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Quasi-open Product Architecture and Technological Lock-in: An Exploratory Study on the Chinese Motorcycle Industry

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Abstract: From the perspective of product architecture, we attempt to explore the reasons why the Chinese motorcycle companies are stuck in the imitation of focal models of foreign makers, on the other hand expanding their production volume to the No.1 position in the world. We propose that the architectural transformation of the original focal models to quasi-open ones mainly through horizontal coordination among local suppliers is the possible mechanism, which blocks the assemblers' paths of accumulating product development capability. This happens at the stage of structural form duplication, which weakens their incentives to progress further and reverse engineering stage.

Keyword: quasi-open architecture, technological lock-in, supplier, motorcycle, China

1. Introduction

One salient paradoxical phenomenon amidst the fast growth of China's manufacturing industry is that while enterprises expand production volumes in a speedy way, the accumulation of their R&D capabilities lags far behind. In this paper, we spotlight the motorcycle industry which is a typical field for examining this problem. Although since 1993 China has become the largest production site of motorcycles in the world, almost all the models are developed by foreign companies mainly from Japan. We attempt to explore the underlying mechanism that drives such technological lock-in of the Chinese motorcycle enterprises from the perspective of product architecture and expect to generalize our analysis to understand the development path of other manufacturing industries of China.

Product architecture is the concept of product design methodology and is defined formerly as “the scheme by which the function of a product is allocated to physical components and by which the components interact” (Ulrich, 1995). It has been shown as a new significant perspective to analyze both business strategy of individual enterprises and the industry dynamics (Baldwin & Clark, 2000; Fine, 1998; Fujimoto, Takeishi & Aoshima, 2001). When looking back to the motorcycle industry of Japan fifty years ago where some similar imitation activities to those of the current Chinese enterprises have been frequently pointed out, we may see that perspective of product architecture can also be persuasive of the industrial dynamics. Until the mid 1950s, there were more than hundred assemblers in Japan who during their primary learning stage conducted imitation of European and American models. The turning point came as Honda developed Super Cub C100 model in 1958 and then achieved mass production in 1961. By completing the product-specific component design internally and realizing the optimal coordination among components, C100 model features in a closed and integral architecture. Combined with the cost down effect from mass production, it became one dominant design and speeded up the shake-out of many competitors from the industry. In the mid 1960s, the industrial structure converged to an oligopoly with only four companies surviving.

The closed and integral product architecture strengthened by cost advantage profoundly changed the dynamics of the Japanese motorcycle industry. Will history repeat in China? The answer appears to be “no”. It is paradoxical to observe that after a long span of about two decades of development, even though the top companies have the capacity of one million units and the collective production volume has overtaken Japan to become the No. 1 in the world, the Chinese enterprises still keep on imitating the models from foreign companies such as Honda’s CG and CB models. What are the factors impeding the incentives of the Chinese companies to go beyond the sphere of the gravitation of foreign product technology? In the following, we will tackle this “lock-in” problem and examine the relationship between product architecture and the industry dynamics in China. Section 2 presents a framework on the process of product development capability accumulation which is derived from design process and the concept of product architecture. Section 3 presents one case study on product development competition in the Chinese motorcycle industry and finally the discussion and conclusion are addressed.

2. Process of Product Development Capability Accumulation

The current situation of product development in the Chinese motorcycle industry has been described as "imitation" or "modified duplication" (Ohara, 2001). We try to operationalize these concepts here by putting them in a systemic framework derived from design methodology and product architecture perspective. We stress that it is important to distinguish two different imitation stages during the process of accumulating product development capabilities, one is structural form duplication and the other is reverse engineering. The hurdle hard to overcome during the transition from the former to the latter is considered to be the core of the technological lock-in problem.

