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An Investigation into Collaborative Novel Technology Adoption in Vertical Disintegration: Interfirm Development Processes for System Integration in the Japanese, Taiwanese, and Chinese Mobile Phone Handset Industries

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Abstract: The study attempts to elucidate how novel technologies are introduced into products through interfirm collaboration under vertical disintegration drawing on the cases of the Japanese, Taiwanese, and Chinese mobile handset industries. The global surge of vertical disintegration enhances the interfirm modularity of development processes. Nevertheless, the adoption of a novel technology platform requires collaborative development processes between a technology platform vendor and a product developer. The level of collaborative processes is relevant to system integration of nested modules, which is driven by the necessity of system knowledge, rather than technology integration. These findings show that effective system knowledge management through intefirm collaboration plays a critical role in the assimilation of novel technology platforms into products even in modularized interfirm development processes. The collaborative process could even secure the systemic evolution of technologies and products under vertical disintegration.

Keywords: novel technology adoption, vertical disintegration, modularized development processes, technology platform, product design, system knowledge, system integration

1. Introduction

In the past decade, interfirm modularity and related open interfirm networks have drawn our attention (e.g., Berger & MIT Industrial Performance Center, 2005; Chesbrough, 2003; Chesbrough, Vanhaverbeke, & West, 2006; Christensen, Verlinden, & Westerman, 2002; Iansiti & Levien, 2004; Sturgeon, 2002). Product modularity, which is based on standardized product design rules and elements, enables manufacturers to decompose complex problem-solving into a set of localized problem-solving steps (Baldwin & Clark, 2000; Langlois & Robertson, 1992).

The shift to modular product architecture has enhanced interfirm modularity. Every specialized vendor covers a specific component/technology development while manufacturers focus on product development by sometimes outsourcing manufacturing. A variety of component/technology vendors and manufacturers have shaped the global, open, interfirm development networks so that even emergent firms may rapidly provide products at a relatively low cost by adopting novel technologies from specialized vendors.

For instance, wireless handset manufacturers in China have taken full advantage of the global interfirm network in which specialized vendors provide element technologies (e.g., wireless cores/platforms) to enable handset manufacturers to quickly release a variety of new models: almost 1,500 models were reported to be on the market in 2006.

The industrial shift seems to blur the role of close coordination within and between firms, which was once regarded as one of the most critical factors in effective product development (e.g., Japanese automobile firms; Clark & Fujimoto, 1991; Dyer & Nobeoka, 2000; Yasumoto & Fujimoto, 2005). Especially in the digital electronics industries, open interfirm networks based on product modularity could upset existing knowledge that has been accumulated in close coordination within and between firms, and thus threaten the competitiveness of incumbent firms (Berger & MIT Industrial Performance Center, 2005; Christensen, et al., 2002).

Firms take advantage of external complementary resources in open interfirm networks, so that the industrial shift enhances open innovation (Chesbrough, 2003; Chesbrough, et al., 2006). Platform vendors which develop and provide standardized technologies with basic system knowledge lead open interfirm networks by arranging proper development environments for suppliers and manufacturers (Gawer & Cusumano, 2002).

Among a variety of element technologies, technology platforms consisting of the chipset, basic software, reference design, and related technological supports play a critical role in shaping open interfirm networks (Gawer & Cusumano, 2002; Iansiti & Levien, 2004; von Hippel, 2006). A technology platform is a set of core technologies, which defines the interdependencies within and between different technologies and components.

The platform provides the condition of product modularity which secures architectural stability. Manufacturers may easily develop products by using the platform that provides standardized architectural knowledge to define interdependencies between technologies/components and realize a set of basic product functions. When product architecture is stabilized as modular, open transactions within/between firms can serve as a forum for product development (Cusumano, 2004; MacCormack & Verganti, 2003). The stability enables firms to refurbish modular products by realigning or replacing a part of element technologies without changing the architectural configurations of elements.

Such technology platforms thereby shape ecosystems that are available to any firm interested in the concerned products (Chesbrough, 2003; Chesbrough, et al., 2006; Iansiti & Levien, 2004: von Hippel, 2006). Firms enrolled in the ecosystem are not assumed to span both the task and knowledge boundaries between them, even though technology/product development capabilities have been thought to rely on the ability to span the boundaries of firms (Henderson & Cockburn, 1994). Rather, firms can do nothing but provide and/or take advantage of standardized components/modules based on the platform.

The traditional idea of such interfirm modularity relies on the presumption that the processes of technology development and product development are mutually independent as technologies are standardized to the extent that any product development firm can easily exploit them. The reality of vertical disintegration shows that processes from technology development to manufacturing are modularized into quasi-independent processes so that different firms can specialize in each process (Jacobides & Billinger, 2006; Sturgeon, 2007).

Typically, vertical disintegration is characterized by the federation of modularized interfirm development and manufacturing processes such as technology platform development, product design, and manufacturing, each of which is implemented by independent specialized firms. Even system knowledge could be provided by specialized vendors, such as technology platform vendors, independent design houses (IDHs), and original design manufacturers (ODMs), in the modularized interfirm networks.

However, the interfirm modularity of development processes is not necessarily secured as presumed. A study of automobile development reveals that existing knowledge boundaries between firms are blurred due to the necessity of both component and system knowledge when new technologies are introduced into automobiles (Takeishi, 2002). The problem can also occur in the industries of vertical disintegration (e.g., digital product industries) in spite of the differences in the levels of product modularity and vertical disintegration from the automobile industry (Takeishi & Fujimoto, 2003).

Particularly, at the beginning of the adoption of a set of novel core technologies, typically a technology platform, the platform is not sufficiently stabilized as a part of a product system. The technology platform development as well as product development would require at least system knowledge in order to reconcile the novel core technologies with product system design(s), even though the technology platform's and related element technologies' component knowledge are each enclosed in specialized vendors in the modularized technology development processes. The fluctuating knowledge boundary would make it difficult to develop a novel technology platform into a distinctive product design without interfirm collaborations between the concerned technology platform vendor and product developer(s).

Previous studies focused mainly on the role of existing platforms in business ecosystem formation and open innovation by presuming modularized interfirm processes based on stabilized core technologies. However, we still do not have sufficient knowledge of how the adoption of novel technology platforms, a set of core technologies, is enhanced under the modularized interfirm development processes.

We attempt to explore how specialized firms participating in modularized interfirm development processes collaborate with each other when the technologies become unstable. More specifically, this study will examine how technology platform vendors and product development firms develop new technology platforms into product systems through collaboration in modularized interfirm development processes. The study hopes to contribute to elucidating how and why collaborative novel technology adoption is enhanced in modularized development processes under vertical disintegration.

In section 2, we review past research in order to propose our perspective. In section 3, we attempt to describe successful collaborative interfirm processes for novel technology adoption to product systems drawing on three cases in the Japanese, Taiwanese, and Chinese mobile handset industries. In section 4, we discuss the findings and their implications for novel technology adoption under interfirm development process modularity. Finally, in section 5, we summarize our findings and implications and point to future research issues.

2. Research perspective

Modular architecture products are characterized by lower interdependencies of functions and components, so that product developers can easily divide the development activities into relatively independent elements (Baldwin & Clark, 2000; Langlois & Robetson, 1992). Standardized knowledge of product technologies, which is independent of firm/product-specific contexts, enhances product modularity, and eventually, the open interfirm division of labor.

Nevertheless, product modularity does not necessarily provide definite architectural system configurations sufficient for modular product designs, and thus product modularity per se would not ensure the openness of interfirm component sourcing networks: interfirm modularity. A modular system often does not contain complete knowledge of the component configuration of a product system.

Even a digital product composed of mutually independent modules is not regarded as a complete modular system, and thus product development is not necessarily attributed to the combination of standardized components/modules (Staudenmayer, Tripas, & Tucci, 2005). Firms often face system-related problems as standardized component/module supplies do not automatically secure system consistency of the product concerned.

At the same time, incomplete modularity provides firms with room to develop proprietary technology platforms and product designs. The availability of standardized technologies also encourages firms to develop proprietary distinctive systems. Standardized technologies which can be transferred and/or shared between firms do not ensure the firms' competitiveness (Pil & Cohen, 2006).

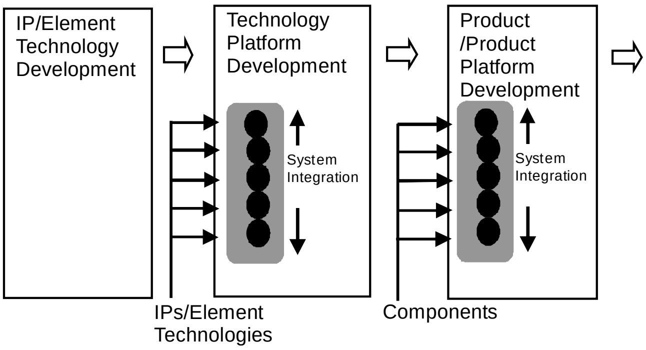
As is reported in many of the cases from the Chinese industries, the availability of standardized technologies in open product development networks is liable to cause harsh competition between firms that adopt the same/similar components/modules and core product technology bases (i.e., technology platforms). Thus, firms are encouraged to shape proprietary designs (e.g., proprietary software platforms, Cusumano, 2004; MacCormack & Verganti, 2003), even though standardized core technologies and modular architectural configurations are provided.

