain [9]. Based on the existing research, the energy level jump mechanism of product innovation, and energy level evolution of product innovation in supply chain and other issues have not been studied.

The structure of this paper is organized as follows: the “wave-particle duality” used in a SCC is discussed, product innovation energy levels based on quantum jump theory in a SCC are presented, mechanism and model of new product innovation in a SCC are reflected in section 2; the co-evolution models are presented in section 3 to analyze the stability of the system; a case study proves our conclusions is in section 4; In the last section, some conclusions and open problems are given.

2 Product Innovation Energy Level Based on Quantum Jump

2.1 Wave-Particle Duality of A SCC

In allusion to the dispute for light is “wave” or “particle” has lasted out more than 300 years, since “wave theory” and “particle theory” of light is opposite, the final result ascribes light is neither wave nor particle, and is the substance of wave and particle with duality properties. If we call “a SCC” is “wave-motion”, and supply chains or enterprise cluster are “particle-motion”, then separation of a SCC and supply chains or enterprises is similar to antinomy for light is wave or particle on earth. The wave-motion of a SCC means that different node enterprises integrated result. There

are two describing variables for "wave-motion", i.e., "nodes" and "nodes centralized degree". With more the social division fine, more complicated and length the supply chain is. Essence of the SCC's wave-motion is that process of "explicit transmission" of the tangible semifinished product and "implicit transmission" of the intangible assets (e.g., information, brand, knowledge), which transmission scope is between semifinished product market and final product market or within SCC, as well as it is the process of supply chain innovation and value realization. In such transmission process, there exists the definite fluctuation like as "wave-motion" among every SCC's nodes, so the SCC can be described as "wave-motion". Otherwise, the organizational model of a supply chain cluster is a network structure formed by upstream and downstream correlative enterprises, every supply chain or enterprise is just like as a "particle" in a SCC. There are two describing variables for "particle-motion", i.e., "node position" and "innovation ability". Enterprises often are changing in a supply chain's node position, thus results in every supply chain is changing, as well as the SCC. And enterprises whether or not find, search, hold or change their node position to reach "robustness" of the SCC, which entirely depends on their innovation ability. Movement or determination of the node position together with magnitude of innovation ability, are closely relative to cooperation and competitive competence of a SCC. Therefore, the "particle-motion" denotes the integration competence of different enterprises along with supply chains.

In quantum physics, "quantum particle" and "quantum wave" is uniform, quantum of particle must depends on "wave-motion", and quantum of wave must depends on "particle-motion" too [13]. In fact, "wave-motion" and "particle-motion" in a SCC is uniform. "Particle-motion" indicates the production innovation of a SCC or enterprises is the drive of the cluster innovation and value actualization. The "wave-particle duality" of a SCC shows the cluster is an organization by way of social division and the division coordination to come true, which is integration of supply chains and enterprise cluster, to implement the effective disposition resources and operation in the SCC, and ensure division and collaboration favoringly. Based on the quantum physics, the Bohr atomic model has three hypotheses, i.e., energy level, jump and orbit. Correspondingly, the Bohr atomic model of a SCC also has three hypotheses as follows: (1) Energy level. Supply chains or enterprises in a SCC always are in a series of discontinuous innovative states, synchronously the product in a supply chain or its enterprises is in a series of discontinuous value state too, such case is called stationary state. Transformation from one state to another often needs definite energy, so this will engenders different energy levels. (2) Jump. Transformation of different supply chains, different enterprises or different products from one stationary state to another usually needs definite energy, in order to offset their shortage of technical and innovative competence, so this likes as jump. At the same time, the process of increasing or decreasing value likes as jump too. (3) Orbit. What is called orbit means nodes of a SCC. There exists energy of technical innovation and difference value among the nodes of a SCC, those nodes often are discontinuous. Therefore, the meaning of the model is interpreted as follows: (i) Nucleus can denote the final product supply chains or enterprises. In Bohr atomic model, proton and neutron likes as the final product supply chain or enterprises in a

SCC, there usually exists a large number of proton and neutron in the cluster. (ii) Electron can show the matching enterprise, core enterprise even supply chain or the cluster bottleneck. In a SCC, electrons located in orbit are semifinished product supply chains, enterprises or matching enterprises, which they are situated in the cluster's nodes. A node may has many enterprises, which form the different multi-level supply chains, and a SCC can be regarded as the dynamic network formed by several multi-level supply chains. (iii) Orbit can denote chain, node or matching radius. Orbit in a SCC likes as nodes of the cluster. Based in the differences of the distance from these orbits to nucleus, they in turn can hanger together from far till close to form the SCC. Since nodes often are located in different positions of the SCC, if technical innovation competence is stronger and value-added is greater, the "energy level" is higher. (iv) "Quantum jump" can denote displacement of the semi-finished product. The semi-finished product between node orbits can move via logistics activities namely "quantum jump". "Quantum jump" shows semi-finished product along its SCC to pursue consummate continuously, transmission often is from low-node (far from the final enterprise) to high-node (close to the final enterprise), then the cluster can implement the whole "jump" process from product innovation to production then to consumption. In nature, the "quantum jump" process is process of innovation and value-added in a SCC.