Generally, the process of product design and development is consisted of the following steps. After the clarification of product concept, the basic design is carried out to formalize the concept during which required functional parameters are specified and functional structures are established. Then preliminary layout and form design optimization of product and their refinement and evaluation against technical and economic criteria are conducted. Finally in detail design process, complete detail drawings of components and production documents are finalized after iterative trial-and-errors (Clark & Fujimoto, 1991; Pahl & Beitz, 1988; Ulrich & Eppinger, 1995).

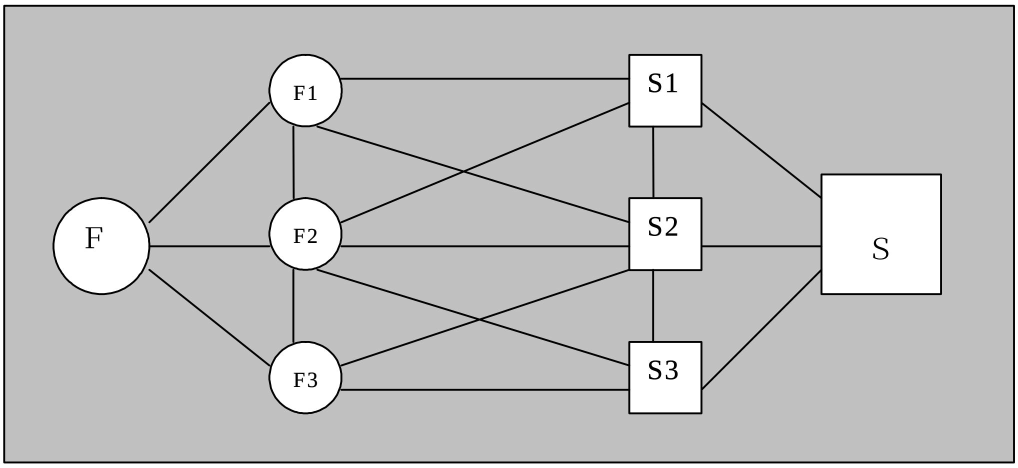
During this process, we can see that "decomposition" and "synthesis" activities are the cornerstone to find the design solutions that manifest the required functional specification. First, the overall function specification should be decomposed into some sub-functions so as to establish function structure. Then after physical principles and form design features are applied to design components that implement sub-functions, the design solution is reached by composition (assembly) of components. We can see that how to decompose functional specifications and how to synthesize components into a systemic whole are actually the issue of product architecture.

As mentioned above, product architecture is "the scheme by which the function of a product is allocated to physical components and by which the components interact" (Ulrich, 1995). In detail, it contains three aspects. One is the establishment of function structure, the second is the mapping from function structure to physical structure of components and the third is the specification of the interfaces among components. Figure 1 shows the diagram reflecting these basic ideas and the design process from left to right (Fujimoto and Ge, 2001; Takeishi, Fujimoto & Ku, 2001).

The framework of design methodology and product architecture provides an analytical apparatus to our concern on the imitation activities of the catch-up enterprises. By looking at the diagram in Figure 1 in an inverse way from right to left, we can derive a framework for analyzing the path of the development capability accumulation for catch-ups. Similarly, the path is also consisted of three steps.

As the first step, the learning companies just disassemble the focal models, make the copies of the physical components and then try to reassemble them. Since the activities focus on the decomposition

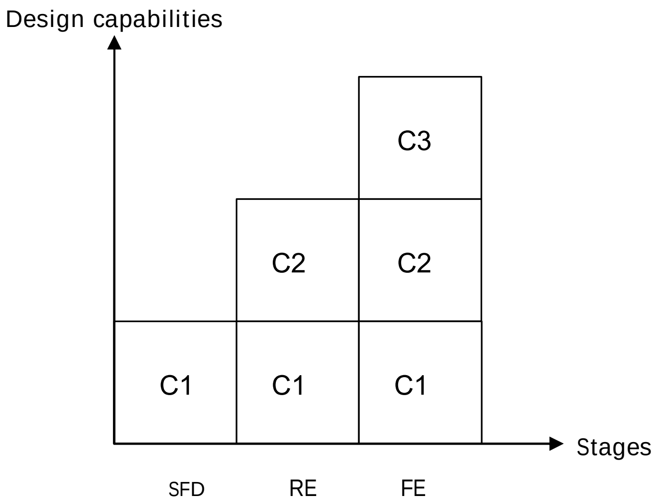
Figure1. Design Methodology and Product Architecture



