水平分業下での企業間分業と製品開発力に関する代替的視点
―携帯電話端末産業におけるシステム知識の普及のケース―

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博士後期課程　許　　経明

An Alternative Perspective on the Interfirm Labor Division and Product Development Capabilities under Vertical Disintegration
― The Case of the Dissemination of System Knowledge in the Global Mobile Phone Handset Industries―

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要約

本研究では、オープンな環境下での製品開発力を検討するため、世界の携帯電話端末産業のケースを参考に、水平分業下での企業間分業についての代替的な視点を提示する。製品のモジュラー化とそれに対応した汎用の部品や技術の供給が、水平分業を促しているとされてきた。しかし、製品開発レベルでは多様な部品や技術を統合するためのシステム知識がいまだに不可欠であり、開発経験や資源が乏しい企業が製品開発を行うのは容易ではない。このような状況ではあるが、製品コア技術を含め製品システムは階層的に分化しており、各階層に対応したシステム知識が、プラットフォームとして専門化した企業によって開発・提供されるようになっている。こうしたモジュラー化した企業間開発プロセスによって製品開発に必要なシステム知識が補われることで、新興企業でも製品開発が可能となっている。一方、開発力のあるメーカーは、もっぱら製品レベルのシステム統合に専念し、自社の蓄積されたローカルなシステム知識、アーキテクチャ知識による製品開発力を保持している。ただし、先進的メーカーでは、こうしたアーキテクチュラルな知識は、各社が実際に行っている開発作業の範囲を超えて製品コア技術の知識にまで及んでいる。これらの発見は、オープン化した環境ではシステム知識が専業企業間で分散しており、そうした環境下での製品開発力は、システム統合のための各社のアーキテクチュラルな知識の特性と範囲に大きく依存することを示唆している。

SUMMARY

The study proposes an alternative perspective to elucidate interfirm labor division under vertical disintegration in order to explore product development capabilities in open environments, drawing on the case of the global mobile handset industries. Product modularization with the birth of supply chain of standardized components/technologies is regarded as the major force to enhance vertical disintegration. Nevertheless, a product developer, particularly a firm without sufficient experiences and/or resources, still faces difficulties with product development because of the firm's insufficient system knowledge to integrate a variety of components into a product system. Under such condition, each specialized vendor develops a platform to provide a part of layered system knowledge according to the level of the nested-module system of a product. Product development processes are modularized into development processes of these specialized vendors and product developers. Inexperienced new entrants are not allowed to develop products until such modularized interfirm development processes collectively complement system knowledge necessary for product development. On the other hand, experienced manufacturers mostly dedicate themselves to system integration at product platform and/or product system levels, and secure product development capabilities based on their accumulated firm-specific local system knowledge, architectural knowledge, at these levels. Yet, leading manufacturers sometimes extend the locus of their architectural knowledge even to core product technologies beyond the locus of their product development tasks. These findings imply that under open interfirm environments where system knowledge is disseminated across specialized firms, product manufacturers' development capabilities primarily rest on the attributes and locus of their accumulated architectural knowledge for system integration at product system levels.

1. Introduction

In the past decades, the surge of vertical disintegration has drastically reshuffled industrial landscapes. The drastic industrial shift is often attributed to product modularization. Antecedents suggest that product modularization with the birth of supply chain networks of standardized components has enhanced vertical disintegration (Baldwin and Clark, 2000; Berger and MIT Industrial Performance Center, 2005; Christensen, Verlinden, and Westerman, 2002; Ito, 2005; Sturgeon, 2002). A variety of component vendors and manufacturers have shaped the global, open, supply chain networks, so that even emergent firms are assumed to exploit standardized components to develop products at a relatively low cost.

However, even in digital product industries, firms often face system-related problems in product development as standardized components often do not provide sufficient system knowledge to properly configure components on a product system. Such incomplete modularity still requires firms to retain knowledge to arrange various elements into a consistent system (Nobeoka, 2005 ; Prencipe, 2003; Staudenmayer, Tripas, and Tucci, 2005; Yasumoto and Shiu, 2008).

Inexperienced firms without such knowledge, mostly firms from emerging markets, can hardly develop products even though specialized vendors prepare standardized core components: technology platforms (Imai and Kawakami, 2006; Marukawa, 2007; Nobeoka and Ueno, 2005). For instance, inexperienced wireless handset manufacturers in China have had difficulties to develop their own products. Yet, since the late 1990s, the networks of specialized vendors have allowed these manufacturers to quickly develop a variety of new models: almost 1,500 models were reported to be sold in the market in 2006 [1]. On the other hand, some leading firms can develop distinguished products and thus hold their competitive positions even though any firms can hardly maintain competitive advantages in such environments under vertical disintegration.

These contradictory situations invite two questions: (1) why inexperienced firms can easily develop products even without accumulating sufficient system knowledge to integrate components/devices into products and (2) why some leading firms can show distinguished product development capabilities even under vertical disintegration. The attempt to answer these questions will contribute to not only streamlining conflicting claims relevant to product/interfirm modularity but also drawing critical issues on product development in open environments under vertical disintegration.

First, in terms of the dissemination of system knowledge, this study proposes alternative perspectives to understand product development through interfirm networks under vertical disintegration. Second, drawing on the cases of the global mobile handset industries, this study briefly describes the dissemination of system knowledge through interfirm networks and the locus of handset developers' tasks and problems relevant to local system knowledge. Based on the description, the dissemination of system knowledge and the attributes and locus of firms' local system knowledge in open environments will be discussed. Lastly, this study draws some implications and points to future research issues.

2. Perspective

In the age of vertical or vertically enclosed integration, "core product technologies" and "system knowledge" were regarded as the principal sources of firms' competitiveness (Aoshima and Nobeoka, 1997; Clark and Fujimoto, 1991; Henderson and Clark, 1990; Iansiti, 1997). Both were considered to arise from firm-specific, inimitable, processes. However, open environments under vertical disintegration has undermined these critical sources of firms' competitiveness.

