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Understanding Industrial Innovation and Upgrade from Modularization's Perspective[1]

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In the era of globalization and information technology, modularization is an approach to solve economic system complexity and the essence of new industrial structure. The source of industrial innovation comes from technology and organization modularization and system integration. Industrial upgrade takes effect through interaction of the following factors: competition of modular firms, knowledge creation, knowledge flow, modular option and absorptive capability. The modular and architectural innovation promotes the industrial upgrade.

Keywords: *Modularization; Industry upgrade; Innovation; Technology; Organization, absorptive capability*

Introduction

With the development of economic globalization and information technology, traditional theory of industrial structure and governmental industrial policy is undergoing a profound change. Knowledge and

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technology gradually has become fundamentals of industrial structure evolution and starting point of government policy. Most of developing countries have the manufacturing industries of low technology and the industrial upgrade depends on the industrial policy preferring to the heavy industry and governmental investment. For China, it experienced several decades of high-speed economic growth since policy of openness and reform. It should search for new approach to improve the quality of growth and industrial upgrade because it becomes a large country of manufacturing industries of low profit and low product quality to some extent. Upgrading industrial structure needs to consider the enterprise as the micro foundation of technological innovation instead of government. Firm theory of modularization has recently become a new perspective of research on industrial innovation and industrial upgrade.

This paper is aiming to analyze industrial upgrade mechanism from perspective of modularization theory. The following paragraphs should first review the literature of modularization, the relationship between modularization and industrial upgrade. Secondly introduce the concept and contents of the industrial structure and industrial upgrading, and point out their new features in the age of globalization and information technology; Then, to analyze the characteristics of modularization and its innovation effect; Furthermore, explain the mechanisms of knowledge flow and absorption ability influencing industrial upgrade. Finally, give the conclusion and proposals for the governments and firms.

Literature review

Actually, the modular concept started from Simon (1962). According to the bounded rationality of well-being and the complexity of economic system, Simon puts forward the concept of approximate decomposition. In other words, modularity is a way to solve complex problems. Baldwin and Clark proposed the definition of modularization in 1997. They gave an analysis of the relationship between modularization and emerging industry clusters in the case of computer industry. Aoki (2003) thought that modularity is a process of system of semi-self-discipline being composed into a complex system, but also the decomposition process of the complex system. Aoki (2003) believed that the modularization is nature of the new industrial structure. Campagnolo and Camuffo(2009) gave a survey of concept of

modularity. Macduffie (2013) distinguished that modularity is a design property of products, organizations, and inter-firm networks. It's a cognitive frame that guides categorization and interpretation of economic phenomena. Modularization is a process to affect those designs and shape firm boundaries and industrial landscape. Fixson and Park (2008) analyzed the relationship between product architectures, modularity and industry structure. As for the relationship between size of firm and innovative activity, Schumpeter (1942) was impressed by the differences between the innovative activities of large corporations and small enterprises, empirical literature has interpreted that Schumpeter's claim for a large firm advantage in innovation. Galbraith (1952) explicitly argued that large firm size has an advantage in innovation.

Some justification expresses the advantage of internal funds, risk reducing and cost spreading. Counterarguments to the proposition (Scherer and Ross; 1990) suggested the loss of management control or, or alternatively; through excessive bureaucratic control, individual efforts of scientists and entrepreneurs diminishes due to conservatism characteristic of the hierarchies of large corporation. Acs and Audretsch (1988) find that innovation and invention output is positively related to R&D expenditure, and unequivocally, negatively related to concentration or unionization. Brusoni and Prencipe (2001) proposed that modularity is common characteristic of products such as aircraft engines and chemical plants. Coordination of knowledge and organization cannot be achieved by automatic mechanism rather than by systems integrators. Rothwell (1992) showed that innovation is a process of knowhow accumulation and combination of internal and external learning. Edquist (1997) distinguished innovation, organization and institution.

Technologic Innovations are introduction of new knowledge or new combination of existing knowledge through interaction between firms and consumers, between different firms, or between firms and other organization. Organizations are formal structures with an explicit purpose and they are consciously created. They are the main vehicles for technological change in that they carry through innovations.

Among Chinese scholars, Tong (2000) earlier introduced modular concept, principle and application. From the perspective of system economics, Zan (2003) thought that economic system provides a wealth of background for modular theory. Economic system is composed of economy

unit and the relationship between economic units. The former is a shared hard system while the latter is a shared soft system. Soft and hard systems can be transformed into each other. Majority of scholars studied modularization from management's perspective. The literature can be summarized into three categories and three units. Three categories are engineering, management and economy; Three units are product, production system and organization modularization. The literature of the relationship between modularization and upgrading industrial structure from Chinese scholars lies as follows: As for works, Zhang (2008) took the software industry as an example to illustrate the modularization role playing in promoting industrial upgrade from the point of view of the industry chain.

The industrial upgrade refers to that of a particular industry; Hu (2009) analyzed the modularization from an economic point of view. Zhu (2006) discussed internal integration of industry from the contract's perspective of modular enterprises. Rui and Liu (2006) studied the integration of industrial chain from the perspective of modular division. Rui and Zhang (2009) studied the construction and operation of knowledge innovation platform of the industrial chain. As for the papers, they can be divided into three categories: First is from the perspective of industrial structure. Cheng and Zhang (2011) explored the upgrade of industry and inter-industry, analyzing modular technology gap between developing and developed countries. According to Hausmann and Klinger's spatial structural module of product realities, Guo (2009) analyzed the adverse impact of the modular upgrading of the industrial structure. Second is for single industry chain such as manufacturing. Gong (2009) analyzed modularization of value, technology and organization, and coordination, lock problem of interface and technology. Ye (2010) analyzed industrial upgrading between the independent innovation and national technology transfer from first moving countries to developing countries from the perspective of relationship. Liang (2007) analyzed the modular manufacturing upgrade from the perspective of modular competition. Third is for a particular industry such as: automotive, electronics and information industries, and other. Cheng and Zhang (2010); Jing Han, Li Fo(2009); Zhou (2008) discussed the relationship between modularization and industrial upgrading.