Sources: Ulrich (1995), Pahl and Beitz (1988), Takeishi, Fujimoto and Ku (2001), Fujimoto and Ge (2001).
Note: F: overall function of product. F1, F2, F3: sub-funtions of product.
S: Physical structure of product. S1, S2, S3: components of product.

of physical products and the superficial imitation of the form of the focal model, we call this step "the structural form duplication stage." On the second stage, the learning companies go further to detect the functional design of components and their structural interfaces. Put differently, the mechanism for mapping the functional elements to physical components begins to intrigue the imitators. Why this component is made in this form and why two components are linked in this way becomes their main concern. Based on the increased understanding of components and interfaces, different combinations (mix-and-match) of components of different focal models or the variation, addition or omission of individual components are made to modify designs to satisfy some special demands. Gauging and testing are essential during this stage and investments in both hardware and software are necessary. Data base continuously acquired from hypothesis testing and experiments are step stones to exploring the function structures of focal models. With the aim at solving the inverse problem of the function-structure mapping issue, this stage is termed as "reverse engineering stage." On the third step, the learning companies have been equipped with the capabilities of reaching physical solutions to functional requirements and they try to create new concepts and formalize them into functional structure. Rather than making imitations and following the inverse process of product development process, the companies are capable of doing the forward engineering and trying to launch new products on markets. Therefore, we call this stage "the forward engineering stage." Figure 2

Figure 2. Three-stage Process of Accumulating Product Development Capabilities



Note: SFD: structural form duplication; RE: reverse engineering; FE: forward engineering
C1: capabilities of copying physical components and structural design;
C2: capabilities of detecting and arranging the function-component mapping;
C3: capabilities of product concept creation and functional structure establishment.

shows this three-step process.

Such framework can make the analysis on imitation operationable. We especially stress that distinguishing the first two stages is important to recognize the imitation activities and predict the development of imitators. The structural form duplication stage is featured by superficial imitations of the forms of focal models and companies cannot progress unless function-structure mapping problems are tackled. By contrast, reverse engineering stage is actually the entrance to the original product design and development. It may be perceived that learning companies can transit smoothly from the first stage to the second as the history of the Japanese motorcycle industry shows, but in the case of the concerning industry in China, we found that some economic forces are locking the companies into the first stage and impeding their incentives to move forward. In the following, we will present a case study of this lock-in phenomenon.

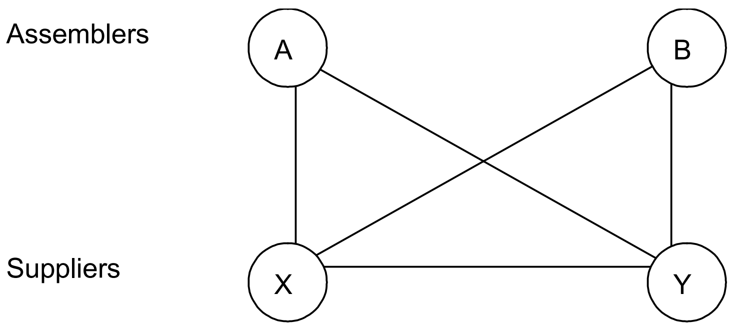
3. Case Study: Product Development Competition in the Chinese Motorcycle Industry