The reality of interfirm modularity shows that competitive technology/product development requires system knowledge to properly arrange various elements in consistent systems. Even though processes from technology development to manufacturing are modularized by specialized firms, each of manufacturers and vendors needs to assimilate various technologies into their products with paying attention to the uneven changes of various components and the interdependencies between them (Brusoni & Prencipe, 2001; Brusoni, Prencipe, & Pavitt, 2001). Firms without essential system knowledge cannot shape, even exploit, standardized component/module supply chains.

The criticality of system knowledge in product development indicates that standardized core technologies, technology platforms, do not automatically secure sufficient system knowledge to realize product modularity and related interfirm relationships. Rather we may predict that specialized vendors and firms under vertical disintegration collectively carry system knowledge through modularized interfirm development processes.

Technology development and product development are conducted separately by different firms in modularized development processes in vertical disintegration. Core technology development from technology planning to platform development is covered by specialized vendors while products are designed by product developers such as brand manufacturers, ODMs, and IDHs. In modularized

Figure 1. System integration in modularization of interfirm development processes



interfirm processes, each of these vendors and firms plays a different role.

Upstream vendors and downstream firms each attempt to integrate diverse knowledge across components or technological disciplines at their focused levels. These vendors and firms implement “system integration” assimilating various elements into consistent systems at each stage from technology development to product development in modularized interfirm development processes (Figure 1). System integration at each stage yields standardized system knowledge available at downstream stages. Such efforts in each vendors and firms together enable process modularity of value chains (Sturgeon, 2007), which is called modular “vertical architecture” (Jacobides & Billinger, 2006).

Product developers build information channels to monitor components and technological changes that could influence their product systems, so that they can shape consistent and distinguished product designs by integrating a variety of product elements into consistent product systems. On the other hand, core technology vendors, such as technology platform vendors, attempt to encapsulate a variety of element technologies into their technology platforms. Technology platform vendors, who attempt to examine and secure both platform stability and consistency with product systems, monitor and integrate element technology knowledge (e.g., intellectual property: IP) in order to devise prominent platforms (Iansiti & Levien, 2004).

Product development processes are in general characterized by interlinked systemic problem-solving (Clark & Fujimoto, 1991; Iansiti, 1997; Takeishi, 2002). In the context of a series of systemic problem-solving, firms at least need to have system integration capabilities to implement the evaluation, test, and selection of components/technologies and product designs.

The scope of system integration may expand even beyond interfirm boundaries between modularized interfirm processes. Drastic changes in core technologies, such as technology platforms, can have a more radical impact on coordination within and between firms. The adoption of novel core technologies, technology platform, may lead to interdependent changes of functions and components to the extent that the existing decomposability between system designs and elements is upset. Such technological changes may not any longer secure interfirm product modularity as the knowledge on modular architectural configurations turns unstable.

Moreover, the degree of integration of product-level functions and technologies into a technology platform may also have a drastic impact on architectural configuration of components/technologies. Continuous improvement of the advanced technology of the semiconductor process fosters the convergence of product functions. Accordingly, specialized chipset vendors (i.e., technology platform vendors) offer technology platforms as nearly total solutions that encapsulate product-level functions and technologies into one chip. Higher degree of encapsulation reduces product design activities. The progress of function encapsulation built on SOC (System on Chip) continuously redefines the architectural interdependencies of functions and components.

These drivers will shake interfirm development process modularity even though task boundaries between upstream vendors and downstream firms are obvious in vertical disintegration. Each technology/product development process is completed within each firm as both task and knowledge boundaries correspond to interfirm boundaries. However, both upstream vendors as well as downstream firms need to mutually exchange related knowledge in intensive contacts when such technological changes occur (Takeishi, 2002). Systemic problems are hardly examined before technologies are applied to real product. Dim knowledge boundaries within and between upstream vendors and downstream firms call for intra/interfirm coordination (Brusoni, et al., 2001; Prencipe, 2003; Takeishi, 2002). Such knowledge overlapping accordingly calls for overlapping problem-solving processes across technology platform vendors and product developers.

Interfirm development process modularity can not be automatically ensured in novel technology platform introduction. Rather problem-solving in novel technology adoption will drive firms to span interfirm boundaries over deeper system knowledge, so that close coordination between firms is indispensable in spite of interfirm product development process modularity. Thus, even in vertical disintegration, collaboration between technology vendors and product developers will contribute to reducing systemic problems in advance and enhance development performances.

Yet, here we should note that novel technology adoption in the modularity of interfirm product development processes is distinguished from “technology integration” (Iansiti, 1997) within a single firm (Yasumoto, 2006). Technology integration is liable to require a single firm to have vast knowledge, even scientific knowledge, to select and refine new technologies. Technology integration is mostly dedicated to cope with high technological uncertainty.

A firm needs to enhance experiment capabilities to generate knowledge which can simulate product development situations at technology development stage (i.e., knowledge generation), to retain the stock of past technology integration experiences which can complement the results of experiments (i.e., knowledge retention), and to team up a dedicated group which can analyze technical feasibility before the beginning of project (i.e., knowledge application).

On the other hand, novel technology adoption under interfirm development process modularity rather focuses on system integration that makes novel technologies suitable for product system designs. Collaborative processes between independent vendors and product developers cannot directly cope with both technological uncertainty and product system complexity. Rather, the processes are oriented to mediate between basic technology system knowledge on underlying core technologies and product system knowledge on product designs. A novel technology platform encourages the overlapping of basic technology system knowledge and product system knowledge, as both are relevant to system integration across the platform development and product system design. Thus, the scope of the interfirm process overlapping under interfirm development process modularity would be largely restricted to system-related problem-solving processes while technological uncertainty is high in novel core technology development.

The necessity of a deeper level of "system knowledge" across upstream vendors and downstream firms would require such overlapping coordination. The system knowledge helps project feasible configurations between core technologies and components/devices. The knowledge is a deeper level of knowledge beyond the architectural level (Prencipe, 2003).

Novel core technology adoption should cause fundamental system instability due to core product technology newness, and thus would require system knowledge which is deeper than specific architectural system knowledge of each technology platform/product design. Unless such deeper system knowledge is available, the application and/or exploitation of new basic technology system knowledge on underlying core technologies and product system knowledge on product designs is out of the question.

Many novel technologies become available in the form of standardized components and IPs in open interfirm networks (Chesbrough, 2003; Iansiti & Levien, 2004). Technology transfer may help firms collect external advanced scientific/technological knowledge and thereby choose apt external technologies. However, assimilation of these technologies into product systems requires ripe and sophisticated system knowledge.

Modularized interfirm processes have blurred how such basic system knowledge contributes to product/technology evolution. In the age of modularity, the lack of sufficient system knowledge due to technology platform renewals could be compensated for with close interfirm coordination, in place of vertical integration, between technology platform vendors and product developers.

3. Case studies

3.1. Research focuses and data collection

The study focuses on the adoption of novel technology platforms to handset designs in Japan, Taiwan, and China. Handset developers in all these countries have increasingly exploited external technology platforms from vendors, though the level of vertical disintegration of handset development processes may differ from country to country. All handset developers in these countries attempt to shape proprietary product designs, particularly product platforms, based on standardized technology platforms. However, several technology platform vendors and prominent handset developers are in cooperation with each other for novel technology platform adoption to handset systems in spite of modularized interfirm development processes.

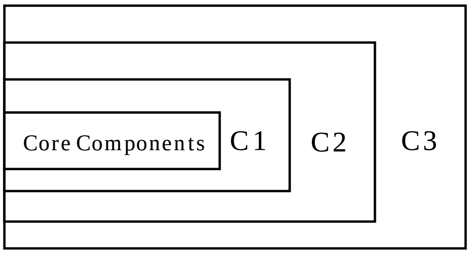
According to Funk (2002), in the initial period of the introduction of second generation (2G) mobile phones from the early 1990s to the mid 1990s (2G digital services began in Europe, Japan, and US in 1992 or 1993), mobile phone handset manufacturers internally developed mobile phone handsets using customized core components. However, specialized vendors started to offer standardized core baseband (BB) chipsets from 1996 to 1998 and technology platform solutions around 2000. After that, technology platforms and product designs were developed separately.