From the above viewpoints about the study of impact of modularization on industrial upgrade. We find they literatures have different focuses. Some focus on developed countries, it's not possible to consider the industrial upgrade of developing countries and their absorption ability. Others analyze the impact of market structure on the innovation, without being related to technology and organization modularization. Obviously, the concept of modularization has become a hot topic from economic perspective. Various modular research perspectives in the academic community so far have not reached unique definition of modularization.

I think, Modularization is a process, in the context of globalization and information technology, Under the leadership of rules system integrator develops, each modular organization engaged in specialized production, fostering knowledge creation, transformation, horizontal competition and vertical cooperation, absorbing new technology, engaging in independent innovation or construction innovation, catching up with advanced technology and get relative value. From a practical point of view, relationship between the organizations becomes one including the followers and the leaders. From a global perspective, modular relationship can also be expressed as industrial division relationship between developed and developing countries. Research on modularization has important practical significance for restructuring large and medium-sized state-owned enterprises in China, such as the electricity, communication and bank etc. sectors or high-tech clusters, such as in Dongguan city of Guangdong or Suzhou city of Jiangsu in China.

Industrial structure and industry

Traditional industry structure theory was introduced to China from the West in 1980s. There are two dimensions including evolution viewpoint and adjustment viewpoint. The former refers to the natural change, while the latter artificial change decided by the government. Regarding the evolving trend, there are also two levels, one theory refers to close industrial structure without regard to foreign trade, and its representatives are William Petty, Colin Clark, Kuznets, Hoffman and Leontief. Another theory refers to open industrial structure, considering the impact of the international division of labor and international trade on industry structure. The main

representatives are Smith, Ricardo, Ohlin and Chenery etc. These theories are the blueprints of majority of existing textbooks about the stages of the industrial development. Because of industrial evolving trend of its own, most scholars will consider upgrade of industrial structure as equal to industrial upgrading. Li (2005) advanced that the upgrade of industrial structure means the process of transformation from primary industry to secondary and tertiary industries sequentially which is the leading industry of the national economy.

The definition and classification of industry is the requirements of establishing and studying the concept of industrial structure. In neoclassical economics there is not an industrial concept but a representative enterprise. So, what is the industry? The traditional industrial concept is based on the proximity of the products, the competition of behavior which stressed the activities of production. Such as the industry definition from MIT Dictionary of Modern Economics (1983), within the analysis in the framework of a fully competitive market, the industry is a large group of competitive companies producing homogeneous products. Zhi(1985) suggested that the industry is concept of a collection, which locates between microeconomic unit (business and household) and macroeconomic unit (national economy). Therefore, industry is a collection of businesses with the same attributes, and also a sector of national economy classified by a kind of standard. Here, the sector and market refer to meaning of the same industry. In the narrow sense, there is a competitive relationship between enterprises which belong to the same industry. Outside the same industry there is no competitive relationship, obviously, this is the concept of static industry. However, it is useful to distinguish the industry and national economic account. In 1971 United Nations published the "international standard industrial classification index" of all economic activities based on national experiences. Its criteria are based on the end uses of the product, the proximity of all kinds of social goods and services, production processes and technology. For purpose of need and convenience of statistics, all economic activity is divided into ten major items. High-level item includes middle items which also include more low-level items. Each item was assigned a unique code. The larger the code number is, the more concrete the item. Most commonly used code is the four-digit code in industry analysis. International Standard Industrial Classification and classification of the three-order industries are of consistency and can be transformed each other.

With technology innovation and diffusion, different industries rely on a set of the same production techniques. Previous separate industries have become much closer such as Rosenberg (1963) describing that an independent specialized mechanic tool industry emerged in the mid-19th century because similar technologies (drilling, grinding, polishing technology) are applied in that industry. This is the kind of new sector after technological integration which would lead to product integration. Technological innovation will change the boundaries of the traditional industries. According to Yu's (2006) analysis, industrial integration can be divided into three stages. The first is the separation stage of different industries which have clear boundaries, entry and exit barriers. The second is the stage from separation to integration because technological innovation will eliminate the barriers between industries, leading to a product or service with similar function provided by different industries. The third is stage of the industrial integration. Originally different industries now form a competitive and complementary relationship because they provide the similar products and services. Such as computer, communication, and cable television sectors, they were originally discrete, and then went toward integration, providing similar products or services, forming a competitive complementary relationship due to the extensive use of digital technology, optical communication technology, software, etc. Another example is financial industry including bank, securities and insurance sectors, and in the 1980s they were discrete. However, due to the introduction of information and communication technology, the industries have convergent trend. Industrial integration here emphasizes heterogeneous industries due to the complementation in technological innovation, acquisitions or strategic alliances.

As for modularization theory, firms of various industries would integrate according to their own characteristics. It is based on the viewpoint of the system, regarding industry as the inter-enterprise cooperation of capabilities, viewing demand of users as primary organizing principle. The elements of analysis are the units of firm. Meanwhile, it's a separate process. It is more marked in the division of skilled labor within the industry. New firms are founded by the employees leaving from the large corporation. Or the corporation outsources its task of manufacturing or R&D. Therefore, modularization promotes the integration of complementary section of the industry. In industry classification based on system, corresponding to the

sub-sector of services, Service Provider stands at the highest sector level in response to the terminal consumer demand. As for the corresponding manufacturing sub-sector, the product manufacturers and service providers stand on the lower deck in response to manufacturing for the services sub-sectors. This classification emphasizes more complementation than competition among the industries, such as complementary between manufacturing and service industries. But they can be assigned into the same industry due to co-corresponding to one group of product demand.

Due to modular development of business organizations and the trend of industrial integration, and the introduction of technology and knowledge into different industries, there are emerging new industries. The previous different sectors within one industry may be both competitive and complementary. Seen in this sense, the relationship between the industries is evolving into the relationship within the industry. Upgrade of industrial structure and industrial upgrade are equal. One point is certain that the upgrading of the industrial structure is not just a transition from first, second to tertiary industries. Furthermore it is the extensive use of technology and knowledge in the industry.