During the historical development of the motorcycle industry in China, there are two generations of imitators. The first generation is a group of state-owned assemblers who have acquired the technology licenses of some focal models through technological cooperation and joint ventures with the Japanese partner companies such as Honda, Suzuki and Yamaha in the 1980s and the 1990s. The second generation of imitators is a group of private-owned start-ups who have achieved fast growth from the mid 1990s. Lifan, Zongshen, Longxin and Dachangjiang are the good examples who not only have relatively large shares in domestic market, but also top the exportation. Without close collaboration with the Japanese makers, they attempt to duplicate and modify focal models by exploiting the strength of local suppliers. Therefore, in our case study, we chose one first-generation state-owned imitator assembler A, one second-generation private-owned imitator assembler B, one frame supplier X and one cowling parts supplier Y. The case setting is shown in Figure 3. The links between assemblers and suppliers show the transaction relationships, and the link between two suppliers shows the coordination relationship. There is no link between two assemblers since they only compete on the market and have no direct relationship.[1]

We chose frame and cowling parts as our samples of components because frame is the backbone of motorcycle and interacts closely with engine, suspension, styling design and other main functions. Cowling parts make a large proportion of exterior styling design of motorcycle and are especially important for imitator makers. Furthermore, frame and cowling parts need good coordination since how well the latter is mounted on the former is important to the appearances of products that influence directly the perception of customers. Our investigations in 2002 found an interesting case of product development competition between assemblers A and B in Chongqing city, during which Honda's Super Cub C100 model was copied targeting the Vietnamese market. By the means of semi-structured interview and cross-investigation on both sides of assembler and supplier, we think the subjective bias of our respondents can be greatly reduced.

When both assemblers A and B almost

Figure 3. Case Setting: An Inter-firm Network



Note: Company A: the first-generation state-owned imitator assembler,
Company B: the second-generation private owned imitator assembler,
Company X: frame supplier,
Company Y: Cowling parts supplier.

[1] See Ge (2004) for details of the case study.

simultaneously determined to launch the copies of Cub model in Vietnam market in 2001, suppliers X and Y also started to duplicate the parts of the focal model independently. Since for imitators the product development process starts from the physical decomposition of the existing focal model rather than from the abstract product concept, suppliers can duplicate the relevant parts as long as their selection of focal models is consistent with the assemblers' choices. As suppliers develop the parts of the focal model in a parallel way with assemblers, transaction patterns between enterprises diverse.

One pattern is closed to "drawing-supplied system (taiyozu)" (Asanuma, 1989) under which assemblers make the imitation of the focal model and outsource only the manufacturing tasks to suppliers. Under this pattern, since assemblers carry out the imitation of the whole system of the focal model in a top-down manner, they are likely to go beyond the superficial form duplication and move to the reverse engineering stage to detect the functional design on a deeper level. The design drawings provided to suppliers contain the specifications of form parameters, installing tolerances, materials, and the processing techniques. The second pattern is "drawing-approved system (shoninzu)" under which assemblers take out the parts from the focal model sample and send them to suppliers. Suppliers are required to make the drawings and then manufacture the parts. In this case, the ownership of drawings belongs to suppliers. The third pattern is "purchased parts system (shihanhin)" in that suppliers duplicate the parts of focal models independently and assemblers purchase them via the catalogue of suppliers. Modification of component design to suit better the needs of assemblers is feasible in this case.

During the competition to launch the Cub model in the Vietnamese market, assemblers A and B adopted quite different strategies in choosing transaction patterns with suppliers. Assembler A conducted the in-house reverse engineering of the focal model and tried to make the optimal coordination of components in a top-down way. It chose "drawing-supplied system" when purchasing the parts from suppliers X and Y. By contrast, assembler B just made the search for the suppliers who have developed the parts and then purchased frames and cowling parts from suppliers X and Y directly by cash. The outcome is the lead time of assembler B was greatly shortened compared to company A. Actually, many other private-owned assemblers adopted the same strategy as assembler B's and rushed to purchase the parts of Cub model and then sent their products to Vietnam. After assembler A completed its development work and launched its products in the Vietnamese market, it turned to be too late since a pricing war had been triggered that made no profit margin for the late comer. Having learned this lesson, assembler A determined to reform its purchasing system and reallocate the authority of procurement from product development department to its purchasing function. Then changes have taken place as purchased parts system and drawing-approved system are increasingly adopted.