On the presumption that core product technologies invest distinctive attributes with products, core product technologies and related development processes are repetitively highlighted as the source of firms' competitiveness (Ito, 2005 ; Sakiakibara and Koyama, 2006). Advanced products with novel core product technologies originate from a firm's integrated processes, "technology integration", which enhances mutual exchange of component knowledge and system knowledge between and within "technology development department" and "product development department (Iansiti, 1997)." System knowledge which helps consistent configurations between various components/technologies is embedded in core product components. Such products based on the core components should be hardly imitable because these core product technologies and system knowledge are nurtured in firm-specific technology integration processes.

However, even such core product technologies become available in the form of standardized technology platforms: a set of core technologies to realize basic product functions (Iansiti and Levien, 2004; von Hippel, 2006). Under vertical disintegration, system knowledge is at the same time assumed to be provided in a standardized manner, a set of design rules (Baldwin and Clark, 2000), bundled with technology platforms. Given such system knowledge, integration of a variety of components into products is no longer complicated as standardized components/technologies share common interfaces based on a set of design rules (*i.e.,* modular architecture).

Product modularity based on technology platoforms is expected to enable any firms, particularly new entrants, to develop products without difficulties (Fujimoto and Shintaku, 2005; Sakakibara and Koyama, 2006). As is typically shown in the Chinese case (Marukawa, 2007), massive firms exploiting similar components/technologies, which are independent of firm/product-specific contexts, have enhanced product commoditization and thereby caused harsh competition. The diffusion of standardized technology platforms can cause a firm to sacrifice its technological and cost advantages of firm-specific core product technologies.

However, even a digital product composed of mutually independent components is still not regarded as a complete modular system. Firms often face system-related problems as complete system knowledge to properly configure components is rarely available as a set of well-documented design rules. Such incomplete modularity still requires firms to retain system knowledge to develop their proprietary products (Chesbrough, et al., 2006; Staudenmayer, Tripas, and Tucci, 2005). Supply networks of standardized components *per se* do not necessarily secure product modularity.

A firm's capabilities rest on its ability to mediate between diverse knowledge within and between firms (Henderson and Cockburn, 1994). When exploiting supplier networks, a firm needs to assimilate components and technologies into a coherent product system with paying attention to the uneven changes of various components and the interdependencies between them (Brusoni and Prencipe, 2001).

Such a requirement calls for experimental system design capabilities to implement the evaluation, test, and selection of components/technologies and product designs even for modular systems (Baldwin and Clark, 2000). Even in the context of product modularity, a firm without essential system knowledge to choose and configure a variety of components/technologies may not effectively exploit supply chains of standardized components/technologies.

Nevertheless, inexperienced emergent firms without essential system knowledge are allowed to increasingly enter product markets. The fact makes us infer that even system knowledge is standardized and disseminated to the extent that such knowledge becomes available to these new entrants. Vertical disintegration may not occur until the availability of system knowledge increases to a certain degree.

A technology platform as a core product component has been assumed to secure interfirm modularity and thus enable product manufacturers to develop products without difficulties. Bundled with system knowledge, a technology platform may offer open environments which give a chance to emergent firms to develop products and enter product markets. The platform provides basic system architecture to

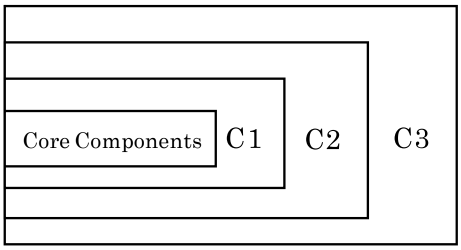

Figure 1 A System of Nested Modules

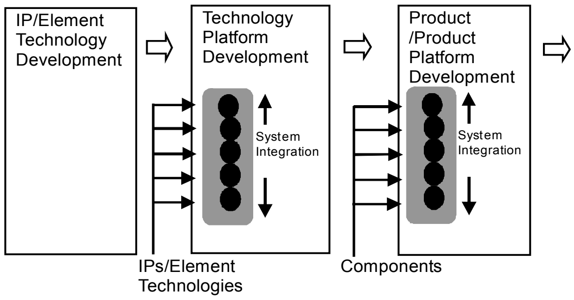

Figure 2 Modularization of Interfirm Development Processes

generally allocate functions to specific components and defines the interdependencies within and between different technologies and components from a variety of vendors. Such an idea of a single platform allows the assumption that modular product system consists of equivalent components with shared interfaces.

However, a single platform often does not prepare sufficient system knowledge even though continuous improvement of semiconductor processes fosters the encapsulation of most of product-level functions into one-chip total solutions [2]. Because of the necessity of functional extension by each product developer, a single platform can neither take place of product systems nor provide all the system knowledge necessary for product development.

Instead, a product system can be reframed as a nested system of module with several system layers (Dosi, Hobday, Marengo, and Prencipe, 2003). A product system, particularly a complex product, is divided into several layers of sub-systems of a system of nested module. For instance, an electronic product system consists of several levels of layers such as C1, C2, and C3 (Figure 1).

C1 level corresponds to core components (*e.g.,* processor) with basic software (*e.g.,* OS: operating system) and related circuits. C2 level arranges devices on print circuit boards (PCBs) and related upper layer software (*e.g.,* API: application program interface). Other product-specific components, applications, and devices (*e.g.,* camera, display) are integrated into the product at C3 level.

Accordingly, technology platform development, board design (product platform development), and product development each can be implemented by independent specialized firms. Development processes are presumed to be modularized into independent processes by specialized firms and vendors (Yasumoto and Shiu, 2008). In the modularized interfirm development processes, these vendors and firms implement system integration at their focused system levels assimilating various elements into consistent systems at the corresponding development stages (Figure 2).