Contents and characteristics of the industrial upgrade

The process of the industrial structure upgrade is associated with the improvement of technological progress and the degree of production socialization, constantly getting out of the declining industries, strengthening the technological foundation of traditional industries, achieving reasonable conversion of the leading industries, supporting the emerging strategic industries, improving efficiency and effectiveness of the industrial structure as a resource converter. Chinese short-term goal of adjusting the industrial structure is to make the industrial structure based on the market economy regime and realize the conversion of the national management functions, at the same time, greatly improve the social and economic benefits. The Chinese long-term goal is to adapt to a series of structural revolution in human social and economic life, and the information technology revolution and the modern market economy, promoting Chinese economy to enter a post-industrial society in the 21st century.

The industrial upgrade aims to achieve a high degree of processing, high value added, high-tech requirements, to promote the upgrade of industrial structure through technological innovation, introduction of technology and transformation of traditional industries through high technology. Technological innovation is the necessary condition for the industrial upgrading. Governmental institution arrangement is sufficient condition to achieve the upgrading of industrial structure.

Most Chinese scholars believe that the industrial upgrade consists of three main areas: (1)In the development process of industrial structure, the dominant proportion evolves from the first industry to the secondary and then tertiary industries. (2)The industrial structure evolves from labor-intensive industries to capital-intensive, technology-intensive and knowledge-intensive accounting for a dominant proportion. (3) The industrial structure evolves from primary products, low value-added products and low degree of processing manufacturing to a high value-added and intensive processing stage.

The upgrade of industrial structure includes the four aspects of the value, asset, technical and employment structure, among which technical structure is the driving force. The asset structure and value structure are the performances. The value and employment structure are the elementals (Guo, 1999). Industrial upgrade requires the independent innovation of industrial technology combining with the introduction of technology. At the same time it strengthens the technological transformation of traditional industries. Industrial technology is aiming to form a production system with a specific structure. There are a variety of production techniques to match the core technology through interrelated technologies focusing on the dominant technology. Industrial technology innovation is to produce structural changes of technology system through the reorganization of a variety of production technology in various departments. The state should promote small, medium and large enterprises to carry out technological innovation and market-oriented transformation of production and services. The introduction of technology should enhance the industrial effect, promoting the appropriate development in upstream, downstream and ancillary industries. It would improve industrial efficiency in the transformation of traditional industries, changing the products of traditional industries to a direction of a multispecies, multifunction, high grade, high efficiency and low Energy consumption through the upgrading of products.

Enterprise Competence and industrial upgrade

The upgrade of industrial structure is based on industrial upgrading. And the microscopic carrier of industrial upgrading is the upgrading of enterprises. Therefore, research on industrial upgrading can be summarized as two levels: first is the enterprise level; second is the industrial chain level.

Research on the industrial upgrading of enterprise level is divided into two schools of thought: first is about the core competencies (Hamel and Pralahad, 1994), second focuses on dynamic capability (Teece and Pisano, 1994). The core competency of an enterprise mainly exists in the following transactions: the ability to provide the required value for the end consumer; relatively unique competitive strategy which most of the competitors cannot control; corporate advantage difficultly imitated which can raise the barriers to entry for potential entrants. The so-called dynamic ability of the company is the ability to integrate, establish and reconstruct the internal and external capacity in response to the rapidly changing environment (Teece, Pisano and Shuen, 1997). It is also the ability to update the competiveness constantly. Teece et al divided the dynamic capability into the 3P: process, position and path. However, the above analyses stay at the enterprise level, not extend to the level of value chain. The latter is supplemented by Gereffi (1999) and (2002).

Gereffi proposed a four-level classification method which contains the upgrade of interdepartmental level. That is from the low-value, labor-intensive industries to capital and technology-intensive industries. Humphrey and Schmitz also proposed a four-level classification method which includes inter-sector upgrade. It applies the ability obtained from a particular part in new areas, or moves to a new global value chain which is also known as the chain upgrade. Therefore, the perspective of western academic research on industrial upgrading is more microscopic. Essentially it views the improvement of the production capacity as well as the competitiveness of the enterprises as the origin of industrial upgrading.

The East Asian miracle of economic development and the rapid rise of high-tech industries (mainly symbolized by the computer and semiconductor technologies) are the examples of the industrial structure upgrade in China. It provoked many scholars to study its high-tech industry development. Matthews (2009) from Australia held that the development of the semiconductor industry in East Asia relied on the company's technical

capabilities and coordination mechanism of the public sector which reduces the risk of joint venture. It is realized by resource leverage, cooperation network and promotion of enterprise entrepreneurship. It summarized the industrial creation and upgrade in East Asian as four stages: first is to ensure that the talent, knowledge, contracts, corporate are in place; second is sowing / planting, technology leveraging and resource leveraging, leading to adapt and improve; Third is that there are financial resources, business development, product development, and infrastructure support in order to encourage enterprises to use technology; fourth is sustainability, upgrading the industrial structure, enhancing research and development capabilities and creating the social structure conducive to innovation.

I believe that, from a modular perspective, industrial upgrading is shown in the upgrade of core technological competence of the enterprise, enhancing market competitiveness and establishing more well-known brand which requires the enhanced ability of knowledge transformation and creation. Furthermore, they play important roles for the institutional arrangements of East Asian countries or regional governments.

Innovation effect of product modularity and process modularization

Despite the modularization has become a popular concept for decades, especially in operations and management research, but it did not seem to have a common definition because modularization includes product, service, process, organization and technology modularization. The definition of modularization about goods products has not yet been formed, let alone service products. A lot of discussions have been provoked in the relationship between the hierarchy of products or services and the level of organization or process, they still did not reach consensus (Campagnolo and Camuffo, 2009). Modularization can be manifested in the modular products, technologies and organizations, and the products are divided into material goods and services. If divided in the level of the product architecture, it can also be divided into modules based on the functions or manufacturing process, the latter is analyzed from the point of view of the life cycle of the manufacturing process. Function-based modules include: slot module, component module, bridge module and hybrid module; Modules based on the manufacturing process are divided into OEM module, assembly module,

big module and conceptual module. The current research literature about the relations between modularization and innovation are as follows: Miozzo (2005) discussed the outsourcing of knowledge-intensive services in the United Kingdom and Germany, analyzing its relationship between modularization and innovation. Ethiraj (2008) discussed the dual role of the module, which is innovation and imitation, modularization causes innovation of performance differences, also causing imitation which obstructs the performance difference. Langlois (1991) discussed the autonomy and system innovation. In china, Hu (2006) discussed the effect of modular innovation. Gang and Xu (2007) discussed the relationship between modular and independent innovation. Lv and Su (2007) discussed the technical ability to grow in system integration enterprise.