The process modularization raised a new issue in the mobile phone handset industry, namely, how to effectively refine and introduce a novel technology platform into handsets. Many vendors renew their technology platform every 1 to 2 years, depending on the evolution of applications and technologies. Yet, it has not been easy to design print circuit boards (PCBs), particularly high frequency and power management circuits, based on a novel technology platform. A novel technology platform does not sufficiently secure product modularity and can cause quite a few problems in PCB design due to the lack of both core chipset stability and verified architectural consistency on handset design configurations. Moreover, the necessity of extended PCB design for application devices and mechanical designs has invited design problems in handset development activities.

A mobile handset product is characterized with a system of nested modules (Dosi, Hobday, Marengo, & Prencipe, 2003). A system of nested modules consists of several levels (Figure 2) corresponding to development processes from core technology development to product design. The core components, a BB chipset with basic software (i.e., drivers, protocol stack, operating system, etc), execute decoding and transferring signals to telecommunication infrastructures.

C1 level consists of basic components, such as several chips (i.e., radio frequency: RF chip, power management IC, memory, etc) and related circuits.

Figure 2. A system of nested modules



C2 level arranges devices (i.e., camera, imaging sensor, speaker, etc) on PCBs and related upper layer software (i.e., middleware, library, application manager/interface, etc). All components, specific applications, and related devices should be integrated into handsets at C3 level. A technology platform may cover not only core technologies but also C1, C2, and C3 levels according to the integration degree.

A novel BB chipset changes the relationships between the BB chipset and C1, C2, and C3 levels, and thus cause system-level stability problems across all the levels. For instance, data accessing timing between BB and external particular memory device (C2 level) needs to be restricted through interface which is defined by BB chipset vendor. However, sometimes, product developers choose the devices that has not verified by BB chipset vendors, so that these devices cause unstable data accessing timing and interrupt other software commands or programs. Once a BB chipset is stabilized, the interfaces of the BB chipset should be verified in the usage of various devices. Yet, in novel technology platform adoption processes, even the interfaces are required to be modified.

The interdependency of technology platform and product design has a critical impact on coordination between upstream vendors and downstream handset developers. Interdependencies may often occur in the handset development process, even though upstream vendors provide standardized technology platforms to define modularized configurations between handset components/devices.

However, novel technology platform adoption would drastically increase process interdependency between technology platform development and handset development, mostly because the consistency between technology platform, handset system design, and other components/devices has not been sufficiently examined and verified. These interdependencies will encourage coordination between the technology platform vendor and its customer handset developers.

This study explains how handset developers collaborate with technology platform vendors in handset product platform development drawing on three cases. More specifically, we explore interfirm collaboration processes for system integration of nested modules paying attention to the interdependencies between core components, C1, C2, and C3 levels' systems and related problem-solving of systemic issues.

The research issues related to interfirm collaboration for novel technology adoption in vertical disintegration still lack references that provide sufficient information as these issues have emerged with recent interfirm modularization. The case study method is useful for exploration and explanation (Yin, 1994) and theory building (Eisenhardt, 1989; Glaser & Strauss, 1967) for such issues. New research issues that are not fully consistent with or explicated by past studies may call for exploratory approaches to lively sources of primary data relevant to new research issues.

The case study method is appropriate for obtaining primary data about such new issues, and thereby helps explore consistent explanation frameworks (Glaser & Strauss, 1967). In addition, case studies shed light on the contradictions between cases and existing perspectives, and urge researchers to shape new frameworks to reconcile them (Eisenhardt, 1989). In particular, multiple-case studies that compare cases with different backgrounds help further excavate and/or refine research issues (Glaser & Strauss, 1967).

Novel technology adoption in modularized development processes may call for new frameworks as it is neither sufficiently explicated by product architecture frameworks nor interfirm technology/product development studies. These advantages of multiple-case study approach encourage us to examine three cases in this study.

The data on handset development was collected by semistructured interviews from 2005 to 2007, in Japan, Taiwan, and China. We can assume that handset business firms in these countries have different backgrounds as their industrial development paths and structures vary (Imai & Shiu, 2007). Yet, we should note that country differences are not our primary focus as the industry is based on the global interfirm networks as is the cases of other electronics industries (Berger & MIT Industrial Performance Center, 2005).

More than 50 firms, including handset manufacturers, mobile service carriers, wireless technology platform vendors, software vendors, component vendors, and IDHs were involved in the study. These firms also include manufacturers and platform vendors from Europe and US. We focus on a relatively competitive handset developer in each country, who develops proprietary handset designs in close collaboration with technology platform vendors. We examine three handset developers since each has participated in the development of a leading novel technology platform, which has significant impacts on the handset business and market in each country and even in the world (Merrill Lynch, 2006; Techno Systems Research, 2007).

About 70% of third generation (3G) handsets of NTT DoCoMo, the largest Japanese operator, were based on the series of the sample platform in 2007. The second platform series is one of the top-selling low cost platforms for the European, US, and leading Chinese manufacturers in the low-end segments of emerging markets, particularly in China, in 2006. The series of the third sample platform is mostly for the Chinese/Taiwanese manufacturers, but accounts for more than 40% of the Chinese handset market in 2006. These achievements make us infer that these samples could provide generalized implications of novel technology adoption even in the global context.

We also make use of information which appeared in published journals and reports. First, we attempt to briefly outline the interfirm handset development networks. Next, we examine the novel technology adoption process in vertical disintegration drawing on three cases of collaboration in these regions.

3.2 Technological structure and interfirm development process modularity

The technological structure of a mobile phone handset is divided roughly into the communication part, signal processing part, power management, and external I/O part. The communication part receives electric waves through antennas and converts the signal to digital data for the signal processing part. The signal processing part has its own central processing unit (CPU) to control the handset system just as Intel processors do in PCs. The external I/O part controls all information inputs and outputs from every component such as display panel and keypad. These parts are laid out on a PCB, which is the terminal main body of a mobile phone handset. The display, key, digital camera, and so on., are devices arranged on the circuit of the terminal main body.

In our investigation, we consider the signal processing part which is in the form of a technology platform because this is the core technology of a mobile phone handset. This part centers on a BB chip that controls signals and implements communication processing. A BB chip is reactive: It is not a passive component that only receives signal. Thus, a BB chip cannot be purchased from integrated circuit (IC) catalogue lists of chip vendors. Recently, multimedia functions have been emphasized in mobile phone industry. Reflecting the tendency, a BB chip not only processes telephone calling functions but also executes multimedia functions, like MP3, high quality of camera imaging, games, video playing, and so on. The value added GSM mobile phone handsets with these functions are called feature phones, smartphones, or PDA phones depending on market segments.

Because of these various function requirements, engineering man-hours required for handset software development have been rapidly increasing. The application, firmware, and operating system (OS) software must be designed in accordance with hardware components. Smartphones and PDA phones often use Windows, Linux, or Symbian OS to control the entire systems of these systems. A feature phone uses real time operation system (RTOS), which conducts real-time switching of each task every 10 micro seconds to control the phone's entire system. Nowadays, as a part of a platform, OS is provided for a mobile phone handset manufacturer by a technology platform vender together with a core chipset.

The development of a BB chip requires system-level knowledge of mobile phone handsets. As multimedia functions have increased, BB chip vendors have had to consider the product architecture for designing mobile phone handsets. BB chip vendors, mostly technology platform vendors, can design powerful BB chips to execute multimedia functions because of advanced semiconductor process technologies. The requirement for system integration may call for a closer relationship between a BB chip vendor and mobile phone handset developer rather than a simple buyer-supplier relationship. In addition, the design of advanced BB chips sometimes involves close cooperation with operators.

Handset developers including brand manufacturers, ODMs, and IDHs need to understand the interdependencies of a chip with handset system design and other components, since the chip is relevant to a variety of functions. The interdependencies drastically increase if BB chip vendors change their chip designs. In a system of nested modules, such innovations of core component design represent movements up the system hierarchy and sometimes lead to revolutionary changes that refurbish basic product system foundations (Henderson & Clark, 1990).