A technology platform vendor attempts to monitor and integrate component knowledge (*e.g.,* intellectual property: IP) to implement system integration examining and securing both platform stability and its performances. On the other hand, product developers, such as independent design houses (IDHs), original design manufacturers (ODMs), and brand manufacturers, build information channels to monitor components and technological changes in order to integrate applications, components, and devices into consistent product platforms and/or products.

System integration at each stage yields standardized system knowledge as platforms to be available at downstream stages. Downstream firms consecutively implement system integration exploiting standardized platforms from upstream vendors. These efforts in each of vendors and firms together realize process modularity of value chains, which is characterized with modular "vertical architecture (Jacobides, 2005)." These processes are continuously spreading essential system knowledge across firms and vendors, so that an industry is characterized with vertical disintegration.

The federation of modularized interfirm development processes, in which independent system integrator firms and vendors participate, may explicate the critical driver of open environments under vertical disintegration. Firms and vendors participating in the federation are expected to collectively carry system knowledge. System knowledge is provided in a decentralized manner by modularized interfirm development processes between manufacturers and specialized vendors to the extent that open environments are prepared.

The original subject of open innovation approaches upstream R&D (research and development) stages. Thus, in the context of open innovation approaches, a firm is required to hold proprietary system knowledge, architectural knowledge, to integrate elements into its proprietary product systems in downstream R&D stages（Chesbrough, 2003; Chesbrough et al., 2006）. Nevertheless, the dissemination of system knowledge can expand the scope of open innovation to downstream R&D stages by bridging the chasm between open component/technology sourcing and product system development.

In the dissemination of system knowledge, generic system knowledge to realize a minimum set of products is furnished in a variety of firms and vendors. Architectural knowledge should not be such generic system knowledge that any firms can exploit, but be firm-specific local system knowledge to yield distinctive proprietary product systems. The locus of such architectural knowledge, which may expand beyond a firm's development tasks (Brusoni, et al, 2001; Takeishi, 2002), prescribes the firm's development capabilities to extend their products' specific functions and features beyond generic system knowledge provided by standardized platforms. Under vertical disintegration where multiple firms and vendors carry generic system knowledge, the differences in products, more specifically product features and functions, by firms may rest on the locus of architectural knowledge to extend product functions and features rather than product development tasks.

3. Case Studies

3.1 Research Backgrounds

According to Funk (2002), until the early 2000s, major handset manufacturers internally developed proprietary handset platforms and derivative models (including software) using tailored core chipsets: digital baseband chips (BB). Specialized chip vendors (TI, ADI, Philips, Qualcomm, etc.) started to offer standardized BB chip hardware between 1996 and 1998 [3]. Yet, Nokia and other major manufacturers kept on using tailored BB chips relying on vendors' chip processes and hardware technologies.

From the late 1990s to early 2000s, specialized software vendors began to offer standardized software essential for handsets' communication and control parts (*e.g.,* modem software including protocol stacks, RTOS: real time operating system). Manufacturers developed handsets and proprietary software combining chipsets with standardized software. Since the early 2000s, chipset vendors standardized technology platforms, which consist of chipsets (*e.g.,* AP-BB SoC: application-baseband system-on-chip), basic software (modem software, drivers, OS), reference design, and other supports and tools, for 2G (GSM), 2.5/2.75G (GPRS/EDGE), 3G (UMTS/WCDMA), and/or

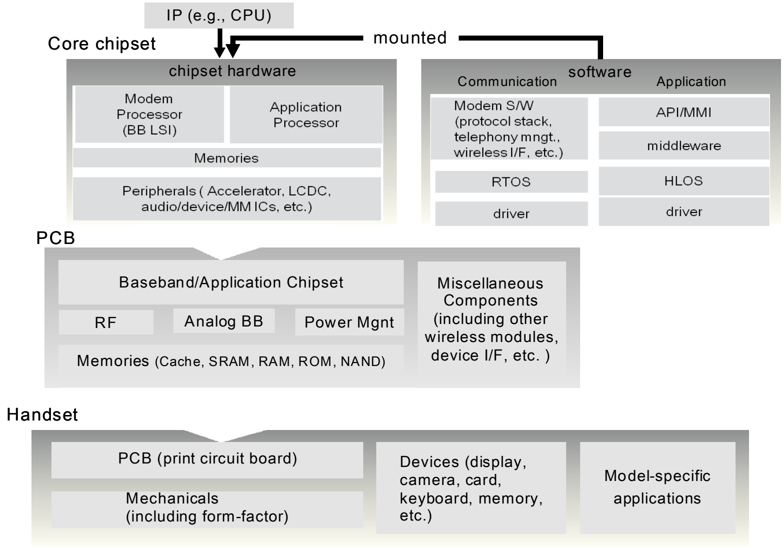

Figure 3 Handset System of Nested Modules

multi-modes, in order to expand their market opportunities.

Afterwards, specialized vendors and/or their collaboration with manufacturers began to provide standardized software platforms for hi-end handsets. These platforms include middleware, API for complicated application processing, UI (user interface), and/or hardware drivers based on high level operating systems (HLOS). HLOS has been also loaded in technology platforms for hi-end phones (*e.g.,* smartphone).

These standardized chipsets, software, and technology platforms allowed ODMs and IDHs to provide PCBs, handset platforms, and/or low/middle-end handsets for both leading manufacturers and new entrants (*e.g.,* the Chinese ones). On the other hand, a few major manufacturers like Nokia has continued to develop handsets and proprietary software on tailored chipsets while exploiting standardized chipsets, software, and technology platforms for low/middle-end products as well.

In Japan, until the early 2000s, major Japanese manufacturers other than CDMA manufacturers, such as Panasonic, NEC, Mitsubishi, and Fujitsu, developed proprietary BB chips and software for local market handset development. Many of manufacturers did not shape proprietary product platforms as combination systems of hardware and software[4]. In the 3G era, from the early 2000s to middle 2000s, most of manufacturers started to adopt standardized technology platforms which are combination systems of standardized AP-BB SoC chipsets and software platforms (HLOS, middleware, and API) for complicated application processing. These core chips and software platforms each are developed by specialized vendors or collaborations between manufacturers, vendors, and operators.