2.2 "Entanglement of Quantum" and "Quantum Jump" in A SCC

In the quantum physics, "entanglement of quantum" shows a phenomenon, i.e., whether how far two particles, one particle's change will affect another, they are interactional radically [14]. There is a special "entanglement of quantum" phenomenon in a SCC, whether government or enterprises themselves, only encircle some of enterprises like as "entanglement of quantum", they can foster and optimize the cluster. "Entanglement of quantum" indicates the relationship between supply chains, supply chain and enterprises or enterprises, which they are neither the entire independent market transaction relations, nor the relative close interior relations within the cluster, and is a "keep it at an arm's length" entanglement relation, such relation shows change of one supply chain or a enterprise must affect other supply chains or enterprises even the cluster, thus forming "entanglement of quantum". Change in "entanglement of quantum" incarnates the change of "quantum state". In the quantum physics, "quantum state" denotes the state of particles (such as atom, neutron, proton), can represent energy, rotation, motion, magnetic field of particles and other physical characteristics [13]. "Quantum state" in a SCC can present the state of "implicit knowledge" in supply chains or enterprises. Implicit knowledge is the supply chains or enterprises own knowledge, technology, brand, information etc. In the quantum physics, studying on "entanglement of quantum" aims to reach "implicit transmission" of quantum information. So, the objective of studying on the SCC to actualize "implicit transmission" of quantum states of supply chains or enterprises. What is called "implicit transmission" that shows just to transmit the carriers (semifinished product or product) of technology, information, brand, value etc., instead of themselves. In the SCC, the objective of "entanglement of quantum"

in supply chains or enterprises is to implement "implicit transmission" of technology, band and so on. The external form of the SCC is the "explicit transmission" of semi-finished product, and the internal form is the "implicit transmission" of implicit knowledge. In addition, with the increase of the production factor price and global extension of supply chain, the government must understand its role (service, coordination or support), if it blindly issues some preferential policies, the SCC will be difficult to develop and optimize. Apparently, using by government's preferential policies to attract enterprises, the ultimate goal is to promote the formation of "entanglement of quantum" among supply chains or enterprises. In this way, a perfect SCC can be built only according to the requirements of "entanglement of quantum", Otherwise the cluster relationship will not stable for long.

In the quantum physics, in order to carry out long-distance quantum cryptography communication or quantum state implicit transmission, we must allow long-distance particles together with short-distance particles can hold maximal "quantum entanglement state" [14]. Similarly, in a SCC, we must try hard to impel the "quantum entanglement state" formed among supply chains and enterprises, i.e., such that "quantum state" presents entanglement state. In addition, the influence of technical standards to the SCC is self-evident, once a technical standard changes, supply chains or enterprises in the SCC will change to fit a new standard. The process of constituting standard is the process of "quantum entanglement state" formed. And the process of implementing technical standards is the process of SCC formed via the standard or implicit knowledge transmission. For example, Microsoft Inc. always perseveres in innovation over time. In fact, the technical innovative process is the process of "quantum entanglement state", once the "quantum entanglement state" engendered, it will drive other supply chains or enterprises change virtually, the "entanglement of quantum" will appear, then results in further integration of the "explicit transmission" of Microsoft Inc. and the cluster. In the quantum physics, because there are diversified unavoidable environmental noises in the communication channel, the quality of the "quantum entanglement state" will decrease as the transmission distance increase [15]. In a SCC, the quality of "entanglement of quantum" among supply chains and enterprise also decreases as their distance increase and environmental noises. In fact, many reasons can cause the environmental noise of the SCC, such as the social economic environment, business strategies, matching model of enterprises etc. Therefore, keeping the "quantum entanglement state" and achieving "quantum jump" are correlative important to the SCC. The process of "quantum jump" is the process of the "quantum entanglement state" maintenance.

2.3 Quantum Energy Level Theory for New Product Innovation

By using "energy levels of quantum jump", we can analyze the innovative mechanisms in a SCC. The product innovation has the following theory assumption of quantum energy levels: (1)The product innovation in members of a supply chain reflects characteristics that is interrupted by non-consecutive, the long-term, gradual change; (2) the contribution and effect of product innovation on a particular subject can be characterized by the concept of innovation energy levels; (3) Differences exists

in the innovation energy-level of different participants of product innovation in the supply chain, the core enterprises are often the dominant, other members can adjust behaviors based on the comprehensive effect of environmental factors and internal mechanism; (4) Innovative state owned by individual member at a time in the supply chain has the quantum state, "uncertainty" but with a statistical expression; (5) The influence of quantum innovation on each other also has quantum state, which can be characterized through transitions of discrete energy levels. Therefore, the product innovation in a supply chain will be expressed into a four-phase of the quantum innovation model.