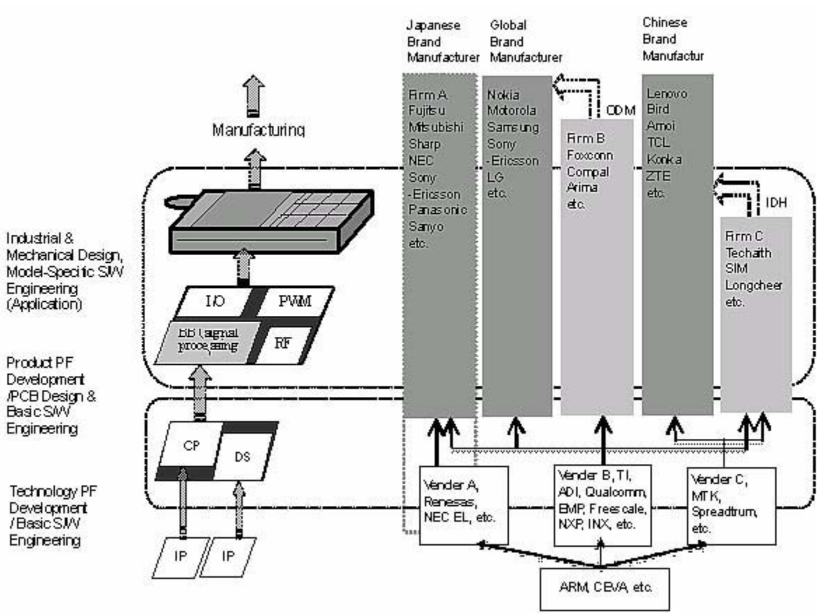
When 2G started booming around 1996, specialized chip vendors (TI, ADI, Philips, Qualcomm, etc.) started to offer standardized BB chip hardware. Nokia and other major manufacturers decided to customize BB chips by exploiting vendors' BB chip processes and hardware technologies. These manufacturers loaded basic software (drivers, wireless interface, RTOS, etc.) into BB chips, and assimilated the customized chipsets with other devices and software for developing their proprietary product/platform designs.

In the early 2000s, these vendors started to provide standardized technology platforms for 2G, 2.5G (GPRS, EDGE), and/or multimodes to expand their market opportunities to new entrant manufacturers, ODMs, and IDHs, particularly in emerging markets. Nowadays, handset development processes are modularized into technology development, technology platform development, handset development, and manufacturing and each is undertaken by specialized vendors or manufacturers (Figure 3).

In Japan, most mobile phone handset manufacturers have developed handsets based on service requirements of operators, and have thus adopted advanced telecommunication technologies such as 3G. Until the early 2000s, major Japanese manufacturers other than CDMA manufacturers, such as Panasonic, NEC, Mitsubishi, and Fujitsu, were equipped to develop proprietary BB chips and software in accordance with individual handset model designs for their local market handsets.

In the 3G era, even the Japanese firms began to adopt customized chips based on standardized technology platforms as they suffered from increasing development costs, which sometimes went up to more than 10 billion yen. Many of these Japanese manufacturers started adopting customized BB chips based on standardized technology platforms provided by specialized vendors or by

Figure 3. Modularity of mobile phone handset development processes



collaborations between manufacturers and vendors.

In Taiwan, PC manufacturers apply their successful ODM business model to the mobile phone handset business. They develop detailed specifications for mobile phone handsets including Ultra Low Cost (ULC) ones by following the specifications from major global manufacturers such as Motorola and Sony Ericsson. At the same time, these ODMs also expanded their component procurement capabilities, and thereby took advantage of economies of scale in their handset development and manufacturing business.

On the other hand, there have been several types of handset development in China. The Chinese mobile phone industry can be regarded as being on a divergent path of upgrading. While export growth has been overwhelmingly led by multinational corporations, the advent of the local handset manufacturers has ignited increasingly fierce competition in the domestic market.

The advent of the local manufacturers has induced a unique industrial evolution in the form of two backward linkage effects: (1) the outgrowth of IDHs specializing in mobile phone handset development, and (2) the emergence of IC fabless ventures that design core ICs for mobile phone handsets. The emergence and evolution of China's mobile phone handset industry will have international implications as the growth of global demand for low-cost and multifunction mobile phone handsets is expected to accelerate (Imai & Shiu, 2007).

Table 1. Brief description of design and test stages

	Circuit/PCB Design	Engineering Verification Test (EVT)	Design Verification Test (DVT)	Production Verification Test (PVT)
Tasks	Simulation, Lists (PCB Check, Net List & Single Pin Check), Checks (Mechanical, Layout Rule, EMI Preview), Placement Confirmation	Pre-Test (Working Samples): Component Test & Simulation, Testing (H/W,S/W, Design Quality, EMI, Application & BIOS)	βTest (Pilot Run Sample): Customer Test, Testing (Total, H/W, DFM, Application, EMI, BIOS), BIOS Porting	Pilot Test (Production Pilot Run Samples): Pilot Run Test, Testing (Production, Total, H/W, DFM, Application & BIOS, EMI,S/W), BIOS Porting
Outcomes	Circuit Design, ICT (Circuit Testing), Gerber File, BOM (Bill of Materials), Driver & BIOS, Draft Manual	αTest Report, Test Reports (EMI Pre-Scan, On Board Function, Driver, Component Templates, Environmental, Assembly System Template, Power Consumption, S/W EVT, Design Quality Margin, Vibration/Shock, Customer Environment Simulation), Reports (H/W Timing, Voltage/Signal & Margin, Chipset Register Check & Performance Adjustment, Component Spec. Check, EVT Pilot Run), Simulation Results & Real Onboard Signal Confirmation, EVT Sample Bug Confirmation, EVT Bug Trace List, Manual	Final Test Report, Reports (S/W DVT Test, Safety, Certification, DVT Pilot Run), EVT Sample Bug Solution Confirmation, DVT Sample Bug Trace List	Transfer to Factory, Formal Test Report, DVT Sample Bug Solution Confirmation, PVT Bug & Limitation

Source: Interviews and documents of firms

Here we focus on a leading IDH since the profits of IDHs are relatively higher than those of the Chinese local mobile phone handset manufacturers. IDHs specializing in the development of electronic devices were born in the US in the trend of design outsourcing beginning in the 1990s. Cellon, a San Jose-based venture established in 1999 by Chinese and US engineers, claimed to be the first IDH specialized in mobile phone handset development. An IDH in the context of the mobile phone handset industry is a firm that is specialized in the development of handsets (Imai & Shiu, 2007).

Relying on electronics manufacturing service (EMS) manufacturer's volume production, IDHs focus on design business to develop handsets according to customer mobile phone handset manufacturers' requirements/specifications. The profits of IDHs come primarily from design fees. Another benefit comes from the printed circuit board assembly (PCBA) business. IDHs provide PCBAs on which components are mounted. The PCBA business's benefits have been increasing compared to design fees since it can benefit from economies of scale of component sourcing. Accordingly, the PCBA business has approximated the ODM business.

In the PCBA business model, an IDH licenses a BB chip from an external technology platform vendor and thereby provides lists of product functions for their customers. After the customers decide target functions, the IDH starts to select preverified components suitable to the customers' requirements for developing a PCBA. Compared to design service based on customer specifications, the

PCBA business model demands more meticulous market research for function proposals and component selections because of the fast market change and shortened product lifecycle in the industry. In our research, we examine the PCBA business model as it shares some critical characters (i.e., original design, component selection and sourcing, and related market research) with brand manufacturers' and ODM businesses.

The study sheds light on handset design-testing stages as these stages are significantly relevant to novel technology platform adoption. Handset developers share the same mobile phone handset development stages, including (1) product definition (function, specification, component definition); (2) product design (industrial, mechanical, hardware designs, and software engineering); (3) pilot production and review (proto production review and design modification); (4) testing and acquisition of compulsory certification; and (5) preparation for volume production. Tasks and expected outcomes of these stages (Table 1) are related to system design of nested modules rather than component technologies.

Sometimes a function of a novel technology platform is implemented by various components. For instance, in the development of the MP3 music function, designers must consider the memory size for storage, the alternative technologies for playback (i.e., software or hardware), the modification of the play settings during calling-in, and other usages.

These problems require handset developers to consider NAND memory (hardware), BB chip (hardware), OS (software), UI (software) and other related components so that MP3 function can be achieved with compatibility between these components. A technology platform that relates these elements to MP3 function is modified and introduced into a product system design in iterative design-testing processes.

Furthermore, a novel technology platform adoption sometimes gives rise to more than 10,000 software bugs and 1,000 hardware bugs. Such processes lead us to infer that novel technology platform adoption requires collaboration within and between firms, particularly between technology platform vendors and handset developers.

3.3. Japanese mobile phone handset manufacturer

Ever since NTT DoCoMo, Japan's largest operator, introduced i-mode service in 1999 and 3G service (W-CDMA) in 2001, the mobile phone handset has been not only a verbal and text communication tool but also a multimedia terminal. In Japan, three operators are competing while 11 mobile phone handset manufacturers have strived for product differentiation. Firm A is one of the late-entry manufacturers, who started the handset business in 1998. However, the firm has developed more products compared to others, and hit the highest market share in 2007.

Firm A's handset business has four business units, including three handset development business units and a platform development center. Three of the handset development business units receive service requirements from three different Japanese operators and develop mobile phone handsets tailored to each of the domestic operators. Although these three domestic operators' requirements are different, Firm A attempts to share components between its handset lineups, particularly for each operator.

In order to share product platforms and common components within and between handset development business units, the firm established the platform development center. This center plans product platforms (i.e., sets of chipsets, OS, and PCB), develops common basic software, applications/user interface (i.e., browser, mailer, etc.), and hardware (display panel, camera module, etc.) in advance of specific model developments, and also manages the libraries of common components that include definite specifications.