On the other hand, from 2007 to 2008, the stream toward standardized platforms has been enhanced particularly in the field of software[5]. The foundations of two major HLOS platforms, “Symbian” and “LiMo” for Linux platform, which consist of major handset manufacturers, operators, and/or chipset and software vendors, started to open their platforms and software development environments in 2008.

In late 2007, the alliance, “OHA (Open Handset Alliance)”, for Google’s “Android” platform was also established by the major manufacturers, chipset vendors, and operators. The application software development environments of Android were also opened in late 2007. Based on open-source Linux OS, the platform is designed more open to any software developers and manufacturers and easier to be loaded on any handset platform chipset hardware than other software platforms, The stream toward standardized platforms has encouraged even the Japanese manufacturers to adopt these global platforms.

A few global manufacturers (*e.g.,* Nokia) and many of the Japanese ones still adopt tailored technology platforms from exclusive contractors or group vendors[6]. Some manufacturers (*e.g.,* Apple and Nokia) also have pursued proprietary software in order to deploy their services. Yet, after these standardized platform releases, technology platforms, software platforms, and handset platforms/handsets can be by and large developed separately by different firms and vendors.

In consideration of these industrial streams, the study explores the platform supply chain networks and the adoption of platforms in handset developers. The study primarily makes use of information which appeared in published journals and industry reports. We also use interview data on handset development for additional information. The additional data was collected by semi-structured interviews from 2004 to 2008, in Japan, Taiwan, China, and US. Fifty five firms, including handset manufacturers, mobile service carriers, technology platform vendors, software vendors, ODMs, and IDHs were involved in the study.

3.2 Handset System Structure

A handset system consists of several levels: technology platform (core chipset), handset platform (PCB), and handset (Figure 3). The basic technological structure of a mobile phone handset is divided roughly into communication part (RF: radio frequency), signal processing part (BB), and external I/O part (input/output).

A technology platform, which defines basic product architecture of a handset system, is the core technology of a mobile phone handset. This part centers on a BB chip that controls signals and implements communication processing (communication part). Recently, a BB chip, often combined with an application processor (ACPU), not only processes telephone calling functions but also executes multimedia functions, like audio, camera, picture, game, video, and so on. The value added mobile phone handsets with these functions are called feature phones, smartphones, or PDA phones depending on market segments and product features.

Because of these various function requirements, engineering man-hours required for handset software development have been rapidly increasing: almost tripled from 2001 to 2006. The application, firmware, and OS software has been designed in accordance with hardware components: typically core chipsets and system designs. Yet, nowadays, standardized OS is prepared for a mobile phone handset manufacturer by technology platforms vender together with core chipsets. Smartphones and PDA phones often use HLOS like Windows, Linux, and Symbian OS to control handsets' application part systems in addition to RTOS for communication part system. A feature phone uses RTOS, which conducts real-time switching of each task every 10 micro seconds to control the phone's entire system. Product developers can adopt even standardized middleware, API, and communication software from specialized venders.

Table 1 Platform Supply Networks in China

Brand/Channel/ Gray Market Manufacturers	Platform Vendors	
	Chinese IDHs	Technology Platform Vendors
Tianyu, Lenovo, Bird, Amoi, Konka, TCL, and others (including gray market manufacturers)	**MTK**, TI, **Spreadtrum**, Infineon, Datang-ADI, NXP, Agere, Qualcom, etc.	
	Longcheer	**MTK**, TI, Datang-ADI, Qualcomm, Infineon
	Simcom (SIM Tech)	**MTK**, NXP, Qualcomm, Datang-ADI
	TechFaith	NXP, TI, Freescale, Qualcomm, T3G
	CECW (exit in 2007)	NXP, **Spreadtrum**
	Huaqin	**MTK**, TI
	Wingtech	**Spreadtrum**, NXP
	Ginwave	**Spreadtrum**, Infineon, NXP

note: Technology platform vendors with bold letters are typical total solution platform vendors. Most of the handsets adopt RTOS.
source: i-Supply (2005), Imai and Shiu (2007), Merrill Lynch (2006), Morgan Stanley (2008), and our interviews.

Based on a technology platform, RF, I/O, and additional components are laid out on a PCB, which is the terminal main body of a mobile phone handset. A technology platform, RF, and application-related components/devices are necessarily arranged with power management unit (PMU) and related circuits on a PCB. System stability, energy consumption, and functional extension (applications) largely rely on the arrangement. Each firm's proprietary common software and device drivers may be added on a technology platform according to the intended applications and devices to be developed on a target handset system. At handset level, devices, such as display, key, digital to be developed camera, and so on, are arranged on the PCB. Model-specific devices and mechanical parts are added at handset level. Also model-specific applications are mounted at the level.

3.3 Modularized Interfirm Development Processes: The Taiwanese/Chinese Case

Specialized vendors for handset platforms/handsets appear mostly in the industrial upgrading processes in emergent countries. In Taiwan, PC ODM manufacturers apply their successful ODM business model to the mobile phone handset business. ODMs provide handsets, mostly low/middle-end ones, on behalf of the global brand manufacturers such as Motorola and Sony Ericsson (including several Japanese ones).