Phase I: Product innovation is in quantum shock-storage phase. In this phase, the relationship among supply chain members is dynamic, the coordination capability among the member enterprises is poor, interruption frequently occurs in the chain, the supply chain strategy is essentially a niche-oriented; Product innovation in the supply chain are mostly counterfeiting, mainly no cost of product innovation, and environmental awareness considered in product innovation is almost zero (the position I is shown in Figure 1), the chain belongs to the counterfeit product supply chain, energy level of product innovation is in small shocks and stable state, there is no significant energy-level jump in product innovation from macro-level, the main task of product innovation is dominated by a single core enterprise, information sharing of product innovation is low, R&D level is low, primarily depends on resources, mainly through the cognition of new products on the market and the accumulation of historical product knowledge, imitation is introduced into their own supply chain, the product innovation aims to maximize the overall benefit and market share rate; From the appearance, each firm joining the supply chain, reflects varying degrees of cooperation and innovation, but from the effect and efficiency, product innovation is relatively low-level imitation, a considerable of members do not really understand the innovation, of course, they are difficult to adapt to innovative behavior. This phase is widespread early in 1990s in China, industrial development is immature, most products are non-brand, the operation of SMEs are reflected OEM or OAM fashion, the product is often from OEM or even purely by taking the counterfeiting or low-level road.

Phase II: Innovation energy level of quantum starts jump. In this phase, supply chain strategy is still niche-oriented together with quality-driven, the coordination of members in the supply chain starts to enhance; product innovation begins to focus on the upstream and downstream cooperation, mainly prior to the integration of the forward supply chain and part of the reverse supply chain, not only through counterfeiting or original counterfeiting innovation to produce quality reliable products, but also by tracking innovation and independent innovation, begin to pay attention to the conduction effects of customer participation, experience and service in the product supply chain, innovation costs begin to increase, however the product innovation process often do not consider the product recovery and remanufacturing, with a larger external negative effects on the environment; The technological level in product innovation is still low, depends on resources all the same, but a greater energy level jump appears, industrial clusters have begun to emerge, began to adjust to each

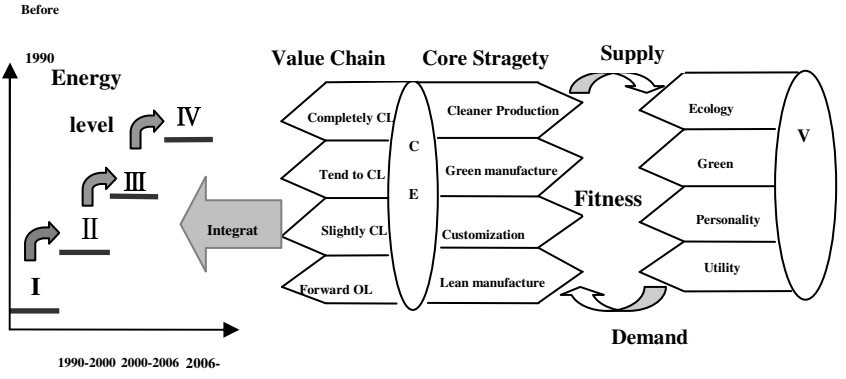

Fig. 1. Energy levels of quantum innovation (where E denotes energy, CE means the core enterprise, V denotes the customer value)

other adaptive behavior (transition process from I to II in the Figure 1). As the level of coordinative innovation understanding increasing, coordination apperception with other mechanisms result greater energy-level jump in the supply chain in innovation process, innovative knowledge has been gradually formed networking, with the innovative smart of "comprehend by analogy", the members as a whole takes on a clear innovative effects, there are some innovation product brands with high quality at home and abroad. In China, this stage is mainly reflected from 1990 to 2000.

Each member in the supply chain digests and absorbs the accumulated external knowledge from phase I, changing its own innovation tacit knowledge, where parts of the "tacit knowledge" will be continued to ferment in their minds, constantly generating new ideas, and strengthening their internal knowledge networks, so as to promote collaborative innovation; the other parts which are based on market-driven mechanism through improving customer satisfaction, building brand, to enhance the core competitiveness etc. The knowledge will be shared with other members through the network or the public, and organization communication, thus further stimulating the innovation networking and regeneration of their own and others. As a result, the adaptive behavior of each member enterprise together to form a positive feedback loops to promote continuous innovation and innovation energy-level jump.