In general, modular innovation effect is associated with monopolistic competition mechanism. Schumpeterian innovations are divided into two kinds: one is the innovation of small and medium enterprises, which existed in European industrial structure since the second half of the 19th century. The second is for large enterprise innovation which existed in large U.S. companies with large R&D laboratories in the first half of 20th century. Schumpeter believes that innovation is the source of capitalism. But it is difficult to determine the source of innovation. What kinds of market structure can generate more innovation? New Schumpeterian emphasizes the role of knowledge and technology, emphasizing the dynamic capability. It absorbed the idea of evolutionary economics while modular theory also absorbed the relative contents. Technical innovation would give rise to profits for the enterprise implementing innovation. If innovation is searched by chance, it would be used and the capital intensity would be increased.

Enterprises with higher productivity and profitability of an alternative will substitute for those with lower productivity in two ways: First, other companies would imitate and utilize the enterprise capabilities with high profitability. Second, the enterprises with high productivity will grow up (Forbes and Weld, 2005).

In the modular industry, the product innovation causes the industrial evolution. The innovation leads enterprises to enter or exit. New firms enter the industry through adopting product innovation, imitating innovation and splitting technology etc. Innovative skill, degree of modularity, sunk cost and market environment will affect the entry of new

manufacturers. The following will instruct modular innovation effect from the two aspects of the functional modules and system modules.

Modular Innovation and Architectural Innovation

First, let's consider the modularization of product. It is shown in Figure 1.

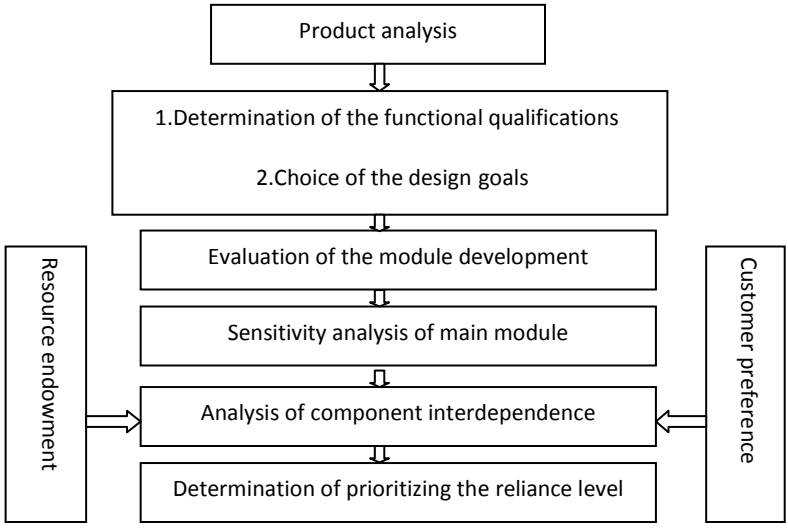

Figure 1: Product modularity

The decomposition process of this product is also described the relationship between the product features and the various components. In order to form the candidate module and complete the design features, the components may be classified. The size and number of modules depend on the features and elements of the terminal product. Upon which modular decomposition can be formed. The innovation occurring inside the module is called modular innovation (Langlois & Robertson, 1992). On the contrary, its framework change is called architectural innovation when the components are stable (Henderson and Clark, 1990). It is worth noting that architectural innovation does not only mean the visible innovation about the system rules. Such as Legos and Tinkertoys, they are the classic modular system, being used to design architectural innovation. This architectural change is re-combination of the same module and does not change their

modular functions. Sometimes, the system function change is called re-combination rather than re-modularization. Upon this case, new system may be not compatible with the existing reserves or irrelevant, incurring losses of the system innovation. This is the focal point of discussion in the literature on path dependence or technical standards. Modular innovation and architectural innovation lead to collaborative innovation, promoting the technological upgrading of products.

Motivating factors that caused the modular innovation and architectural innovation lies in the follows.

Modular option value and innovation return

Under modular mechanism, the implicit design principle of module products endows independent functional modules with free innovation space, the modules of same function faces parallel competition. Each module product has a real option. This theory became the innovative driver of many modular producers. They can get access to innovative revenue. Because the enterprises with the similar production share the platform, the exchange of information further promotes the innovation generated.

Open innovation and sourcing

From the viewpoint of biological evolution theory, Nelson and Winter (1982) analyzed the relationship between the innovative organization evolution and organizational capabilities, creatively putting forward the dynamically evolving view of the innovation system. There, let corporate theory be included in the analysis of evolutionary economics. Integration of the innovative resources is the power of enterprise innovation under the conditions of technical and market uncertainty. The modular innovation lies in the integration of internal and external resources to achieve open innovation.

Modular production evolved from vertical specialization of production networks. The latter has a central firm such as automobile manufacturing industry in Japan while the former is decentralized. In a sense the modular system is open for a certain kind of innovation. The decentralized network can simultaneously test in a variety of options setting up on a modular basis, resulting in learning of a rapid trial and error. In the

centralized network, more entry points exist for new companies and new ideas. The large firms should out-source or in-source some functions of productions. But it's not sure for the production in vertically integrated industries such as the union of approximate function. In this sense, the modular system may develop technology more quickly in the case of uncertainty and fluidity.

Division of knowledge and innovation cost

Because of the knowledge division, the system can promote a modular internal innovation. The network standard with compatibility promotes the autonomy innovation. In various stages of production the innovation needs a smaller coordinating cost. Professional producers or users focused on individual modules. A modular system will be able to take advantage of knowledge division for providing the innovative services, innovation will be carried out in such a way, that is, the development of bottleneck components become the center of the changes, the old system can be compatible after the innovation of the module, so that the cost of innovation is smaller.