For instance, most parts of user interface application software do not have product-specific feature characters, so that such parts can be regarded as a common software platform and shared with different mobile phone handsets. To give another example, DoCoMo's 904, 905, and 705 handset models share the same PCB design, while the 904 model has video graphics array (VGA), 3 mega camera pixels, and other functions, the 905 model adds an extra mobile television function, and the 705 abandons high functional performance in exchange for a slimmer body.

These handset development business units use different technology platforms. The business unit for DoCoMo handset development manages technology platforms (i.e., core chipsets and Symbian OS), which are common between Firm A's handsets for DoCoMo. Firm A had used iTron OS on NEC-Panasonic BB chips and TI OMPA application processors until 2003. However, the increasing cost and lead time of software engineering, which accounted for more than 60–70% of engineering-hours of handset development, encouraged Firm A to adopt a common Symbian-based OS for DoCoMo's 3G handsets from 2004. Accordingly, NEC-Panasonic chipsets and PCBs were shared between several Firm A's models such as 902i, 702iD, 902iS, and so on.

In 2007, Firm A released its models based on the first generation of Vendor A's handset technology platforms. Vendor A developed the first generation in cooperation with DoCoMo, focusing on application rather than communication. The platform series was deployed on the basis of de facto standard high-end application processor chipsets both in Japan and worldwide, which Vendor A released in 2002.

The platform series was equipped with high speed BB, application processors, large-capacity memory for application processing, full hardware accelerator, effective power management, and a variety of other modules and interfaces. The platform series was expected to be more suitable to the Symbian-based OS that was developed and/or shared between several DoCoMo manufacturers. Yet, the Linux OS of an Indian software vendor, Wipro

Technologies, also became available on the platform in 2005.

The newness of a technology platform can cause unexpected software bugs and system-related problems. Long debugging and testing processes, sometimes lasting more than 6 months, are always required. The lack of practical usage experience causes various unexpected bugs and problems during the development stages of both a chipset and its handset systems. Moreover, a technology platform with advanced multimedia functions, which are required for advancement and to meet market competition, can aggravate compatibility issues with software and hardware components. For example, when Firm A used a technology platform composed of a NEC-Panasonic BB chip and a TI OMPA application processor to design 900i series mobile phone handsets in 2003, it had to make enormous efforts to debug to verify system stability.

In addition, product developers need to cope with other design issues related to electromagnetic interference (EMI), radio wave interference, and power consumption by examining the compatibility of core chipsets with the circuit design and other components (particularly for RF and power management circuit designs). Usually, a vendor offers development boards and reference designs for problem-solving and to shorten product development lead time. However, even though Firm A referred to the development boards and reference designs offered by vendors such as NEC, Panasonic, and TI, they often did not include information indispensable for proprietary handset designs.

This problem made Firm A believe that a deep reliance on vendors' development supports would hinder the understanding of interactions among components and the nurturing of knowledge about product system design. Moreover, Firm A did not have the experience of designing core chips, which other major competitors had. The lack of the experience made it difficult for Firm A to check chip-related design problems and/or to create product system newness. In practice, Firm A's handset development lead time was up to 18 months in 2002, which was longer than the 10–12 months average lead time in the industry.

These experiences led the firm to conclude that it was necessary to closely cooperate with technology platform vendors in order to assimilate required system knowledge into these vendors' core chipsets. Afterward, in early 2006, Firm A joined the technology platform development project with DoCoMo, Vendor A, and two other manufacturers. In the project, they attempted to develop a series of comprehensive mobile phone handset platforms with the Symbian-based OS. The new technology platform series was expected to help accelerate the global adoption of the W-CDMA 3G services and reduce the cost of handsets for mobile phone handset manufacturers at the same time.

The technology platform for dual-mode phones supporting W-CDMA and GSM/GPRS was built on Vendor A's existing single-chip LSI, which was a combination of a BB chip and an application processor as of July 2004. The technology platform added new functions such as supports for HSPDA and EDGE technologies, and covered OS, middleware for multimedia applications, and drivers. This technology platform serving as a base system for W-CDMA handsets could eliminate the need for mobile phone handset manufacturers to develop separate systems each for specific handset functions, and thus it would reduce the time and cost of development to almost half. Further cost reductions in mobile phone handsets are expected if more firms adopt the platform.

Firm A started to participate in the collaborative development processes before the sample chipset release. That was more than 10 months before the technology platform release. This cooperation enabled Firm A to propose their requirements for technology platforms at the platform specification planning stages and put its IPs into the platform to receive royalty fees. At the later stages, Firm A carried assigned software engineering portions, examined prototype chipsets on engineering boards, and thereby contributed to settling problems from the stages of testing and debugging for chipset prototyping.

As a technology platform vendor, Vendor A did not have sufficient know-how on application management, system stability, electronic current control, unexpected handset usage analysis, and other system-level issues. The collaborative processes encouraged Vendor A to assimilate such know-how into the technology platform earlier. At first, the information of handset system, particularly related to application, helped the platform's function/specification design at platform planning stages. Such design determined function-partitioning and interfaces between the chipset, other components/devices, and software.

At the later stages of chipset development, the collaboration from the chipset's system verification related to handset functions also contributed to examining and improving the stability of handset system designs. System problems related to the chipset had been probed in the handset system designs of Firm A and other collaborative manufacturers. The processes helped cope with system problems at the early handset development stages.

Firm A enjoyed other benefits of time-to-market compared to its competitors. It took about 10 months to complete a new handset design after receiving a novel technology platform (derivative handset designs based on matured technology platforms needed 4–6 months). The overlapping of technology platform verification and early handset development stages could reduce the handset platform development leadtime. In the collaborative processes, Firm A could understand the characteristics of the novel technology platform and the critical testing points for debugging and handset design verification. Handset development leadtime may be shortened to less than half if firms are acquainted with such information.

Yet, more essential is the fact that the involvement in the collaboration allowed Firm A to enjoy its earlier release of the first handset model with the novel technology platform months ahead of its competitors. Total development leadtime from the technology platform development to the first handset release is about 2 years; more than 12 months for platform development and 10 months for handset development. However, the total leadtime in this case was expected to be 16–17 months. Novel technology platform adoption would be accelerated in the collaborative interfirm processes rather than modularized ones.

3.4. Taiwanese mobile phone handset ODM

The Taiwanese mobile phone handset industry began in approximately 1994 when BenQ began to develop mobile phone handsets. In 2000, the Taiwanese PC ODMs such as Quanta Computer, Compal Electronics, Inventec, and Arima Computer simultaneously started investing in their mobile phone handset subsidiaries or in-house divisions to launch the production of mobile phone handsets. Between 2001 and 2004, Chi-Mei group, Hon Hai Precision, High Tech Computer, Asustek Computer, Mitac International, Wistron, and Gigabyte Technology also entered the business. Some firms developed their own brand mobile phone handsets, while others applied the ODM business model of PC to the mobile phone handset business.

Firm B entered the mobile phone handset industry in 1999 and became one of the biggest handset ODMs in Taiwan. Nowadays, Firm B has seven product development teams for developing 2G, 2.5G, and 3G handsets. In 2006, its mobile phone handset models were developed based on several different technology platforms including 2G chipsets such as Calypso and LoCosto from Vendor B and 3G chipsets from Qualcomm. Firm B used Calypso and Locosto to develop two to three product platform models and six derivative models in 2006.

In the R&D division, the “New Product Development Team” surveys several different technology platforms and proposes to their customers to replace their current core chips if new technology platforms perform better and show a cost advantage. It receives specifications from Motorola and so on, and took charge of detailed mobile phone handset designs, verifications, and manufacturing.

Firm B develops software (i.e., native applications, device drivers, file manager, UI, etc.) for multimedia functions and integrates some IC chips (i.e., Bluetooth, NAND memory, melody IC, image sensor, etc.) from third parties. However, when adopting a new Vendor B’s platform for developing mobile phone handsets, Firm B faces a number of system problems. For instance, the initial period of adopting a novel technology platform involves innumerable software and hardware bugs related to critical components and devices. The reason for these bugs is the fact that Vendor B does not commit to total solutions with complete information on product system architectures, because its platforms allow customer firms to develop proprietary product designs with specifications proper to these customer firms.

Vendor B provides the platform as a package consisting of a set of core chipset and basic software, a reference design with a sample board, bill of materials (BOM), test and verification data reports, technical supports, and so on, which could help customers' handset development. However, the availability of its platforms on handset system designs should be examined according to customers' design and specification requirements. In addition, Vendor B does not intend to cover all the usages of customers. Thus, for instance, a handset design based on a Vendor B solution could easily run out of battery if inexperienced customers attempt more picture/video functions than expected.