Phase III: The quantum state of innovation energy-level belongs to relative steady-state higher phase. Along with environmental concerns, green supply chain appears, green product innovation strategy becomes one of the Government strategy, innovation energy level is relatively stable, innovation activities are mainly related to the whole forward supply chains and most reverse supply chains, not only focus on innovation and discontinuous conduction effect for customer participation, experience and service in the product supply chain, but begins to focus on the environmental governance among various members in the supply chain. Although the green supply chain management focuses on waste products and packaging recycling etc., but the consideration of reusing waste and energy is relatively lack. This phase is collaborative innovation decision-making stage or to adapt to the environment

behavior process, cost of product innovation is in increasing trend (higher energy state represented III in Figure 1). Each member in the supply chain has a stable internal control mechanism, the initiative social responsibility become the main objective of product innovation, the innovation emergence period is a non-steady-state process, each member must adjust their behavior to adapt to changes of the environment, to implement the environmental governance as feasible as possible, and therefore such behavior tends to close to their preliminary environmental adaptation, and the organizational structure tends to the closed-loop. This phase is from 2000 to 2006 in China, the supply chain strategy towards value-oriented or environment-driven, energy-level jump of product innovation is not so clear as it from I phase to II phase, but the recognition of corporate social responsibility is the appropriate motivation of organizational innovation decision-making. Environmental consciousness innovation begins to encourage each member to conclude their own innovation experiences and adjust their behavioral process, while other kinds of green products theory, Government environmental regulation (e.g., WEEE) etc. are also actively pushing the outcome of the entire innovation process to change as much as possible into supply chain knowledge database for a long-term sharing in supply chain members.

Phase IV: The quantum innovation energy-level belongs to most steady-state phase. Since 2006, environmental management and industrial ecology concepts have been blended into the supply chain, then formed the highest energy-level, i.e., ecological supply chain (ESC), involving the complete closed-loop system formed by entire forward supply chain and the reverse supply chain. A ESC uses the basic principles of industrial ecology and recycling economic thought, modeling on natural ecological processes in the materials closed-loop flow and material echelons, not only concern the cost savings and internal business environment improvement and product innovation, but also give full consideration to the impact on the environment from manufacturing to distribution process, as well as how to deal with waste and emissions, recycling and reusing and so on, eliminating the external diseconomies caused by environmental pollution. The main work of product innovation in this phase is modeling on natural ecological processes reflect the innovative products of naturalization, resources refining technology, human nature (IV is shown in Figure1), supply chain strategy is toward value-oriented and ecology-driven. As with the scarcity and timeliness of social resources, as time goes on, the impact of new technologies will enable product innovation to comply with the limited nature operation. There is harmonious co-existence relationship between human and nature, the importance of innovation in the supply chain is concerned that the timeliness and reduce external diseconomies, and innovation product factors are directly proportional to zero pollution. On the other hand, only the ecological concept is applied borderless, full closed-loop operation, ecological innovative products and people, nature or enterprises can be harmonious coexistence, so the efficient evolvement of supply chain can be guaranteed. Eco-products have gradually become geared to the demand of consumers, the supply chain cluster is also contributing to the ecological operation of product innovation.

3 Co-evolution Models

Cluster supply chain is the coupling body of supply chains and industry clusters, which formed by a complete or relatively completes network-based supply chain system in the same industry cluster, the external performance has the network characteristics of industrial cluster, but also has the organizational structure of supply chain characteristics. In this system, the horizontal scale has a complete supply chain structure system from suppliers to manufacturers, distributors and end customers; the vertical scale has the highly developed division of labor and cooperation among enterprises. If the supply chains lack collaborative innovation characteristics, the enterprises in the cluster will produce homogeneous, non-differentiated products, eventually lead to vicious competition among enterprises; if no cluster features of eco-innovation networks in the cluster, supply chain organizations will because only cooperation but not of competition were eventually reduced to the low efficiency of the organization, i.e., the system refers to in the form of the composition interrelated, co-evolved continuum, which is formed in a particular space, the economic, social and ecological environment related enterprises or organizations by means of material flow, energy flow, capital flow, information flow and knowledge flow.

According to the similarity of cluster and ecosystem, co-evolution in cluster members of the ecosystem refelects inter-firm competition, cooperation, parasitism, predators and prey models to promote product innovation energy level transition, This co-evolution depends not only on cash flow, material flow, energy flow, but also depends on the information flow, knowledge flow (Jouni Korhonena et al., 2004). The ecosystem development of the supply chain cluster complies with Logistic model. Co-evolution shows that any supply chain in cluster can affect the maximum output level of another chain, considering there are two supply chains in the cluster, and then we have:

$$\dot{x}_i = r_i x_i \left(1 - \frac{x_i}{N_i + \omega_i(x_j)} \right), i \neq j, i, j = 1,2 \ . \tag{1}$$

Where x_i denotes that the level of innovation output for i supply chain is a function of time t, i.e., with t change, the level of output subjects to their own resources, access to information, innovation ability, innovation cost and other changes; $\dot{x}_i$ denotes the change rate of output level at per unit time for i supply chain; r_i is the growth rate of output level under full use of a variety of resources for i supply chain, with the continuously raising the level of output it declines and ultimately tends to zero; N_i is the limiting value of output level for i supply chain, i.e., the maximum level of output under full use of all resources; When i supply chain subjects to the impact of j supply chain, with expressed by $N_i + \omega(x_j)$, $\omega(x_j)$ means the effect or earning or loss of i supply chain by j supply chain.