Blurring of firm boundaries and re-modularization

Independent innovation of Modules lies in its changing capsulation boundary. The modularization is worth doing in the face of market uncertainty. The question now is not whether or not to modularize or how to modularize, but what kind of modularization is best decomposition? The purpose is to reduce their interdependence, clearly decompose the system. However, the definition of enterprise capsulation boundary is in question in the dynamic context. Innovation and development tasks (projects) cannot be determined in advance because the knowledge is changing. Thus, the modularity of the system will be carried out continuously. Re-modularization is necessary as long as the learning takes place.

If it is the innovation of the entire system, it's equal to the innovation of system standards or rules. Due to a positive network feedback in the existing industrial structure, this innovation will inevitably bring about the transfer costs. That is to say, the members incur the transfer cost from technological lock-in (Shapiro & Varian, 1998). The technology is

difficult to industrialize, fail to create a new industry (Zhang and Xu, 2007). Because internal module may be an alliance with a larger dependence, coordination cost of such internal modules is great. Of course, innovation does not always occur in the re-modularization process. For a large number of cases, innovation occurs in a fixed or predictable modularization. The personal computer is the obvious example (Langlois and Robertson, 1992). Since the emergence of IBM PC in the early 1980s, a large number of innovations have emerged from components, rather than the connection improvement between components. For example, the improvement emerged in a microprocessor, software, modem and peripheral devices.

Generally, an excellent modular decomposition needs the clear design rules. It is fixed, not ambiguous. If the rule is not stable, then the module innovation or the re-combination of mixed match will be limited. For example, IBM PC are not necessarily the best platform today, but it's standardized modules reducing the cost and improving the technology, making other strong competitors dwarfed. There is a method to provide system innovation, called real-time embedded systems (Garud and Jain, 1996). One hand, it is sufficient certain to promote modular innovation, on the other hand, it is loose enough to be conducive to the system evolution.

Characteristics of modular technology innovation

Fundamental driving force of modular technology innovation is efficiency. Modularization of bringing efficiency can be analyzed both from a static point of view and also from the dynamic point of view. The latter refers to the impact of modularization on technological progress. As for complex products, the design, production of modularization has more advantages than those of integration. From the technological innovation point of view, modularity helps to promote technological innovation. It is expressed in the following points:

Modularization reduces learning costs, promoting distributed innovation

Rothwell(1994) distinguishes five patterns of innovation from the management point of view. First generation is linear technology-push innovation or new classical innovation from about 1950 to the second half of

the 1960s. The model assumed a stepwise from scientific discovery through applied research to technological development and production activities in firms, then leading to the products into marketplace. Second generation is demand-pulled innovation during the latter part of the 1960s. Innovation is to meet the needs of market. Third generation is interactive or coupling innovation during the 1970s. The process of innovation represents the confluence of technological capabilities and market needs within the framework of the innovating firm. Fourth generation is the integrated innovation. This representation focuses on the two primary internal features of the process, i.e. its parallel and integrated nature. In the mid-1980s Japan highlighted the cross coincidence of various departments to shorten the response time. And production cost can also be reduced. Fifth generation is system innovation and networking (SIN) after 1990s. From the first to fourth generation of innovation model, the core is internal innovation. By the 1990s, it emphasized the need to integrate a variety of external resources. Emphasis on information exchange, information and communication technology (ICT) applications becomes a driving force for the development of this mode. From a network perspective, it establishes Union, and focuses on the construction of explicit knowledge, such as knowledge management, data infrastructure. Roberts (2004) proposed that the above innovative patterns ignored the role of tacit knowledge, therefore, proposed a sixth-generation learning innovation theory. The generation theory includes all learning theory; the most critical elements are tacit knowledge and connectivity. It can be called a theory of learning and innovation.

Modular role is to reduce the interdependence of technological innovation on tacit knowledge between the modules and reducing tacit knowledge learning costs, the product of the integrated design can be taken into two kinds of modes of production. First is overall production inside the enterprise. Second is production outsourcing upon which it forms specialization design or production between different enterprises. Upon the decentralized production, enterprises can get the advantages of specialization, such as cost reduction and efficiency increase, but it will increase the tacit knowledge learning costs such knowledge is difficult to transfer and ignorance of other enterprises. While integrated production, learning cost of tacit knowledge can be decreased, but manufacturing cost, management cost rose. In case of modularization, Enterprise need not trade-off between these two cost. With the accumulation of tacit knowledge,

learning cost and specialization cost curve also move down parallels (as in Figure 2), the vertical axis stand for specialization cost while the horizontal axis integration cost. The equilibrium point drops from A to B. Modular design is conducive to innovation. This innovative pattern is called the seventh generation innovative model. The most important feature of this model is to internalize the reliance of innovation on tacit knowledge, reduce tacit knowledge learning cost (see Figure 2), and makes the innovation more open.

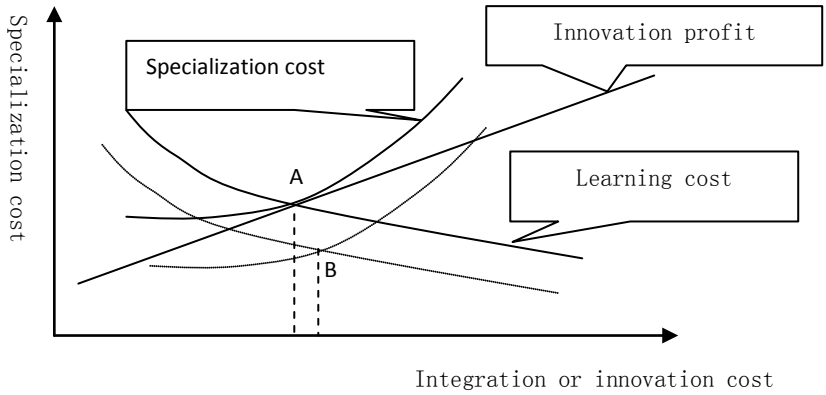

Figure 2: Impact of learning costs and specialization costs on innovation

As it can be seen, the seventh generation of innovative model is open. Open innovation is the use of purposive inflows and outflows of knowledge to accelerate internal innovation, expanding the market so that the external parts can also use the innovation (Chesbrough, 2003). It is different from the knowledge management approach of vertically integrated corporate. First, the traditional approach emphasizes the sequential transferring process so that the various components should be designed and produced in order. There is a time problem of information feedback and loss. It requires close cooperation among the various groups. Second, although you can use cross-network to settle the process can avoid the loss of information products through information sharing to some extent in various stages of development, it still requires close cooperation between groups in various stages of product development. Modular product design helps to overcome the problem of information feedback and information

loss. Various independent components focus on improvement of the core competencies, independent innovation and change and integration of external ability with their own ability. As such, modularization is helpful for the system integrator to make on-time reaction to market changes with a small cost and provide a favorable environment for suppliers and customers.