Exploiting standardized technology platforms, OS platforms, and customers' upper layer software (*e.g.,* applications, API, UI: user interface), ODMs develop detailed specification, handset hardware and software, manufacturing process, and produce handsets according to the requirements/specifications from major global manufacturers. At the same time, these ODMs also exercise

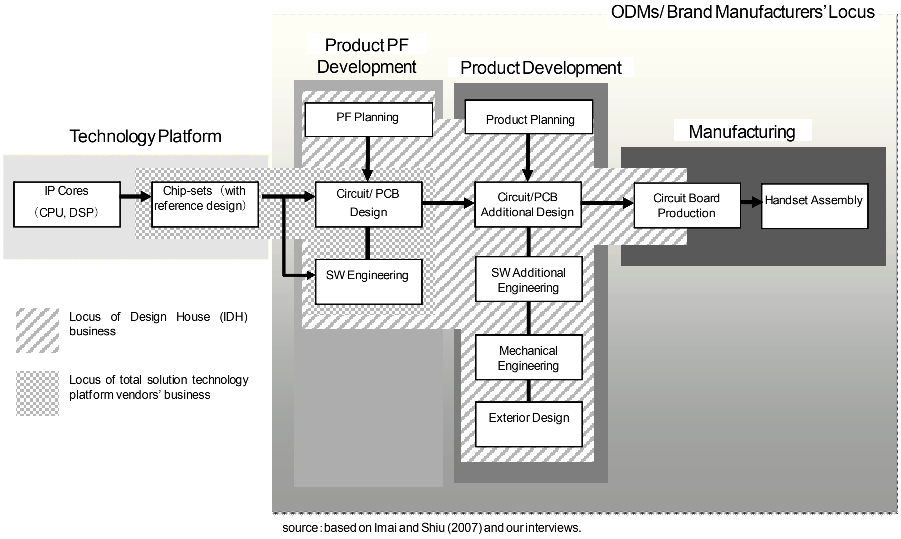

Figure 4 Modularized Handset Development Processes

their component procurement capabilities in order to enjoy scale economies in their handset development and manufacturing operations.

Yet, the ODM business in the global mobile phone industries has changed since around 2006 or 2007. Since 2007, Apple released "iPhone" series taking advantage of an Taiwanese ODM (Hon-Hai)'s manufacturing and procurement capabilities. The case of Apple is different from the traditional ODM business. Apple in person developed iPhone's handset system and software except most of applications and mobile communication software while fully exploiting external components (*e.g.,* BB chipset technology platform from Infenion, application chip from Samsung).

In late 2008, Google released the first Gphone series. An ODM, HTC, has designed and manufactured Gphone based on Google's Android software platform exploiting external components including a SoC core chipset from Qualcomm (Android may also function on other chipsets). Some of the critical software parts (*e.g.,* RTOS) and applications each were developed by independent software integrators and third party vendors in US and the world. Google prepared Android and software development environments for external vendors and manufacturers, and covered handset software system design. These cases show that as even hi-end handsets become developed in interfirm networks, ODMs come to play a critical role in the development and manufacturing even in hi-end segment handsets in the global handset development networks.

The Chinese handset industry demonstrates a case of more vertically disintegrated handset development in the industrial upgrading. In the Chinese handset industry, handset development processes are implemented in more decentralized manners. Sub-systems of a handset system are provided separately by technology platform vendors including European and US ones, local IDHs, and local handset manufacturers (Table 1).

The advent of the local manufacturers has induced the unique industrial evolution: the outgrowth of IDHs specializing in mobile phone handset development [7] (Imai and Kawakami, 2006; Imai and Shiu, 2007). In place of inexperienced local manufacturers, IDHs have develop PCBs and/or handsets for low/middle-end segments coping with systemic design issues (Figure 4).

At the beginning, an IDH appeared as a firm that was specialized in the development of handsets (Imai and Shiu, 2007). Relying on electronics manufacturing service (EMS) manufacturer's volume production, IDHs focus on handset development according to customer mobile phone handset manufacturers' specifications. Based on standardized technology platforms, IDHs develop hardware (*e.g.,* PCBs, mechanics, forms) and mount software (*e.g.,* applications, UI) on core chipsets for customer manufactures.

The profits of IDHs also come from the printed circuit board assembly (PCBA) business and related mass component procurement. IDHsNOP provide PCBAs, on which core chipsets and other components are mounted. The PCBA business's benefits have been increasing compared to design fees since it can benefit from scale economies of component sourcing. Accordingly, the PCBA business has become similar to ODM business.

In the PCBA business model, an IDH licenses a BB chip

Table 2 Platform Variety within and between Leading Manufacture (2005-2006)

Customer Handset Firms	BB	A-CPU /Co-Processor	HLOS
Nokia	Nokia & TI, Nokia & TI SoC (feature)	TI, Nokia & TI SoC (feature), TI/NECEL (partly hi-end), etc.	Symbian S60
Motorola	Freescale (3G, 2.X G), TI(2.X G)	NVIDIA(3G), TI (Symbian, Win, partly 3G) AMD (2.X G) , Marvell (Linux, 2.X G)	Linux(2.X G) , Win(2.X G), Symbian UIQ (3G)
Samsung	Qualcomm(3G), TI, Broadcom, LSI Logic, Agere (2.X G), etc.	Marvell (Win, Linux), TI (Symbian), etc. (3G, partly), Mtek Vision, Core Logic, NVIDIA etc. (partly, 3G)	Linux, Symbian S60, Win, etc. (partly 3G)
SEMC	EMP (3G, 2.X G)	NXP,NVIDIA etc. (partly 3G)	Symbian UIQ (partly 3G)
LG	Qualcomm(3G), EMP (partly 3G)	ST (Symbian), Marvell (Win), Core Logic, Mtek Vision (2.X G)	Symbian S60, Win(2.XG)

Note: Light gray shaded cells include platforms customized to, dedicated to, or co-developed with the manufacturers.
Source: Techno System Research (2007) and our interviews.

from an external technology platform vendor and thereby prepares lists of product functions for their customers. After the customers decide target functions, the IDH starts to design hardware, develop software, and select pre-verified components in parallel in order to meet the customers' requirements. Compared to design service according to customers' specifications, the PCBA business demands more meticulous market researches for function proposal and component procurement because of the fast market change and shortened product lifecycle.