When there is competitive co-evolution between the supply chains in the cluster, according to Gause's competitive exclusion theory, two species occupy the same

niche will be bound to happen fierce competition (F. Ge, 2002). In the cluster system, the supply chains occupied similar ecological niche to obtain more resources or market shares, they compete with each other, the follow reflects:

$$\begin{cases} \dot{x}_1 = r_1 x_1 \left(1 - \dfrac{x_1}{N_1 - \alpha_1 x_2}\right) \\ \dot{x}_2 = r_2 x_2 \left(1 - \dfrac{x_2}{N_2 - \alpha_2 x_1}\right) \end{cases} \tag{2}$$

Where $\alpha_1, \alpha_2 > 0$, because of competition, negative α_1, α_2 means supply chain B can inhibit level of innovation output in suplly chain A; and vice versa. Equation (2) has four equilibrium points: $E_1(0,0), E_2(0, N_2), E_3(N_1, 0), E_4\left(\dfrac{N_1 - \alpha_1 N_2}{1 - \alpha_1 \alpha_2}, \dfrac{N_2 - \alpha_2 N_1}{1 - \alpha_1 \alpha_2}\right)$. Suppose the impact on the competition evenly matched between two supply chains, i.e., $\alpha_1 = \alpha_2$. Then, the stable point is $S_1\left(\dfrac{N_1 - \alpha_1 N_2}{1 - \alpha_1 \alpha_2}, \dfrac{N_2 - \alpha_2 N_1}{1 - \alpha_1 \alpha_2}\right)$, and the stability condition satisfies $\alpha_1 \alpha_2 < 1, \alpha_1 < \dfrac{N_1}{N_2}, \alpha_2 < \dfrac{N_2}{N_1}$. To describe the interaction co-evolution between the supply chains, using by non-dimensional transformation, assume that $x_1 = N_1 \omega_1, x_2 = N_2 \omega_2, t = \dfrac{\tau}{r_1}$, and take the initial values $x_1^0 = 0.25, x_2^0 = 0.75, \alpha_1 = \alpha_2 = 0.35$, based on the simulation analysis (see Figure 2), we can see under the impact in the competition factors being equal and less than 1 (weak fair competition), two competing supply chains will eventually tend to a stable point, that point is less than $\min(N_1, N_2)$. Therefore, co-evolution of competition limits the largest level of output of two supply chains.

When there is the cooperative co-evolution between two supply chains in the cluster, for example, in the cluster there is research and development, sharing of technologies etc. The cluster can improve technological innovation to enhance production efficiency, thus promote the rapid development of the cluster, the cooperative co-evolution model follows:

$$\begin{cases} \dot{x}_1 = r_1 x_1 \left(1 - \dfrac{x_1}{N_1 + \alpha_1 x_2}\right) \\ \dot{x}_2 = r_2 x_2 \left(1 - \dfrac{x_2}{N_2 + \alpha_2 x_1}\right) \end{cases} \tag{3}$$

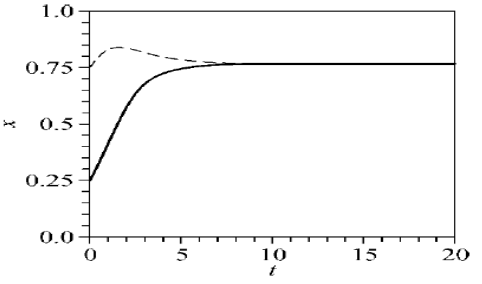

Fig. 2. The co-evolution between the competitive supply chains

Where positive α_1, α_2 means that in cooperative period, which will co-promote growth of innovation output level for two supply chains; and vice versa. Equation (3) has four equilibrium points: $E_1(0,0), E_2(0,N_2), E_3(N_1,0), E_4'\left(\frac{N_1+\alpha_1 N_2}{1-\alpha_1\alpha_2}, \frac{N_2+\alpha_2 N_1}{1-\alpha_1\alpha_2}\right)$, and the stable point is $S_2\left(\frac{N_1+\alpha_1 N_2}{1-\alpha_1\alpha_2}, \frac{N_2+\alpha_2 N_1}{1-\alpha_1\alpha_2}\right)$. Choosing the initial value $x_1^0 = 0.25, x_2^0 = 0.75, \alpha_1 = 0.15, \alpha_2 = 0.85$, using by the simulation analysis (see Figure 3), it is easy to see the final stable point of two supply chains is greater than $\max(N_1, N_2)$, therefore, cooperation is conducive to improving the innovation output capacity of two supply chains.