In the process of industrial upgrading and enterprise enhancing competitiveness, R&D innovation is an important aspect. Distributed innovation is a common organization mode of R &D innovation in innovation competition. According to the definition of Coombs and Metcalfe, distributed innovation is distribution type of technology and related ability which are needed by innovation in multiple companies of knowledge production. Simon's approximate decomposability and loosely coupled systems can contribute to our understanding of distributed innovation.

Distributed innovation is a model of integrated innovation and open innovation. But its focus is different from that of open innovation but closer to integration innovation. From a modular perspective, dominant firm has the architectural knowledge of system or owns preliminary results of innovation. It gives clear direction of innovation and development. Functional modular enterprises have tacit knowledge. Units or partners are involved in parallel competition. Leading companies and modular firms circulate knowledge flow (including knowledge creation, transfer and integration). Finally, they form innovation. It is shown in Figure 3.

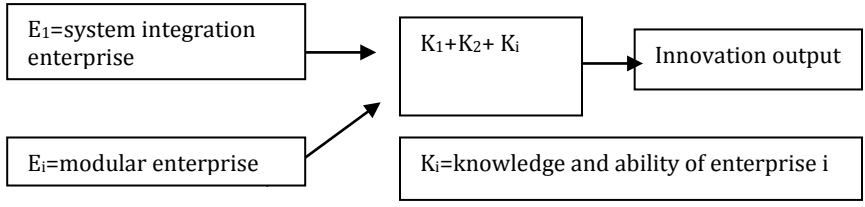

Figure 3: Modular Distributed Innovation

Modularization promotes knowledge production

As we know, Solow residual technology is exogenous in the economic growth mode of neoclassical theory. But in endogenous economic growth model, the technology is endogenous. It ignores the complexity of the product or knowledge. In a society technological progress should occur as long as there is the incentive of technological progress. However, the person's rationality is limited so that the presence of incentive at this time does not necessarily produce a high rate of technical progress. There is a great degree of impact of knowledge complexity on innovation. As long as person's rationality is to some degree, the Innovation requires more complex knowledge. More complex the knowledge is, more difficult the innovation. Therefore, the existing stock of knowledge has a negative impact on innovation. Endogenous growth theory in the simplified form of knowledge production model can be expressed as follows.

$$Y(t) = [(1- a_k)K(t)]^{a}[A(t)(1- a_l)L(t)]^{1- a} \qquad 0 < a < 1 \qquad (1)$$

Where, K is capital, L represents labor a_k represents capital of R & D department , a_l represents labor of R & D. A_t represents the stock of knowledge. Assume that the increase of new knowledge depends on labor, capital investment and the stock of knowledge. Its production function is a generalization of the Cobb-Douglas production function, namely:

$$\dot{A}(t) = B[a_k K(t)]^{b}[a_l L(t)]^{g} A(t)^{q- NK} K(t)^{f - NK}, B > 0, b, g \neq 0 \qquad (2)$$

The difference of this equation and general equation of knowledge production equation is that the introduction of a complex and tacit knowledge .Complexity is represented with standardized NK. N represents the number of modules which is expressed to a normalized value. K represents the linkages between modules. q-NK represents the impact of knowledge stock on R & D success or failure. If it is greater than 1, it indicates the progressive increase of knowledge growth rate. Tacit knowledge is only obtained through learning by doing. The simplest model

of learning by doing considers the learning as a by-product of new capital production. So, increase amount of tacit knowledge is a function of the capital stock. Select a power function as follows:

$$A(t) = BK(t)^{f - NK} \tag{3}$$

Modularization can reduce the complexity. If the system consisting of N modules is divided into n symmetric modules, the complexity will be reduced to (N / n) K, the knowledge production function becomes:

$$\dot{A}(t) = B[a_k K(t)]^b [a_l L(t)]^g A(t)^{q - NK/n} K(t)^{f - NK/n}, \tag{4}$$

Because NK is always greater than or equal to zero, therefore, as long as *n* is greater than 1, the value of the above equation is always greater than the equation (2) .In fact, Ignoring the learning costs and other factors, the modularization results in the improvement of innovation frequency. Tacit knowledge and regional knowledge is crucial for technological innovation, Accumulation characteristics of local knowledge and technology derived from the practice, that is, technological accumulation is interactive. New technology is almost generated in the previous learning and knowledge (including tacit knowledge of work) (Forbes and Wield, 2005).

Modularization promotes knowledge creation

Knowledge or technology is the source of enterprise technology innovation, and the creation of knowledge is the pushing hand to enhance the enterprise competitiveness. It's necessary to introduce the Ba before enterprise how to create knowledge under modular condition. It played a key role in the transformation, integration and creation of internal or external knowledge. The Ba refers to a place. Many philosophers have discussed the importance of the workplace in the activities. Plato considered the place as the birthplace of Chora, to Heidegger it as a place of human existence. To include the concept of a place like this, and limited to knowledge creation, we refer to the Ba (in Japanese meaning of the place), where people carry out dialectic dialogue and practice, to achieve the goals and visions of the company's drive.