These cases above suggest that handset systems are designed in the interfirm networks of independent specialized firms and vendors. Any single firm or vendor can hardly design an entire handset system which consists of a core chipset, software OS/platform, and handset design. Yet, even in the specialization of development tasks in the modularized interfirm development processes (*e.g.,* chipset vendors are dedicated to technology platforms), the loci of handset development task and knowledge may change in industrial and technological progresses and vary by product developer's strategies.

3.4 Proprietary Handset Development: Leading Manufacturers' Cases

Leading handset manufacturers, including the Japanese ones, cover more of development processes even under vertical disintegration while also exploiting external technology platforms and software platforms from specialized vendors (Table 2).

The table indicates that top 5 leading manufactures, which account more than 80% of the global handset shipment volumes, are mostly dedicated to developing proprietary handset platforms/handsets and upper layer software platforms (*e.g.,* API, middleware, UI) for their main handset lineups: hi-end, middle-end, and special featured[8]. On the other hand, most of leading manufacturers, Nokia, Motorola, and Sony-Ericsson, somewhat exploit ODMs for their low and mid-low segment handsets though the outsourcing ratio may differ by manufacturers (each estimated about 10%-50% of volumes for the global markets)[9].

Yet, the commitment to technology platforms and software platforms may differ between leading manufacturers. The European and US leading manufacturers more or less exploit customized, virtually proprietary, technology platforms using chipset vendors' semiconductor development and manufacturing processes. This is partly because some technology platform vendors and manufacturers originated from the same manufacturers (*e.g.,* Freescale from Motorola, EMP (Ericsson) and Sony Ericssson (SEMC) from Ericsson). Among all, Nokia are actively involved in the development of its exclusive chipset development by TI while raising the adoption of standardized technology platforms from other vendors.

Yet, it should be noted that these manufacturers themselves do not cover technology platform development in reality, but only provide requirements/specifications and IPs for technology platform vendors and/or examine platforms on their handset system designs. These leading manufacturers have been also engaged in software platform development, Symbian and Linux, in collaboration with each other, other manufacturers, and vendors.

On the other hand, the Korean manufacturers mostly focus on proprietary handset platforms/handsets and upper-layer software modules/platforms (*e.g.,* applications, API, UI)[10] while LG partly adopts customized solutions based on EMP. The Korean manufacturers started to release handsets by taking advantage of external CDMA core chipsets of Qualcomm in 1996 or 1997. After that, the Korean manufacturers extended their handset lineups to GSM/GPRS/EDGE (2-2.5/2.75G) and WCDMA (3G) handsets in the late 1990s in order to deploy their handset business in the global markets.

The Korean manufacturers have also left a part of handset development to the Korean exclusive contract vendors (*e.g.,* local IDHs) in their growth in the global markets (Imai and Kawakami, 2006). In these experiences, the Korean manufacturers have fully taken advantage of a variety of standardized technology platforms and software platforms, including BREW middleware/OS for CDMA chipsets from the early 2000s, in order to effectively develop handsets focusing on hi-end and middle-end segments. Yet, in

Table 3 WCDMA Platform Standardization in Japan

Customer Handset Firms	Chipset Combination	04	05	06	07	08
Panasonic (Linux OS: MOAP L)	BB ACPU Co-Processor	Panasonic TI/ARM9 Panasonic (hi-end)	Panasonic TI/ARM11 Panasonic (hi-end)	Panasonic Panasonic /ARM11	(AdCoretech BB IP) Panasonic SoC for hi-end TI SoC for standard	(AdCoretech BB IP) Panasonic SoC
NEC (Linux OS: MOAP L)	BB ACPU	NEC EI TI/ARM9	NEC EI TI/ARM11	NEC EI TI/ARM11 Qualcomm /ARM9 for low-end	(AdCoretech BB IP) NEC EI Ovia SoC	(AdCoretech BB IP) NEC EI Ovia SoC
Sharp (Symbian OS: MOAP S)	BB ACPU Co-Processor	NEC EL TI/ARM9 Renesas	NEC EI TI/ARM11	NEC EI TI/ARM11	Renesas SoC	Renesas SoC
SEMC (Symbian OS: MOAP S)	BB ACPU	NEC EI TI/ARM9	NEC EI TI/ARM11	NEC EI TI/ARM11	NEC EI TI/ARM11	Renesas SoC
Fujitsu (Symbian OS: MOAP S)	BB ACPU Co-Processor	Fujitsu TI/ARM9 Renesas	Fujitsu TI/ARM9 Renesas	Renesas SoC	Renesas SoC	Renesas SoC
Mitsubishi (Symbian OS: MOAP S)	BB ACPU Co-Processor	Fujitsu TI/ARM9 Renesas	Fujitsu TI/ARM9 Renesas	Renesas SoC	Renesas SoC	exit

Source: Techno System Research (2007) and our interviews.

Table 4 UMTS/WCDMA Platform Diversity (Vodafone/Softbank) in Japan

Customer Handset Firms	Chipset Combination	04	05	06	07	08
Sharp (API: i-POP)	BB ACPU Co-Processor	EMP Toshiba	EMP Toshiba	EMP Toshiba	EMP ACPU SoC Toshiba	EMP ACPU SoC Toshiba
NEC (API: i-POP)	BB ACPU	NEC EI TI	NEC EI TI	EMP	NEC EL SoC	NEC EL SoC
Panasonic (API: i-POP)	BB ACPU Co-Processor			IFX AMD	IFX AMD	Panasonic SoC with Unifier
Toshiba (API: i-POP)	BB ACPU Co-Processor	Qualcomm Toshiba	Qualcomm Toshiba	Qualcomm MSM+BREW Toshiba	Qualcomm MSM+BREW Toshiba	Qualcomm SoC (7200) (Toshiba?)
Samsung (API: i-POP?)	BB ACPU Co-Processor	Qualcomm	Qualcomm	Qualcomm	Qualcomm (Telechips?)	Qualcomm SoC (7200) (MtekVision?)