Firm B emphasized that in order to overcome these problems it enhanced the debugging capability by hiring more quality assurance engineers 3 years before. More essential is the fact that Firm B started to cooperate with Vendor B as its α-site customer. Since the release of LoCosto engineering samples in 2005 by Vendor B, Firm B had exerted efforts on debugging for the new core chip. Firm B participated in the later stages of Vendor B's technology platform development after the chipset engineering sample release, which followed testing and verification at the chipset level.

As an ODM, Firm B had rich system-level experiences such as circuit designs, component compatibility, device arrangement, EMI and signal interference management, power management, and other system design issues which are closely related to the usage of customers. Thus, the collaboration with Firm B could be expected to yield feedback on system-level verification from Firm B, thereby leading to an improvement in the consistency of technology platforms with handset designs. As an α-site customer, Firm B contributed to stabilizing the new technology platform.

At the same time, the role of an α-site customer helped Firm B eliminate system problems on handset designs before the formal platform sample release. Firm B received a novel chipset engineering sample about one year earlier than its competitors. Thus, Firm B could start its handset design and engineering sample verification on the basis of the new technology platform well ahead of its competitors.

The earlier access to novel chipset knowledge enabled Firm B to design its handsets with checking the compatibility of the platform with handset system designs and other components before the technology platform release. The earlier access also contributed to reducing handset development lead time, sometimes from 10 months to 6 months. The collaboration fostered the assimilation of a novel technology platform into handset designs in accordance with system-level requirements.

3.5. Chinese mobile phone handset design house

In the early 1990s, the mobile telecommunication service industry started its full-fledged global expansion. The trend soon spread to China. Driven by the surge of demand from the international and domestic markets, China’s mobile phone handset industry has exhibited a spectacular growth since the late 1990s. Export and domestic consumption grew at almost parallel rates until 2003. In 2005, around 75% of handsets produced in China were exported. Although the local mobile phone handset manufacturers recently became outward-looking, multinational companies still account for approximately 95% of China’s total mobile phone exports.

When we turn our eyes to the domestic market, however, a strikingly different picture appears. Starting from just around 5% in 1999, shares of local brands rapidly increased until 2003, when China’s official media triumphantly announced that the Chinese mobile phone handset makers had captured more than 50% of the domestic market. However, the majority of the local mobile phone handset manufacturers slid into a retreat after 2004 that continued until early 2006. In 2006, even with their financial achievements, the improvement is still smaller in market share compared to major foreign companies such as Nokia, Samsung, and Motorola.

The increasingly heated competition in the domestic market encouraged the local handset manufacturers to introduce organizational or technological innovations which were ignited by strong cost sensitivity and an enduring quest for product variety. One can find innumerable phone models; there are estimated to be more than 700 new models released in the market in 2006 (about 1,500 models were on the market in total).

Yet, the number of sales for each model is relatively small, on average less than 50 thousand units. Handset manufacturers aim at 500 thousand units of sales per one model in Japan; however, in China, 50 thousand unit sales are the minimum volume to make a profit. In Japan, the lifecycle of a model is 6 months, but there is no rule for the lifecycle of a model in China. On average, the lifecycle of a model is 9 months, but some models are sold for longer than 2 years. The fall in the Chinese local manufacturers’ market share will continue if they cannot release a variety of models every month.

The Chinese local manufacturers’ lack of ability to develop a variety of models has been compensated for by IDHs. The performance of the IDH industry did not fall as much as the local mobile phone handset manufacturers did. According to the investigation of a U.S. research company, iSuppli, there were about 50 to 60 IDHs in China, and it was expected that the products that IDHs design would account for 50% or more in terms of the volume of shipment of the local mobile phone handset manufacturers (iSuppli, 2005). The top 5 IDHs were once estimated to account for 70% of the Chinese mobile phone handset market.

Major IDHs have the ability to implement all the processes of mobile phone handset development: PCB circuit design, software engineering, component arrangement, industrial/mechanical design, testing and verification, certification, and preproduction preparation. IDH’s business model provides total solutions for customer firms.

This type of business model has gradually expanded to component procurement and manufacturing services, areas in which ODMs are strong. Yet, a conformational shift of the chipset market has radically changed the business environment for IDHs in China in recent years. IDHs procured chipsets mainly from American and European venders such as TI, Phillips (NXP), and Infineon until 2004. However, the Taiwanese IC technology platform vendor, Vendor C, started to release its proprietary total solution chipsets at the end of 2004, suppressing the license fee. The market share of Vendor C had radically increased to about 40% in 2006, so that it exceeded the market share of the top vendor TI as the adoption of the total solution platforms by IDHs increased (Merrill Lynch, 2006).

Compared to TI's technology platforms, Vendor C's technology platforms perform more powerfully when executing multimedia functions. In other words, Vendor C's technology platforms integrate more multimedia functions such as Bluetooth, camera, and MP3 than TI's chipsets. In addition, Vendor C's platforms enable faster handset development since they integrate a large portion of handset functions and provide real PCB board reference designs. However, the total solution platforms contain a lot of system problems. Vendor C needs an α-site customer in order to effectively settle such problems.

The α-site customer of Vendor C's 6217, 6218, and 6219 chipsets was the Taiwanese IDH called Darts where Vendor C invested before 2004. However, two of Darts' development teams were pulled out of the Taiwanese ODMs, Arima and Foxconn. Although the situation demanded Vendor C to search for a new α-site customer, major Chinese IDHs and manufacturers except for Firm C were not willing to adopt the platforms. Thus, after 2004, Vendor C chose Firm C as an α-site customer in order to develop 6226, 6228, and 6229 chipsets. Vendor C expected that rich experiences in both handset development and customer/market contacts helped Firm C become an important α-site customer for Vendor C.

On the other hand, Firm C concluded that Vendor C's technology platforms would fit the requirements of the Chinese market, and thus began to adopt them for its handsets beginning at the end of 2004. Firm C emphasized that a successful mobile phone handset development should match the needs of the target market with available related technologies. When Firm C observes a selling point in the target market, various divisions including the sales and R&D divisions are organized into a "Project Research Committee."

The members of these divisions are expected to include different technologies, market demands, and/or operator perspectives in the discussion of the possibility of the chipset commercialization. Unlike other major mobile phone handset manufacturers, the committee of Firm C is not a permanent organization for advanced technological researches, but is a task force for analyzing both technical trends and market requirements. Vendor C's chipsets are at first studied in the committee.

A chipset development takes 10 months or more while a handset development based on a novel technology platform needs at least 10 months. Firm C cooperates with Vendor C for 6 months. At the time of Firm C's involvement, Vendor C has already completed its chipset engineering samples. Reference design (and BOM) development and preproduction testing follow the engineering sample release. Firm C helps Vendor C develop reference designs, giving the information to Vendor C on what the system architecture of the handsets would be. Firm C checks the chipsets' problems concerning product system and the interdependencies of the chipsets with other components at system level. Firm C develops real PCB board reference design which provide a practicable PCB circuit design and related component configurations while Vendor C improves its chipsets.

In close cooperation with Vendor C, Firm C has attempted to solve system-level compatibility problems at the early stages of its handset development projects. At these stages, Firm C has verified the compatibility of chipsets on real product system designs, not only debugging Vendor C's chipsets but also examining other components or devices in laboratory tests. The problems of compatibility come up unexpectedly, so that it is necessary to fine-tune the settings between Vendor C's chipset and components/device drivers such as image sensors and flash memory.

Firm C emphasized that cooperation with Vendor C helped in checking the chipsets' problems concerning product system and interdependencies between components. Moreover, Firm C also pointed out that this cooperation shortened the product development lead time compared to that of its competitors. Firm C can take advantage of novel chipset knowledge 6 months earlier than its competitors. The early availability of novel chipset information has allowed Firm C to precede its competitors by 4 to 5 months in new product releases. Firm C has already verified the system compatibility of the chipsets on its real handset design by understanding the system-level characteristics when novel technology platforms are released.

In 2006, Firm C successfully developed nearly 50 types of proprietary product platforms, each of which used Vendor C's several technology platforms. To this date, the number of Firm C's mobile phone handset models that have been developed by these product platforms has exceeded 100 types.

4. Discussion

In modularized development processes, any single firm, even a system integrator, can hardly invest in and control all the complementary knowledge necessary for novel technology adoption. Knowledge boundaries are sometimes beyond firm boundaries in spite of definite task partitioning between firms (Brusoni & Prencipe, 2001; Brusoni, et al., 2001; Takeishi, 2002) under interfirm development process modularity. Particularly in technological change, close cooperation between partner firms is regarded as a vehicle to acquire complementary knowledge beyond their task boundaries (Takeishi, 2002).

Interfirm modularity seems to blur the role of close coordination within and between firms. However, this study shows that close, bilateral communication channels between product developers and technology vendors are also indispensable in modularized development processes when core technologies change. Each firm's business scope is not oriented to vertical integration. Nevertheless, the coordination is not as open in the transition of core technologies as shown in past researches (Chesbrough, 2003; Iansiti & Levien, 2004; Sturgeon, 2002).

