Global Modular Production Network: from System Perspective

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\textbf{Abstract}

Modularization is a method to simplify complex product systems. Modular production was originated in the machinery industry to reduce the complexity of a product system, and then widely used in the information technology industry and manufacturing industry. Modular production network is the result of intra-product division under economic globalization. The information governance in modular production network includes both personal information encapsulation and system information assimilation. This enhances the innovative capability and anti-risk ability in modular production networks.

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\textbf{Introduction}

The development of information industry and machinery manufacturing industry after World War II was closely associated with modular production methods. To a large extent, PC industry has contributed the most to the development of the whole Information technology industry. The first electronic computer was invented in mid-1940s, the size of a large room, consuming hundred times of the power that a modern personal computer needs. Mainframe computers were invented from late 1950s to 1970s. The emergence

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of personal computers in the 1970s and 1980s brought the explosive growth to information technology industry. Nowadays, the storage capacity and processing speed of modern computers have sky-rocketed at much lower costs [1]. What was the force of this remarkable growth in IT and PC industries? It was closely related to modular production according to researches.

Modularization is an effective way to manage a complex system. A product is divided into subsystems or modules so that it can get enormous flexibility on production and diversity. Different IT companies are in charge of separate modules in production process and produce reliable products through collective efforts. IBM System360 invented in 1964 was the first computer with modular design [2], illustrating the approach to modularization. After 1964, with the development of modular design in computer, many module designers resigned from IBM one after another and set up their own IT companies. They created modular plug-ins and other products compatible with IBM System360 [1]. This process had accelerated much of the modularization of computer industrial structure and the evolution of modular design. Eventually the modularized trend in making computers led the IT industry to the age of modular networks. The modular production network can be defined as: on the basis of modular decomposition of product system, different intermediate products are assigned to different enterprises and then integrate, thus form a network among enterprises in IT industry, called modular production network.

1. Review on the studies of modularization

At first, modularization was used as a method of process design in watch industry, and then gradually applied in machinery manufacturing, national defense engineering, computer manufacturing and other industries. The first study on modularization is done by the Nobel Prize winner Herbert Simon. Simon pointed out that hierarchical structure is the principle to organize complex systems made up of interrelated subsystems; and a subsystem has its own internal structure and subsystems [3]. In the industrial economy era, “Fordism”, also known as mass manufacturing, was the most popular pattern of industrial organization. Modularization was only an approach in process design. Since 1990s, flexible manufacturing, modular production network, and other post-Fordism organizations has become the dominant form in many industries, and caused many economists’ attention on modularization theory. In the book Mass Customization: the New Frontier of Competitive Theory published in 1992, American scholar Pine II indicated that the best way to accomplish mass customization was to set up modularized components and apply them in various products and services [4]. In 1997, Baldwin and Clark published their classic paper Managing in an Age of Modularity in Harvard Business Review [1]. Then in 2000, they published Design Rules: the Power of Modularity (Volume I) [5] in Boston. Baldwin and Clark finally declared that we are presently in a new age of modularization through the analysis of Silicon Valley. Masahiko Aoki defined some special terms in his book Module of the Times: the Nature of the New Industrial Structure in 2003. He defined module as a semi-autonomy subsystem, which could form a more complex system or process together with other subsystems by following the system rules. The process of dynamic decomposition and integration through standardized interfaces within a complex system is called modularization [6]. In a narrow sense, modularization is production and process design of modules; while in a broad sense, it refers to the dynamic decomposition and integration process of a system, which includes products, organization, process, and so on.

2. System nature of modular production network

2.1. The system structure of modular production network

Modular production network is a new model of economic organization in the global network of
production. On the one hand, modularized products cater to personalized consumer needs; on the other hand, it can reduce the risk, uncertainty as well as the complexity of production. In the economic globalization age, manufacturing industries have developed into a system of global network of modularized production. In system economics, a system is an organism composed of a set of economic elements and relations among the economic elements. An economic system can be expressed as: economic system = (economic elements, relation among economic elements). It is an important feature that, an economic entity is considered as a "black box" when used as a single economic element to constitute an economic system. Moreover, we often consider the economic entity’s external links only but ignore the internal structure and information. In this sense, the economic element is equivalent to the module [7]. Modular production network can be expressed as: modular system = (modules, relation among modules). Fig. 1 shows the structure of modular systems. Modular production network \( X \) has two sub-modules \( \alpha \) and \( \beta \) with system information communication between them. There could be parallel competition or complementary relationship between \( \alpha \) and \( \beta \). In each module, \( \alpha \) or \( \beta \) has its own sub-module system. Also in Modular production network \( Y \), there is similar structure within the system; sub-modules \( \gamma \) and \( \delta \) have their own sub-module systems. Naturally, modular production network at the same level like \( X \), \( Y \) and others can be part of a higher modularized system. Because each module is a relatively independent system, so each module can make its decision independently according to its particular circumstances. Thus, the modular systems have the adaptability to deal with the external environment.