According to the first meaning Established by Japanese philosopher (Nishida, 1970, 1990 [1921]), we have the Ba defined as the dynamic context, where you can share create and use knowledge. When individual empathizes in the context of sharing, its knowledge should be shared and thus new knowledge generated. "Ba" has the following characteristics: First, its essence is the context and meaning of a particular space and time, rather than the space itself. Second, it is a dynamic context. Third, context is the interaction of subjects with others, sharing ideas and understanding each other. Thus learning occurs in the interaction, while Simon believes that learning occurs inside the brain in individuals (1991:125). Grant also believes that knowledge creation is a thing of personal activities, and the company is just the application of existing knowledge. Nishida think "Ba" is "no" which is open to others and accept others' opinions by losing itself. Fourth, "Ba" requires a permeable boundary so that it can receive the necessary context. Fifth, "Ba" within the company has multi-levels: formal meeting, informal repeated communication, economic and non-economic dimension. Drawn on the knowledge creation theory of the firm and combined with the modular concept, enterprise knowledge creation mechanism structure is shown in Figure 4:

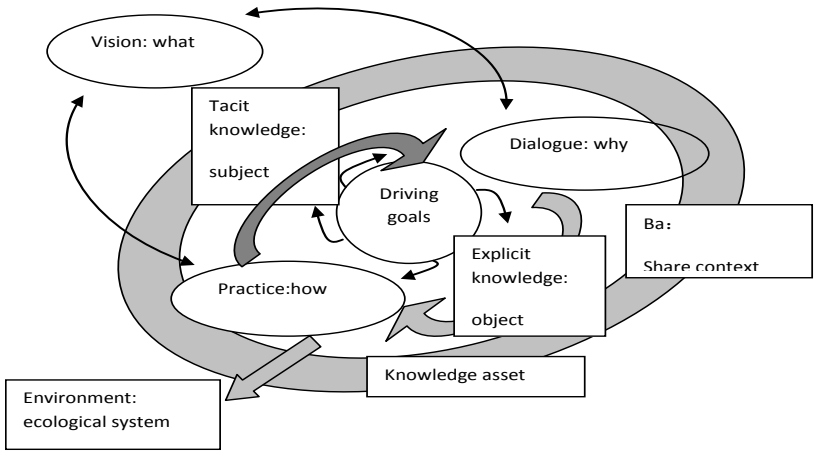

Figure 4: knowledge creation enterprise structure
Source: Nonaka and Toyama. (2005). pp.423

It mainly includes the following four parts:

First part is knowledge vision. It gives the direction of the company to create which is concerned with knowledge creation and goes beyond the existing capacity of company. The company can change the vision of knowledge because it comes from the company's basic ontology. It provides a consistent value system, to tell people what is truth, goodness and beauty. It can encourage, assess and confirm the knowledge company creation. For example: the vision of Japan's Olympus is "society in", rather than "Market-in". It values exist of people living in the community.

Second part is driving goal. It is the embodiment of knowledge vision. It refers to the specific concepts, goals and action standards driving knowledge creation process. For example: Japan's Suzuki motorcycle company, for the development of a new scooter, proposed: "1CC = 1000 yen". It drives the entire company to create knowledge. They asked what is nature of the scooter. In this way, they add the necessary components in the framework, minimizing cost and using the latest technology. This driving goal integrates various differences, such as those of R&D, manufacturing and sales.

Third part is dialogue and integration of ideas. The dialogue refers to putting everything in a context, and then in accordance with the general understanding, rather than as an absolute truth. The dialogue helps people to pursue conflicting attributes of the event, and then accept the other person's points of view. The importance of dialogue is its meaning rather than its form. The dialogue is a process of externalizing tacit knowledge (externalization), internalizing explicit knowledge and a process of forming new knowledge (combination).

Fourth part is practice and activity synergy. The practice has established a foundation through which experiences and tacit knowledge are shared (socialization). It manifesting explicit knowledge, connecting it to a special context, and then transforming into the tacit knowledge (internalization) .Concepts and assumptions become into reality through dialogue and practice. The practices include action and a feedback. They understand their activity meaning each other, and use it to guide further activity.

Modularity promotes the knowledge flow

Knowledge, in many ways, is quintessential public good, meaning it is non-rival and non-excludable. It may seep into the public domain in publications. It may travel with individuals who change employers or set up new firms. There are numerous channels through which technology might spread between firms. The extent to which knowledge flows through these different channels depends upon the capability of the recipient. Levin et al (1987) discovered that independent R&D was considered to be the most effective means of learning. Licensing occurred in industries where channels based on interpersonal communications (publication, conversation). Us semi-conductors industry provides a fairly clear example of knowledge flow. Liberal licensing policies combined with relatively high rates of exit by scientific personnel from established companies to join other companies or set up their own spin-off firms combined to generate extremely rapid diffusion rates of available, state of the art technology in this sector during 1950s-1960s.

However, as the basic technology shifted innovative activity away from discrete devices and towards integrated circuits, blurring the boundaries between electronic components and electronic systems, the ability of individuals leading to new product innovations has fallen off. The case of AT&T in the semi-conductor industry also suggests that it may encourage knowledge flow by informal know-how trading apart from licensing. The informal trading includes exchange of data in conference, training of workers of competing firms, instruction from specialist's commercial rivals.

Absorptive capacity and related institutional arrangement

Modularization innovation is different from the separate module innovation and architecture innovation, it is cross-cutting. It needs help of an intermediary. Absorption capacity takes effect through the intermediary. It comes from open innovation system. Only experiencing internalization, socialization, externalization and merging, explicit knowledge and tacit knowledge can complete the knowledge and technological innovation. The knowledge spillover distributes from the core enterprise to non-core business. The core enterprise has a leadership role, to enable enterprises to

work closely. The technical innovation of the non-core businesses depends on its ability to absorb. Absorption capacity refers to knowledge creation and dynamic capability to use, in order to gain and maintain a competitive advantage. It can be divided into two types, first is the potential ability including knowledge acquisition and digest ability; second is achievement ability focusing on the transformation and development of knowledge, result and its transformation. Nurturing absorption capacity can have a variety of approaches, such as establishment of the strategic alliances, purchase of the patent, introduction of the relevant engineers for training and guidance. The latter can shorten the gap with the advanced technology after enterprises master the skills. Such as the development of Taiwan's semiconductor industry shows that the improvement of absorptive capacity generally is realized through government in East Asian countries or regions. For example, government educates or trains personnel for high-tech development, sending technical engineers to the United States to study, exchanging technology with corporations. These institutions played the intermediary roles in increasing absorptive capacity of enterprise technology.