Source: Techno System Research (2007) and our interviews.

contrast to the European and US manufacturers, the Korean manufacturers are reported to not necessarily contrive proprietary product platforms due to their extended product variation (more than 300 models are released in a year). The Korean manufacturers are also involved in standardized software platform development along with other leading manufacturers and vendors.

In contrast to these leading manufacturers, many of the Japanese manufacturers, more specifically NTT DoCoMo original equipment manufacturers (OEMs), have not contrived proprietary product platforms due to their reliance on customer operators' strategies, but covered wider range of handset system levels: from technology platform and software modules/platforms to handset (Table 3). Traditional top manufacturers, such as Panasonic and NEC, have developed proprietary chipsets and software as well as their handsets[11].

However, in the mid 2000s, the market saturation of the Japanese market encouraged these manufacturers to adopt more standardized technology platforms (AdCoretech BB, Renesas SH-Mobile SoC) and software platforms (MOAP L: Linux, MOAP S: Symbia). software platforms have been almost NTT DoCoMo-proprietary developed from 2002 or 2003 in the collaboration of manufacturers, vendors, and NTT DoCoMo[12].

On the other hand, OEMs for Softbank, which also adopt UMTS/WCDMA technology as NTT DoCoMo does, exploit a variety of external standardized platforms (Table 4). These manufacturers only share Softbank's common API: POP-i. This is because they started to provide handsets for Softbank (Vodafone) since 2004 when WCDAM technologies were almost stabilized. The fact shows that once a communication technology standard gets stabilized, manufacturers may be more dedicated to developing handsets taking full advantage of external standardized platforms.

In the early period of a novel technology platform adoption, manufacturers lack sufficient level of system knowledge on the basic handset architecture configuration and its compatibility with other components, platforms, and telecommunication systems (*e.g.,* base-station). A manufacturer cannot simply exploit a novel platform,

Table 5 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, DV Sample Bug Trace List	Transfer to Factory, Formal Test Report, DVT Sample Bug Solution Confirmation, PVT Bug & Limitation

source: Interviews and documents of firms.

when attempt to develop a consistent and stable system with functional expansion for proprietary handset ones (Yasumoto and Shiu, 2008).

The European, US and Japanese advanced leading manufacturers are liable to cover even the knowledge at technology platform level in order to deploy proprietary functions. Instead, the Korean and some Japanese manufacturers for KDDI and Softbank would rather put emphasis on product level design to exploit stabilized technology platforms using a variety of verified components and standardized platforms.

In 2007 and 2008, these streams toward common software platforms which are divided between the world and Japan began to converge into the several international platform streams: Symbian, Linux, and Android[13]. At the same time, some major manufacturers like Apple and Nokia have still prepared their proprietary platforms and software development environments in order to deploy their applications, contents, and services with the assistances of external software vendors.

The foundations of two major HLOS platforms, Symbian and LiMo, took the direction to more open systems in 2007 and 2008. These foundations have been dedicated to developing and/or standardizing these platforms. In 2008, these foundations were reorganized and declared that they started to open their platform software and application software development environments, SDK and sometimes source cords, to external firms and vendors so that more firms and vendors can adopt these platforms for free or with lower cost and/or contribute to application software development.

After the release of Google's Android SDK in late 2007, the platform has drastically accelerated the stream toward platform standardization. OHA established in 2007 has promoted the platform. The platform based on Linux OS is planned to be more open to any software vendors and manufacturers and easier to be installed into any handset platform hardware than other software platforms, which means that the platform does not depend on hardware. The first handset with the platform was released as "G1" of Google's Gseries, which was designed by HTC based on a Qualcomm Chip and released in late 2008.

These streams toward standardized platforms have encouraged even the Japanese firms to commit to these global platforms. In 2007, NTT DoCoMo and the Japanese manufacturers of WCDMA handsets for NTT DoCoMo decided to shift from MOAP to the globally standardized Symbian or Linux platforms. These standardized platforms are applicable to handsets for multiple operators. Thus, several Japanese manufacturers have already released handsets based on these platforms for both NTT DoCoMo and Softbank in 2008[14].

These manufacturers and NTT DoCoMo also agreed to introduce the "operator pack" into the application and API layers in these standardized platforms in order to customize software according to multiple operators' and manufacturers' application/service requirements[15]. The operator pack particularly for Linux platform has been developed by ACCESS, one of the exponent API platform vendors in the world, since 2008.

3.5 Systemic Problems in Handset Development

In the surge of vertical disintegration, even leading manufacturers develop hi-end handsets relying on the interfirm networks of independent specialized firms and vendors. Manufacturers increasingly get dedicated to handset system design exploiting common software OS/platforms as well as standardized core chipsets. However, the loci of handset development tasks and knowledge of handset developers are fluid in both hardware and software.

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 at handset design and test stages (Table 5), which aim at achieving a product system's consistency and stability, are related to product level system design of nested modules.

A technology platform defines basic product architecture of mobile phone handsets. Based on the architecture, handset developers including brand manufacturers, ODMs, and IDHs need to design a handset system arranging other components. Baseband, radio frequency, and power management are related to each other. The problems related to radio frequency have drastically reduced since most of radio frequency circuits are digitalized and integrated into a single chip or technology platform since the mid-2000s. Yet, baseband and power management should be still arranged neatly in order to realize both functional extension (applications) as well as system consistency and stability[16].

Functional extension is relevant to not only baseband/application processer capabilities but also energy consumption. A firm needs to control the energy consumption and system stability of application software and devices. The components of baseband, power management, and application-related devices (including memories) should be selected according to both cost restriction and target product specifications, and properly arranged on a PCB. A handset system should also control application devices and programs implementing effective application switching and realtime operation. These attempts for functional extension and related energy consumption largely rely on the arrangement of both hardware circuit design and software configuration.