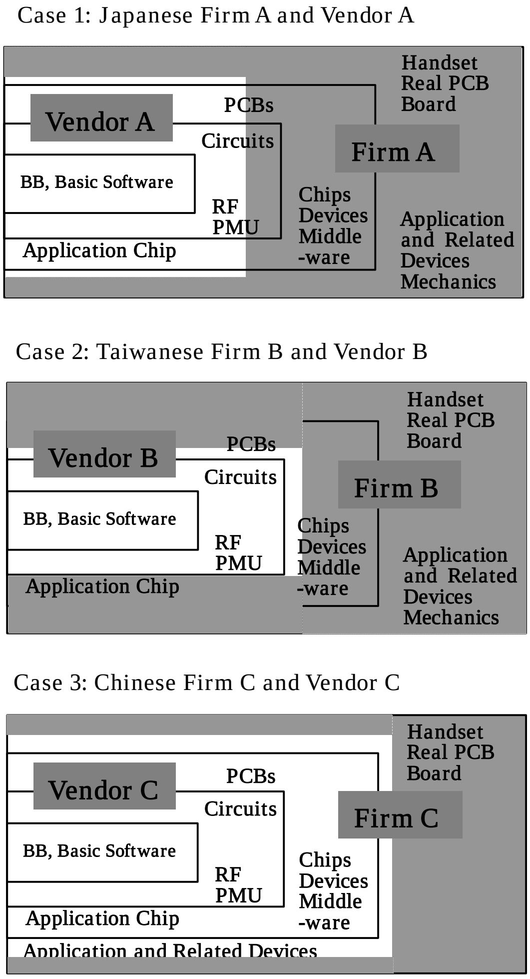
Our interviews with the Chinese local mobile phone manufacturers and IDHs since 2005 also provide some evidences of the criticality of interfirm collaborations between technology platform vendors and product developers. Even the Chinese local mobile phone handset manufacturers and IDHs, which have been thought to rely on modularized interfirm processes, share the same perspective: "the cooperation with core chip vendors will contribute to their product development." The interviewees all emphasized that in their handset development projects for novel technology platforms it was sometimes difficult to identify where the problems came from. As a result, these problems have always delayed their product development.

Technical information and support from core chip vendors usually help solve these problems. Furthermore, some of them attempt to be α-site customers while others commit to deeper cooperation with core chip vendors. An IDH established in 2005 pointed out that it was necessary to be an α-site customer of Vendor C, not only because the firm could receive lower sell prices but also because the firm could develop their handsets with the latest core chipsets earlier than competitors. These firms also emphasized that vendors expected to make use of the design capabilities and end-user experiences of these firms in the collaboration.

In general, a simple buyer-seller relationship is not proper to related firms, especially when novel core technologies are adopted in modularized interfirm relationships. In reality, one of the major IDHs, Techfaith, established in 2002, also launched a joint venture with a technology platform vendor, Qualcomm, in 2006 as the multimedia functions would be more value-added in the future. A local mobile phone handset manufacturer, Amoi, provides another emblematic case. Amoi has also worked with Spreadtrum, China's local technology platform vendor, to develop GSM/GPRS mobile phone handsets and the Chinese 3G standard TD-SCDMA handsets.

The collaboration within and/or between firms may be enhanced by technological uncertainty as shown in past researches (e.g., Iansiti, 1997; Takeishi, 2002). The uncertainty accruing from new technologies would be relevant to supplier-manufacturer relationships. In spite of the country differences, the Japanese, Taiwanese, and Chinese firms would all face high technological uncertainty when adopting new technology platforms. Such technological uncertainty would invite technology integration across firms.

Figure 4. The range of interdependencies



However, novel technology platform adoption under vertical disintegration is characterized with system integration rather than technology integration. The cases here show that collaborative processes are not driven by technological uncertainty, but are rather triggered by systemic problems resulting from the adoption of novel technology.

The vertical integration of product development of complex products like automobiles may require more complete fusion of element technologies with product systems. In practice, in design-in collaboration between a vendor and a customer manufacturer, the vendor is involved in the manufacturer's product development from the early stages in order to closely accommodate technologies/components to the manufacturer's requirements (e.g., Clark & Fujimoto, 1991; Dyer & Nobeoka, 2000). Such a tendency could demand technology integration including the search and selection of element technologies in close collaboration between a vendor and a manufacturer (Takeishi, 2002).

On the other hand, in modularized interfirm development processes, technology platforms are standardized while the insides of technology platforms are kept in black boxes developed within specialized vendors. These cases here are witness to the fact that vendors and product developers each have heterogeneous capabilities to cope with different development problems under vertical disintegration. Vendors need to be capable of managing technological uncertainty of new core technology development while product developers are destined to manage product system designs. The search and selection processes of technologies are left for vendors.

Reflecting such interfirm labor division, the collaborative processes between vendors and product developers rather focused on system integration to ensure system stability of technology platforms and product designs. Firms collaborated with each other based on system knowledge, which enhanced systemic problem-solving, relevant to the interface between core chipsets, product designs, software, and other components. According to our interviews, firms attempted to check both novel technology platforms' system stability and compatibility with handset designs and other components in close cooperation.

In our cases, product developers made efforts to acquire new core technology knowledge, which defined the basic configuration of product technology bases, in order to quickly design their products' configurations consistent with novel technology platforms. At the same time, technology platform vendors took advantage of these collaborations to refine and verify their solutions according to system knowledge of product circuit designs.

These cases show that the necessity of system knowledge rather than technological uncertainty drives collaborative novel technology adoption under interfirm development process modularity. Accordingly, the overlapping processes are restricted to the late technology platform development and early product development stages, though the scope of collaboration could vary depending upon cases.

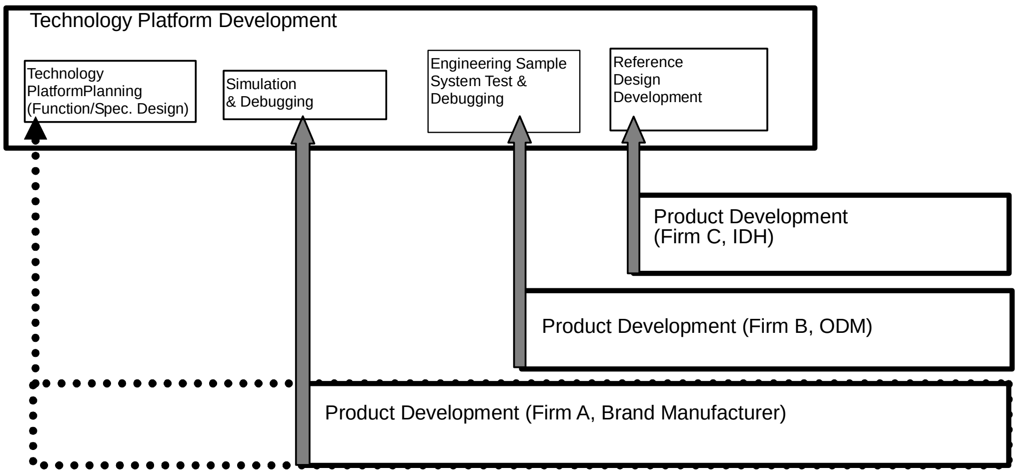
The range of interdependencies is different by the cases (Figure 4). Firm A adopted Vendor A's new technology platform in order to develop 3G high performance and multimedia smartphones. Firm A participated in collaborative technology platform development with Vendor A and several firms. High performance requirements, particularly related to complex application processing, required sufficient consideration to the function-partitioning and interfaces between the core and other levels in interfirm collaboration. Firm A provided the information of function/specification requirements and contributed to application-related system simulation and test, while sharing necessary information about the BB chipset architecture with Vendor A.

The technology platform of Vendor B did not offer a complete solution set of chips, software, and devices, but provided a low cost solution with basic handset functions. Yet, the development needed systemic checks of the platform in product system. Firm B worked with Vendor B to solve systemic bugs of unidentified interdependencies, while obtaining the BB chipset information related to handset design.

In the case of cooperation between Firm C and Vendor C, the total solution development faced high degree of interdependencies between several levels. Vendor C coped with the interdependencies within the firm by learning from customer firms how to encapsulate the interdependencies into the solution. Firm C helped develop the reference design, while learning how to exploit the solution in its handset development.

These cases show that the difference in collaboration timings must be explicated by the issues of system level problem-solving rather than technological uncertainty (Figure 5). Firm A was involved in the technology platform development from the beginning of platform planning (e.g., functional requirement and specification setting) collaborating with DoCoMo, Vendor A, and some

Figure 5. Differences in collaboration object and timing in Japan, Taiwan, and China



manufacturers.