When co-evolution of the cluster exists wandering relations, wandering relation refers to the level of innovation output for some wandering enterprises depends on the supply chains in the cluster, while the latter level of output without much relationship with the former, the former is called wandering enterprise, The latter can be called the host supply chain, there is the following co-evolution model:

$$\begin{cases} \dot{x}_1 = r_1 x_1\left(1-\dfrac{x_1}{N_1+\alpha x_2}\right) \\ \dot{x}_2 = r_2 x_2\left(1-\dfrac{x_2}{N_2}\right) \end{cases} \tag{4}$$

Where α is influencing factor for the host supply chain impact on the wandering enterprises, considering the latter little effects on the level of innovation output of the former, it can be negligible, equation (4) has four equilibrium points $E_1(0,0), E_2(0,N_2), E_3(N_1,0), E_4''(N_1+\alpha_1 N_2, N_2)$, and the stable point

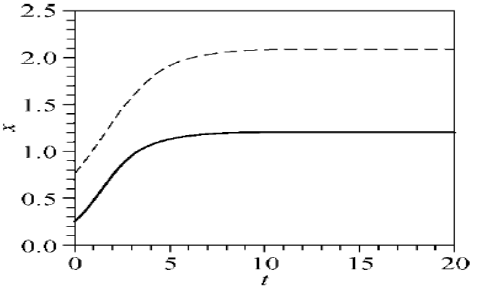

Fig. 3. The co-evolution between the cooperative supply chains

is $S_3(N_1+\alpha_1 N_2, N_2)$. Choosing the initial value $x_1^0=0.25, x_2^0=0.75, \alpha=0.4$, using by of simulation analysis (see Figure 4), it can be seen that the level of innovation output for the wandering enterprise x_1 increases with α increases, and the final stable point exceeds its maximum output level N_1, which may develop into a supporting enterprise of the host Supply Chain; and when the host supply chain x_2 keeps alone development, it reaches the maximum output N_2. The wandering relation reflects without prejudice to the host supply chain development circumstances. It can promote the wandering enterprise development.

When there is predator-prey co-evolution in the cluster, usually reflect the cluster to achieve further development among the core enterprise and the supporting auxiliary enterprises through mergers or "eating into the market", the co-evolution model is as follows:

$$\begin{cases} \dot{x}_1 = r_1 x_1\left(1-\dfrac{x_1}{N_1-\alpha_1 x_2}\right) \\ \dot{x}_2 = r_2 x_2\left(1-\dfrac{x_2}{N_2+\alpha_2 x_1}\right) \end{cases} \tag{5}$$

Where x_1, x_2 are the prey and predator enterprise, respectively, negative α_1 means a predator will impact on a prey enterprise, which can inhibit the latter's level of innovation output, positive α_2 means a prey enterprise will impact on a predator enterprise, which can promote the predator enterprise to increase the level of innovation output. Equation (5) has four equilibrium points: $E_1(0,0), E_2(0,N_2), E_3(N_1,0), E_4'''\left(\dfrac{N_1-\alpha_1 N_2}{1-\alpha_1\alpha_2}, \dfrac{N_2+\alpha_2 N_1}{1-\alpha_1\alpha_2}\right)$,

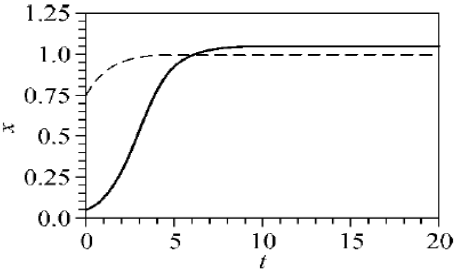

Fig. 4. The co-evolution between the host supply chain and wandering enterprises

and the stable point is $S_4\left(\frac{N_1-\alpha_1 N_2}{1-\alpha_1\alpha_2},\frac{N_2+\alpha_2 N_1}{1-\alpha_1\alpha_2}\right)$. Choosing the initial value $x_1^0=0.25, x_2^0=0.75, \alpha_1=0.8, \alpha_2=0.2$, using by simulation analysis (see Figure 5), it can be seen that the level of innovation output of predator enterprise is greater than the maximum value of its individual development, while the level of innovation output of the prey enterprise is less than the maximum value of its individual development, and may eventually become bankrupt, i.e., the predation model can be conducive to large enterprise merge small and medium enterprises and enhance the status of core enterprise in the cluster.