Conclusions

According to the above analysis, Modularization is changing the structure of organization and technology. Large corporate keeps the core competence and small new firms enforce innovation due to competition or through outsourcing from large firms. It has innovative effect on upgrade of industrial structure. Innovation subsystem functions including local technological innovation of modules and the architecture innovation of system (or rule innovation). The modularization innovation is a kind of synthesis innovation and combination of function innovation of sub-system and architecture innovation of interface system. Knowledge creation, knowledge flow, tacit knowledge and learning by doing helps industrial innovation and upgrade. Seen from the inside, innovation effect is the common result of the interface rule, value-oriented and knowledge creation, transformation and integration together. From the outside, it comes from the institutional framework and industrial policy for the promotion of technological innovation and the allocation of resources from the government. Modular interaction of industrial upgrade is as Figure 5.

Vol. III, Issue 6
December 2013

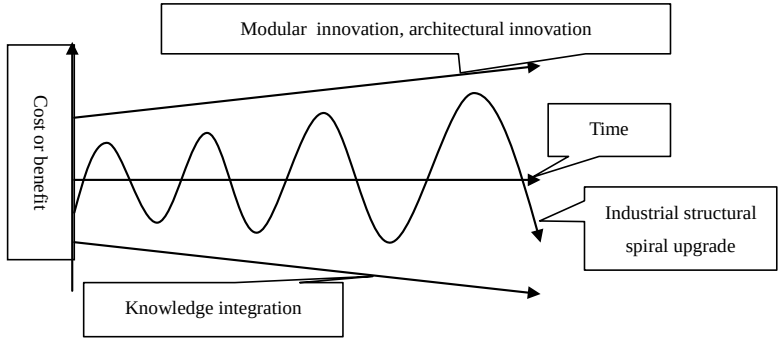

Figure 5: Interaction of modular synthesis innovation and knowledge integration

From modular perspective, modular independence and synergy of explicit knowledge and tacit knowledge generate the innovative effect. Independent innovation is driven by the tacit knowledge under the steering of the explicit design rule. And coordinated effect takes place through option value, cooperation task network, knowledge integration platform and rules made by system integrators. Specially, system integrators' rules play vital role of upgrade and coordination of the industrial structure, to promote the spiral industrial upgrade.

Since the reform and openness policy, China has gradually integrated into the international industrial production net. China has become the world's manufacturing factory with FDI, especially multinational manufacturers and global suppliers entering China gradually. China has become the node of modular industrial chain. Since China got access to WTO in the early 21st century, with computer and communication technology widely used, China has emerged a cluster of high-tech industries like Dongguan city in Guangdong province, Suzhou in Jiangsu province. In China there are industrial clusters, internationally they are the modular production nodes. The economies of these places also develop faster. Their GDPs per capita are at the forefront among the highest in the prefecture-level cities. However, China's manufacturing industry is still at the low end of the value chain which is inclined to be locked. With the construction of knowledge integration platform and the positive institutional arrangements, Chinese government can gradually solve this problem. Therefore, the main

problem is the upgrading of industrial structure in the era of economic or industrial modularization, solving the problem of the transformation of the economic growth, such as strengthening the correlation of specialized production clusters of neighbor provinces. It is meaning for the decomposition of old industrial enterprises in northeast China, state-controlled petroleum enterprises, communication and financial service industries. Only in perfect market system can modularization be achieved. For promoting modular implementation, the government should change the path of administrative allocation of resources to adjust the industrial structure. It should design policy system, nurturing large enterprises with leading technology and rule-making power, establishing a knowledge-based public infrastructure platform for the promotion of this technology. Particularly, we should learn from the experience of Japan, the East Asian countries or regions. That should play the role of government agencies or public research institutions which government sets up, bringing private intermediary organizations into play. on the one hand, Government should reduce the barriers to entry of new firms into some industries, on the other hand, Government should promote the vertical or horizontal cooperation, strengthen the correlation between the upstream and downstream industries or share investment risk of firms.

As for the firms, they should actively integrate into the global industrial chain, strengthen cooperation of supply chain and develop its core competency. Because industrial upgrade is now in the era of globalization, enterprises should actively become embedded in global value chains to gain a firm foothold, seeking the upgrade of the industrial chain. As enterprises in developing countries, they usually take action as followers in the industry and then gradually shift to upstream or downstream of industry chain. Various organizations in the industry chain, both independent and dependent in the industrial chain, take the structure knowledge of system as an interface, transforming into tacit knowledge. Enterprises are looking for technological innovation in an open environment, identifying and developing core competencies. Through absorbing and seeking innovation, thereby, promoting upgrade in the industry chain.

As for the Government as a public organization is concerned, Certain institutional arrangement such as the improvement of the financial system, tax system for SMEs, technological policy will stimulate the entry of new firms and the innovational activities of private firms. From the

perspective of system-based industry classification, it emphasizes the complementary relationship of supply chain rather than a competitive relationship. System integrator as the maker of rules plays vital role in knowledge distribution and transfer. Government still has to play a certain role in making industrial policy and systems of technology, bringing the power of civil organizations into play, promoting technology diffusion strengthening protection of intellectual property rights. It should be complementary to system integrator. Industrial upgrade cannot only focus on the role of the government's unilateral support and strengthen for existing businesses and products, but also play the role of non-governmental organizations, enterprises and other organizations, improving market regime, promoting competition. It not only focuses on technical innovation, but also focuses on the commercialization of technology and cultivation of commercial actors. However, commercialization needs the cooperation of the government, firms, schools, research institutions and universities. It also depends on the establishment of the management system and the learning mechanism of technology diffusion and absorption. At the same time, the protection of intellectual property rights should be paid attention. It would increase the incentives of innovation and promote the development and upgrade of emerging firms and industries.

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