DoCoMo has intended to establish common software platforms to accelerate its service introductions reducing development cost. Corresponding to the attempt, these firms including Firm A started to develop a technology platform based on the vendor's application chipsets. Firm A partly coped with technological uncertainty reduction with its partner firms at the stage of technology platform specification planning and software engineering stage, particularly in simulation process. However, Firm A did not exert development capabilities until the chipset was tested and verified in terms of product system consistency.

On the other hand, Firms B and C were involved in collaborative problem-solving after the engineering sample releases, when technological system configurations had been already nailed down by technology platform vendors. Firm B helped debug the system after the partner platform vendor prepared its chipset engineering samples. Firm C was not involved in chipset development until reference board design was started by the partner technology platform vendor. The firm contributed to the partner's real PCB board reference design development by implementing chipset debugging in relation to other components on PCBs.

Firms B and C were mostly engaged in system-related problem-solving (e.g., device compatibility, internal/external interfaces, electromagnetic and wave interferences, power management). The differences in collaboration object and timing result from the fact that the scope of system integration in technology platforms differ between Firm B and Firm C. Firm B used less integrated chipsets while Firm C adopted total solutions of more integrated chipsets.

These findings suggest that collaboration purposes and timings may reflect the level of system knowledge requirement rather than technological

Table 2. Brief description of differences in collaborations

	Firm A	Firm B	Firm C
Technology Platform	3G(W-CDMA); Symbian OS and RTOS	2G/2.5G (GSM/GPRS), Nucleus RTOS	2G/2.5G (GSM/GPRS), Nucleus RTOS
Range of Platform (Vendor's Coverage)	Core, A part of C1 and C2	Core, C1, A part of C2	Core, C1, C2, A part of C3
Interdependencies between Core Chipset and Other Levels	with C1 (Circuits, Recommendation Components), with C2 (PCB Reference Board Design, Some Chips and Devices, SW), with C3 (Some "Advanced" Applications and Devices)	with C1 (Circuits, Recommendation Components), with C2 (PCB Reference Board Design, Some Chips and Devices), with C3 (-)	with C1 (Circuits, Specific Components), with C2 (PCB Reference Board Design, Specific Chips and Devices, SW), with C3 (Real PCB Board Design, Specific Applications and Devices)
Collaboration Type and Purposes (Product Developer's Role)	Collaborative Partner for Technology Platform Development with Vendor A and Several Firms	α-site Customer of Vendor B for System Test & Debugging	α-site Customer of Vendor C for Reference Design Development
Collaboration Timing	Partly from Platform Planning (Function/Specification Design), Simulation & Debugging before Engineering Sample Tape-out	System Test & Debugging for Engineering Sample	Reference Design Development

uncertainty (Table 2) and interdependencies. Firms have several levels of interfirm collaboration for technology development and product development according to the difference between the platform range and the range of interdependencies between core components and other system levels of nested modules, though interfirm relationships are often characterized by simple classifications, such as closed/open dichotomy.

The capabilities of novel technology adoption rather rest on the management of system knowledge of nested modules across firms even in the interfirm modularity of technology development process and product development process. Technologies have the attribute of a "system" in nature (i.e., they are embodied in multicomponents and interrelated to each other). A set of components together is integrated to provide utilities for customers.

System performance is rather dependent on its ability to mediate between a variety of types of knowledge within and between firms (Henderson & Cockburn, 1994) to the extent that mutual compatibilities between core technologies and components/devices are ensured (Brusoni & Prencipe, 2001; Brusnoi, et al., 2001). Thus, the ability to span knowledge boundaries between firms is particularly highlighted in modularized interfirm development processes (Prencipe, 2003).

At last, we should note that some of the Chinese local mobile phone handset manufacturers suggested that Vendor C's total solutions would make it difficult to develop distinguished handsets. This situation is also the case in other digital product industries (e.g., DVD player). Although Vendor C's total solutions can shorten product development lead time to market, customer firms can hardly differentiate their products as Vendor C encapsulates most product functions into the chipsets or bundles other components with the solutions.

In the case, not only task boundaries but also knowledge boundaries are enlarged to product system design beyond traditional technology platform vendors' boundaries. Accordingly, Vendor C is rather oriented to vertical integration in place of mutual interfirm coordination. As a result, handset manufacturers can hardly balance the tension between cooperation and competition. This fact would imply that the management of system knowledge beyond interfirm boundaries of modularized development processes would shape not only the firms' competitiveness but even the dynamism of interfirm labor division structures.

5. Conclusion

The technology development and product development of many industries has been modularized into relatively independent interfirm processes. Development and manufacturing processes is often regarded as the critical source of manufacturers' inimitable competitiveness. Nevertheless, nowadays, product developers can exploit even core technologies from specialized vendors as such vendors provide standardized technological solutions. Drawing on the cases of the Japanese, Taiwanese, and Chinese firms, the study attempts to elucidate how and why product developers and technology platform vendors collaborate with each other for novel technology platform adoption in the modularized interfirm development processes.

Cooperation under interfirm development process modularity is oriented to system integration of nested modules rather than technology integration. The cases studied in this paper revealed that the partial distribution of system knowledge as well as component knowledge across firms drives the collaborative process. Each single firm cannot maintain all the knowledge relevant to problem-solving (Brusnoi, et al., 2001). Novel technology adoption requires product system knowledge of nested modules, which provides a deeper level of knowledge beyond the architectural level (Prencipe, 2003) even in modularized interfirm development processes.

A product developer should acquire new core technology knowledge, which provides basic architectural system configurations according to underlying product technology bases, in order to quickly design their products consistent with novel technology platforms. At the same time, a technology platform vendor needs to examine and refine its solutions according to product system knowledge of product system designs. The interfirm overlapping processes between late technology platform development and early product development enhances problem-solving for sharing/refining such system knowledge.

Product development capabilities depend upon the interfirm management of both component and product system knowledge and related boundary spanning, particularly in the vertical integration of product development of complex products like automobiles (Clark & Fujimoto, 1991; Dyer & Nobeoka, 2000; Takeishi, 2002). On the other hand, the cases here show that the capabilities of novel technology adoption will be relevant to the management of system knowledge of nested modules across technology development process and product development process under the interfirm process modularity.

These finding should contribute not only to revealing the managerial issues involved in novel technology adoption in modularized interfirm development processes, but also to explicating the dynamism of the technology development and product development in open interfirm networks. As elucidated in the HDD case, the lack of system knowledge may decay firms that depend upon product modularity and corresponding modularized product development (Chesbrough & Kusunoki, 2001).

However, the cases elucidate that complementary knowledge (i.e., system knowledge) is provided in the collaboration between manufacturers and vendors. The finding would show a witnessing fact that product modularity and corresponding modularized product development does not necessarily hinder the system reformation owing to technological changes. Specialized firms under interfirm development process modularity can support each other to overcome such knowledge insufficiency problems.

The Chinese 3G TD-SCDMA development may confirm this finding. The Chinese digital product industries seemingly rely on and take advantage of interfirm product modularity. However, the TD-SCDMA development collaborative networks between base station vendors, technology platform vendors, brand manufacturers, IDHs, and software vendors have successfully advanced TD-SCDMA technology development. The insufficiency of technological and system knowledge in the Chinese local firms would be compensated for by major global technology platform vendors (e.g., ADI, TI, Infineon, NXP) and brand manufacturers (e.g., Nokia, Motorola, Samsung, LG) who have been indirectly involved in the networks through partnerships with the local firms.

On the other hand, several total solution vendors attempt to encapsulate various functions into their standardized chipsets in the continuous improvement of the semiconductor process. Encapsulation would unilaterally urge product developers to exploit total solution platforms so that these developers can develop products without sufficient system knowledge accumulation. In order to deploy distinctive product systems, manufacturers need to make sufficient investment in system knowledge (Brusoni & Prencipe, 2001). However, encapsulation yields a variety of homogeneous products to cause harsh competition without remarkable product evolution while accelerating product development.

Encapsulation seems to enhance thorough interfirm modularity, more divided relationship of development processes between vendors and product developers, and thus hinder bilateral mutual learning between them. However, as revealed in this study, bilateral relationships encourage both vendors and product developers to nurture system knowledge of nested modules to the extent that this knowledge helps novel technology adoption and product evolution.

This study elucidates that a novel technology platform is not refined without collaborative interfirm coordination processes between technology platform vendors and product developers even under vertical disintegration. Our findings may encourage collaborative firms to gain a deeper appreciation of (1) which aspects of product functions have been covered by a technology platform, (2) how product functions have been partitioned with interface setting between a technology platform and other components/devices/platforms, and (3) how product evolution shapes the alignment of a technology platform, complementary components, and software on product systems. These issues require us to illuminate the historical dynamism of interfirm knowledge/task boundaries and related coordination of processes within and between technology/product development firms. Such issues must be left to future research.

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