The merit of shortening development lead time by outsourcing design tasks is obvious in this case. In addition, the open transactions conducted by suppliers with multiple assemblers can also reduce costs as production volume increases. The question is that whether design quality can be secured through the purchased parts system when the components such as frame and cowling parts are closely interacted and have great influence on the styling appearance of motorcycle. Has assembler B in our case just wanted to send the cheap products quickly to the market while sacrificing the quality? Our further investigation found that the quality concern such as tolerance coordination was not considered as the secondary issue by assembler B, as suppliers were responsible for the quality guarantee under the purchased parts system. Frame maker X and cowling parts supplier Y had relatively close communication during developing the parts of the Cub model. The technical staffs had exchanged the parts of each other to make the test installation and attempted to adjust the parts to better coordination. The cowling parts supplier Y also purchased lamps from another supplier and made the subassembly of lamps and cowls, which was another important styling design quality point. Therefore, under the coordination between suppliers, the subassembly of frame, cowls and lamps was achieved. We can call this kind of subassembly a "module" since it can be delivered to multiple assemblers like a standard one.

4. Discussion and Conclusion

Our case study showed that the bottom-up coordination between suppliers resulted in modules that can be procured by assemblers using the purchased parts system. The advantages in lead time shortening and cost reduction of such strategy dominated the reverse engineering by assemblers in a top-down manner and the choice of the drawing-supplied system. Due to its bottom-up feature, the coordination between suppliers is localized within the close neighborhood of the parts they make and is different with the top-down modularization in which components' interfaces are specified beforehand. By such efforts of independent suppliers, almost all best seller motorcycle models have been copied with their components transformed as standard parts that can be ordered via catalogues. We call such phenomenon "the architectural transformation" in that the closed integral architecture of the focal models by the Japanese makers has been changed while the models are decomposed into several series of components that can be easily procured from open market. While mix-and-match of different focal models' components is yet relatively few, we call such architectural attribute of motorcycles in the Chinese market as "quasi-open" to differ it with the open product architecture with total compatibility (Fujimoto, 2002).

The quasi-open architectural attributes of motorcycles deeply influenced the competition rule within the industry. The advantages on the aspects of lead time and costs speed up the product life cycle and make price competition fierce, and paradoxically, weaken the incentive of enterprises to invest in long-term R&D activities. While suppliers can improve manufacturing quality and their understanding of the parts they produce and the interaction between other parts in the close neighborhood, the knowledge is still the local one. The more serious problem is that suppliers are very likely to have no interests in understanding why the parts are designed in those configurations and what the roles of the parts play in the overall product. Using our terminology in the previous section, suppliers may have less incentive to understand the function-component mapping and let alone the establishment of the functional structure. For assemblers, the design outsourcing has made the knowledge of components dispersed in suppliers. It is difficult for them to accumulate the integration or synthesis capability.

Therefore, our conclusion is that the quasi-open architectural attributes achieved by the bottom-up coordination efforts of suppliers, together with the design outsourcing strategy adopted by assemblers to shorten the lead time and increase production volumes lead to the paradox that enterprises in the Chinese motorcycle industry have been locked into the existing product technologies since the incentives of making reverse engineering are impeded on the path of accumulating their product development capabilities. Future studies are needed to examine other key functional components such as engine and suspension, and so on and to exploit quantitative survey to get more generous recognition. We are also curious to know that how the Chinese enterprises move forward out of the lock-in situation and how the perspective of product architecture can offer strategic solutions to the problem.

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