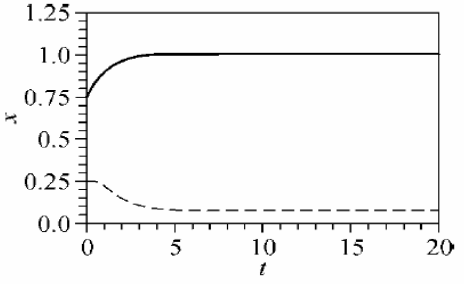

Fig. 5. The co-evolution between predator and prey

4 Case Study-Guitang Group

As the largest stock company in the Guigang city of Guangxi province in China, Guangxi Guitang Group (GTG) was established in 1954 to produce cane sugar initially. Today it is the largest sugar-making company in China which has several other industrial enterprises, such as a pulp-making plant, an alcohol plant, a cement mill and a fertilizer plant together with forming an ecological supply chain cluster,

which is a single centralized SCC. The annual total production includes sugar (120,000 tons), paper (85,000 tons), alcohol (10,000 tons), cement (330,000 tons) and fertilizer (30,000 tons) so on (Zhu and Cote , 2004). All these plants are based on by-products generated from the sugar refinery.

The sugar industry has been a major polluter, especially in China, as most the refineries with a small scale can not meet the existing environmental standards. In fact, GTG development path in line with the above-mentioned energy-level jump phase of product innovation in its supply chain. Since "National Eco-industrial (sugar) Demonstration Park-Guigang" project was approved, which is first large-scale enterprises as a leading eco-industrial park construction plan. Nowadays, GTG sugar product innovation has achieved conversion of industrial pollution prevention from the end governance to the whole process control. Through these years development, GTG has formed the circular economical rudiment, and built a circular product innovation system in which product involves sugar, manufacturing paper, alcohol, light calcium carbonate etc., sugar production is generated by bagasse, molasses, filter mud and other waste after proper processing, all achieved overall recycling, waste utilization rate of 100% and the comprehensive utilization of products have been much higher than sucrose value of the main product. It is leading domestic level that has enjoyed a number of independent intellectual property rights with environmental protection leading domestic level. GTG product innovation attaches great importance to cleaner production, putting in a lot of special funds for environmental protection, widely utilized new environmental technologies and new techniques and new equipment, with emphasis on comprehensive governing the emission of slop, waste water recycling, flue gas desulfurization etc., the use of high-tech and advanced applicable technologies to transform traditional industries, and constantly enhance the efficient use of resources and environment protection. To reduce resource consumption and environmental pollution, the sugar production innovation based on GTG is established to recycle these product wastes and returns from the end of pipe to gain simultaneously economical, environmental, and social benefits. Initially, the SCC was built within GTG and slowly extended to external firms. Now the sugar ecological SCC consists of an agriculturally ecological farm, a sugar refinery, sugar distributors and retailers and other firms acting as the reclaiming agents. Reclaiming agents include an alcohol-processing plant, a compound-fertilizer plant, a pulp plant, a thermoelectricity plant, a cement mill and other recyclers. The Figure 6 shows three main innovation production flows in the ecological SCC model: (1) the forward product flow from sugarcane farmers to end users, (2) the reverse supply chain from customers to suppliers. Some returns from consumers are processed within the sugar refinery, some useless wastes are send to recyclers, such as water recovering plant.(3) the by-products flow from sugar refinery to reclaiming agents, in which the by-products generated by the sugar refinery are reused.

In order to optimize the environmental and economic performance of the whole network of companies within GTG, GTG complied with the ecological design principles to develop new technologies, optimized the production processing and adopted ecological management. Within the sugar chain, three innovation approaches can be seen to treat the residual products, i.e., reuse, volume reduction and disposal.

By-products such as sugar slag, spent molasses and filter sludge, become the raw material of the pulp plant, the alcohol plant and the cement mill separately to produce pulp, alcohol and cement. The by-products of alcohol plant, residual alcohol can also be reused by the fertilizer plant to produce compound fertilizer that is sold to the raw material producer, the sugarcane farmers. To reduce the amount of residual products, cleaner production technologies are employed. And new technologies to improve water efficiency are developed, which is expected to reduce the wastewater between 30% and 40%. As other by-products produced during sugar refinery which are the most severe pollution problems for the sugar industry, GTG has collected them, and began to use them as raw materials. In addition, the sugar refinery sent sugar slag to the thermoelectricity plant, and the reverse flow is electricity and vapor. The recycle resources from the recyclers, such as water, are also sent reversely to sugar refinery. Hence, there are some recycling flows in the sugar ecological SCC, which not only minimize the damage to environment, and maximize the utilization of resource, but also improve the whole SCC financial performance.