![Fig. 1. The Structure of a Modular System](image)

### 2.2. Information governance in modular production network

There are two types of information within a modular system: visible information and invisible information. Visible information is shared by sub-modules in the same system, and can establish clear link rules among sub-modules. Invisible information is encapsulated by modules and implicit in all subsystems. It is private information that can not be seen by others. Aoki put forward three types of organizational information processing: Hierarchical Decomposition (HD), Information Assimilation (IA) and Information Encapsulation (IE) [8]. We will compare these three types with the information processing pattern of Modular Production Network (MPN). In Fig. 2, \( x \) and \( y \) refer to two different units, arrows indicate the direction of information flow. We assume that any information organization in a system can be divided into system information related to system environment, and personal information related to a specific unit [8]. In HD pattern, \( x \) knows \( y \)'s personal information, but \( y \) do not \( x \)'s personal information. \( X \) supervises system information and makes decisions, and then \( y \) makes decisions according to \( x \)'s order. In IA pattern, \( x \) and \( y \) know exactly the same information, including each one’s personal information. We call it information assimilation. Here \( x \) and \( y \) will affect each other’s decision-making and form a fully cooperative connection. In IE pattern, there is back to back competition between \( x \) and \( y \). Actions of each party will not affect the other one’s decision-making. In other words, \( x \) and \( y \) share no personal information. In MPN pattern, there is a third-party intermediary, \( I \) in the system environment, and usually \( I \) is the designer (standard-maker) or integrator of modularized system. Because of the information encapsulation between \( x \) and \( y \), they have no exchange of personal information, and their actions will not
affect each other. However, with the coordination of intermediary $I$, $x$ and $y$ can exchange system information through compatible interface without affecting each other. This can be called “weak assimilation”. MPN type has the nature of both information encapsulation and information assimilation, which leads to co-opetition in modular production network.

There are three roles in a modular production network: system rule designers, system integrators and ordinary modular manufacturer. Standard designers have the competitive advantages on their super ability of innovation so that they have the Highest-level status in the system. Integrators have strengths on marketing network and usually have High-level status, while the modular makers only have ordinary technology ability which keeps them in the Low-level status. Obviously, standard-makers and system integrators have greater influence than ordinary module manufacturers.

2.3. Network effect in modular production network

Network Effect, also known as positive Network Externality, is one of the most important concepts in the information economy. The value of products is increased when there are more users using the same products or compatible products, which leads to the positive Network Externality [9]. Network Effect follows Metcalfe’s Law: the more users that a product has, the greater utilization of the product each user have. It is critical that Network Externality can improve the modular production network’s competitiveness. In a modularized system, module suppliers are responsible for the production of specific modules. A system integrator is in charge of the decomposition integration of the modular system [10]. Unified link rules ensure that module integrators can find suitable module suppliers in modularized system. The larger the network is and the more high-quality module suppliers available, the more module combinations we can choose from. In addition, the general interface ensures that the system knowledge can be shared in modularized systems and generate collective learning effect. Second, module suppliers can choose competitive integrators to cooperate with. This leads to the formation of the optimal and competitive modular production network.

2.4. The innovative capacity of modular production network

The encapsulation of information process makes modules work independently without external interference, hence one module can have its own innovation activities. The paralleled work of the modular system can widen the range of products to meet with the increasing consumer’s demands on personalized products. “Back to back” competition is like a tournament game, which can greatly generate the enthusiasm of innovation. Aoki believed that the whole Silicon Valley is a big module clusters. Each company is a unique module in the clusters. To better understand the modular production network, we added three dimensions associated with innovation (see Fig. 3). First, the time dimension $T$. Second, knowledge control parameters $\lambda$ in the innovation process. Third, the knowledge dimension $\kappa$, which includes both explicit and tacit knowledge, and “local knowledge” in a specific environment raised by
anthropologist Geertz, and so on. Then we can explain the process of modular innovation in three-dimensions. A and B are two module producers provide same intermediate goods in high-tech industries but there’s no personal information exchange between them. We define this as "back to back" competition. The nodes from $a$ to $j$ shows the division and evolution of innovation knowledge, and the connections between nodes represent the possible evolution paths of innovation.

At time $T_0$, A and B start their innovation activities, A starts from $S_1(\kappa, T_0, \lambda_1)$ while B from $S_2(\kappa, T_0, \lambda_2)$. Both A and B start from the same time, but quite different in their knowledge coordinate and control parameters, which shows the differences in their knowledge and the ability to innovate. A and B evolved a different number of nodes because their difference in $\kappa$ and $\lambda$. Till the time point $T_1$, A has evolved 6 innovative nodes ($a$, $b$, $c$, $d$, $e$ and $f$) and 7 further evolution paths; while B has evolved 4 innovative nodes ($g$, $h$, $i$, $j$) and five further evolution paths. Altogether A and B have evolved 12 innovation paths that could be further evolved. Innovative modular branch can raise the variety of innovative options.

The heterogeneous innovative options in branches give a variety of options for modular system integrators to choose. This greatly increases the competitive ability of the whole industry.

2.5. The adaptability of modular production network in dynamic environment

The more closed a system is, the higher risk that it may lose its competitiveness. A modular production network is an open and self-organized system that can evolve spontaneously. Therefore modular production networks can cope with the endogenous risk. We can take Silicon Valley as an example to show how industry clusters gain unique advantages to avoid risks through modularization. First, according to Williamson’s theory on Specific Assets, the risk of specificity assets can be avoided through vertical integration. However, at the same time, vertical integration may increase the levels of organization, and cause “X low-efficiency” problems. The modularized industrial clusters can solve the problems of specificity assets [10]. This is because the modules in the clusters can work paralleled, and each module’s innovation activities will not affect the other modules. That is, modularized clusters can lower the risk from excessive Idiosyncratic Exchange. Secondly, because of the “back to back” competition, modules in the modularized industrial clusters tend to work independently. This can better avoid the risks of strategic convergence. In other words, any module supplier could be replaced by potential competitors. There are many alternative module suppliers available for integrators to choose to avoid future risks and uncertainties [11]. Moreover, because of the united link rules, modularized systems can evolve automatically without pre-concentration.
2.6. Competition in Modular production network

A modular production network is a system with competitive and dynamic vitality. In modular production system, each sub-module is a relatively complete sub-system and functions independently no matter at which level. According to system economics, property rights arrangement should firstly meet the property rights demand of lower level economic subjects when the property rights demand of low-level economic subjects are met. There are also property rights arrangements for the high-level economic subjects [7]. The economic subjects in modular production network have their own property rights arrangement no matter how low the level of economic subjects is at. Problems inherent from bureaucratic organizations can be avoided through proper arrangement on property rights. Each economic subject has its own independent “personality” which stimulates all economic subjects’ enthusiasm for production and innovation. Meanwhile, because of the system information assimilation, the economic subjects in modular system have big pressure on potential competition.

3. Conclusions

Information encapsulation enhances the heterogeneity innovation activities and increases the possibility of successful innovation. System information assimilation advances the free play of innovation activities in each sub-module. These provide a variety of innovative options for the future. Companies with the advantages in technical and human capital should strive to become standard makers in the market. The owner of standards can get excess profits because of the Network Externalities and super innovation capability. Companies with advantages in social capital should try to be integrators in modularized system. In addition to the standard makers, system integrators can gain high profits. The development of intra-product division is an obvious trend. Medium and small-sized companies need to have competitive advantages in their own specialized field in order to gain relative competitiveness. And they need to avoid over-diversification. Companies should emphasis more on coo-petition rather than competition. Under the conditions of modular system, the whole industry chain can be split, rearranged, and divided into several smaller modules. Free competition would arise in many areas, even in natural monopoly industries. Market concentration rate might be increased because of network externality or modularized network effect. Market concentration rate is no longer a criterion to judge the market’s efficiency. More attention should be paid to the market’s monopolistic behavior rather than its monopolistic structure.

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