GTG product innovation also maintains close relationships with his primary suppliers, the sugarcane farmers. As mentioned above, GTG sells the fertilizer produced from residual products back to the farmers. Thus, the chemical fertilizer which can decrease the quality of sugarcane is avoided to be used by farmers. In addition, GTG gives technological and financial supports to farmers to improve the quality of sugarcane and resolve the production problems, encourage them to develop scale economics. The long-term contract with farmers also ensures the quantity of sugarcane and the benefit of farmers. All these efforts make innovation product

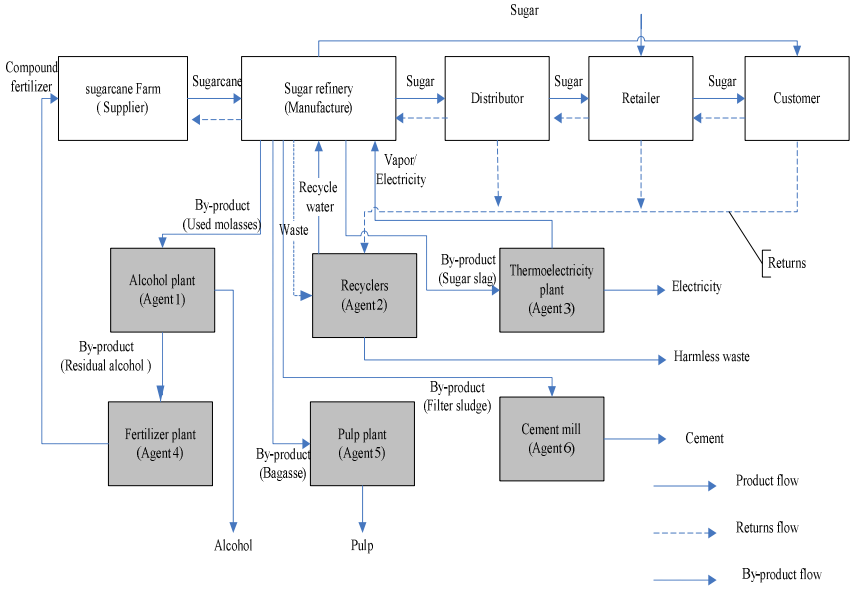

Fig. 6. The innovation production flow of Guangxi Guitang Group

(sugar) with a high quality and a low cost, which increase the competitive advantage of sugar in the international market. At the same time, GTG has worked on establishing better relationships with their customers. GTG produces the best quality sugar in China according to color, sulfur and impurity content, and thus sharing a large market. Its average sugar price was between 30% and 35% higher than that made by other Chinese sugar refineries because of good quality.

By taking full advantages of by-products and product following innovation in an environmentally, socially and economically responsible manner, GTG has realized multi-win of human, nature and society. In the product innovation of GTG, it considers traditional 'waste' as resources, which reduce the material cost. Besides ensuring cooperation of upstream and downstream, the ecological SCC also helps GTG to decrease the transaction costs arising from interactions within different members in the SCC. They can share updated information and easily establish cooperative relationships. As a result, some transaction costs are reduced. Since all sugarcane is produced by the farmers in the Guigang city, GTG can also benefits from the low transportation cost. Coca-Cola and Pepsi-Cola who used to purchase sugar from other countries have established joint ventures in China, now begin to buy sugar from GTG. Many domestic soft drink companies such as the Wahaha Group buy sugar only from GTG. The key reason is that the sulfur content in the sugar made by GTG is lower than that made by other Chinese sugar plants. This is due to improved environmental technologies developed by GTG and the resulting higher quality of "green" product. Barrier related to information dissemination and communication is the key obstacles to ensure the effective ecological innovation of the supply chains. Fortunately, in our case, most enterprises in the SCC are linked tightly around GTG, which facilitates communication among the members.

The government and employees of GTG also can benefit from the ecological SCC innovation management, as they can get more revenue and salary. The problem of lacking water resource has been resolved and the quality of water from the rivers is ensured as a result of by-products reusing. Similarly air quality is improved as most CO_2 and other toxic gases are processed. The rapid development of the firms in the sugar SCC drives the development of the relate service industry and increases the job opportunity and the living level of local people. Therefore, GTG can keep the "quantum entanglement state" and promote "quantum jump", and institutional arrangement on division in such SCC is integrating continuously, GTG has made progress both economically and environmentally while most sugar companies in China are still struggling for survival.

5 Conclusions

Based on the physical theory and the wave-particle duality, a SCC is the special organization whose characteristic is wave-particle duality. The product innovation energy levels based on quantum jump theory is analyzed. We discuss mechanism and model of new product innovation in a SCC. By constructing the co-evolution models, the stability of the system is analyzed. Finally, a case study proves our conclusions.

There are some open problems include: how to determine new product innovation matching model based on innovation energy levels in a supply chain? What is the relationship between cost of product innovation and innovation energy levels? What is the relationship between product innovation energy levels and the compensation mechanism of government and enterprises? What are compensation options for ecological consumption? Whether there is isomorphic relationship among Product creations, ecological innovation and zero pollution production? What mechanism is forward and reverse coordination under reverse Engineering? What is co-opetition mechanism in the ecological homotopy innovation?

Acknowledgment

This work is supported by the National Natural Science Foundation project "A study on in continuous innovation energy level based on the product supply chain" (70971111) and Natural Science Foundation of Fujian Province project "Logistics security mechanism for emergency management research in Fujian Province".

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