A core chipset/technology platform itself is also relevant to a variety of functions. Each firm's proprietary common software and device drivers may be added on core chipsets according to the applications and devices working on a PCB. Sometimes a novel function is implemented by multiple components. For instance, in the development of MP3 music function, designers must consider the memory size for storage, alternative technologies for playback (*i.e.,* software or hardware), modification of 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. The technology platform that relates these elements to MP3 function may be modified and introduced into a product system design in iterative design-testing processes.

Furthermore, a novel technology platform can cause quite a few problems in PCB design due to the lack of both core chipset stability and verified architectural consistency with handset design configuration[17]. A novel technology platform adoption sometimes gives rise to more than 10,000 software bugs and 1,000 hardware bugs.

In a system of nested modules, the innovation of a core component represents movements up the system hierarchy and sometimes lead to revolutionary changes that refurbish basic product system foundations (Henderson and Clark, 1990). It is not easy to design PCBs, particularly the hardware arrangement and software control, and power management circuits, based on a novel technology platform. Moreover, the necessity of extended PCB design for application devices and mechanical designs invite systemic hardware design problems in handset development (*e.g.,* physical and electro-magnetic interferences).

4. Discussion

Past academic studies presume that system knowledge is carried by single system integrators: product manufacturers (Brusoni and Prencipe, 2001; Brusoni, Prencipe, and Pavitt, 2001; Clark and Fujimoto, 1991). To the contrary, under vertical disintegration, powerful technology platform vendors are expected to prepare system knowledge (Baldwin and Clark, 2000; Gawer and Cusumano, 2002; Iansiti and Levien, 2004).

However, in modularized development processes, any single firms can hardly invest in or control completed system knowledge necessary for product development (Prencipe, 2003). Our data witness that system knowledge which is divided into portions of complementary knowledge is carried by multiple specialized firms according to the levels of a nested module system. That is to say, technology platform vendors, software platform vendors, product platform vendors, and manufacturers each implement system integration in a dispersive manner. These multiple firms and vendors collectively carry system knowledge in open environments under vertical disintegration.

For instance, in the Chinese handset industry, such dissemination of system knowledge through the networks of these specialized firms and vendors enables product developers without sufficient experiences and/or resources to develop products. Inexperienced product developers can exploit system knowledge embedded in sets of technology and product platforms and/or total solution platforms.

On the other hand, product platform vendors (*i.e.,* IDHs or ODMs) or capable handset manufacturers in person implement handset development adopting external technology and software platforms whose coverage is restricted to relatively low/middle levels of nested module systems. In the modularized interfirm development processes, these manufacturers are liable to exploit complementary system knowledge from external vendors in order to mostly dedicate themselves to system integration at product platform and/or product design levels.

Studies have found firms' competitiveness in both core product technologies (Iansiti, 1997; Sakakibara and Koyama, 2006) and/or development capabilities to integrate a variety of components/technologies (Aoshima and Nobeoka, 1997 ; Henderson and Clark, 1990; Henderson and Cockburn, 1991). These witnessing facts here reveal that under vertical disintegration, the competitiveness of product manufacturers primarily rest on development capabilities for system integration to integrate a variety of components/technologies in product system development processes.

In technology integration (Iansiti, 1997), core product technologies are effectively developed integrated with a variety of components/technologies. Yet, in the case of system integration under vertical disintegration, firms adopt core product technologies embedded in external standardized technology platforms. Manufacturers in most of cases focus on system integration without participating in technology development. In the dissemination of system knowledge under vertical disintegration, many of manufactures' development capabilities are replaced with standardized system knowledge embedded in platforms or related development supports from external vendors. Nothing but system knowledge for product system design can be virtually proprietary local knowledge, architectural knowledge, of each firm.

Open innovation environments all the better highlight the role of product manufacturers' architectural knowledge at downstream development stages for product development (Chesbrough, 2003; Chesbrough et al., 2006). The data of platform supplies imply that such architectural knowledge of both hardware and software can not be simply attributed to disseminated generic system knowledge only to realize a common, sometimes bare, product system, but should be firm-specific local system knowledge to yield a distinctive product system.

Our findings reveal that many of manufacturers do not enclose core product technology development tasks within these manufacturers, but are dedicated to system integration based on external core product technologies. A BB chipset, a set of core product technologies, new to a manufacturer influences other system levels of a handset system, and thus causes system-level stability problems across all the system levels.

Data accessing timing between a chipset and other devices (*e.g.,* memories) needs to be controlled through interfaces defined by the BB chipset vendor. A manufacturer should also design power management and system extension by properly arranging the chipset, related components (including software), and other devices. The adoption of an unprecedented BB chipset often requires product developers to employ components and devices that are not verified by BB chipset vendors.

These components and devices may cause unstable data accessing timing, inefficient power consumption, and interrupt software commands or programs. Such problems related to the adoption of a technology platform, particularly a novel ones, call for product level system integration, hardware system design and system-related software development, including the examination and verification of the product system (Yasumoto and Shiu, 2008)[18].

Yet, reflecting external platform vendors' technology specifications and roadmaps, manufacturers make efforts to acquire core technology knowledge at technology and software platform levels, which defines the basic configuration (*i.e.,* functions and interactions among components) of a product system. The involvements of leading manufacturers in the development of technology and software platforms indicate that manufacturers' architectural knowledge may even range over core technology knowledge beyond their locus of product development tasks.

Particularly in technological changes, knowledge boundaries are sometimes beyond firm boundaries in spite of definite task partitioning between firms (Brusoni, et al., 2001; Takeishi, 2002). Even under vertical disintegration where interfirm task boundaries are definite, novel technology platform adoption may shake knowledge boundaries between upstream vendors and downstream firms.

Total solution adoption reveals typical problems in the change of knowledge boundaries between firms and vendors. A technology platform vendor may give tension to product manufacturers if the vendor expands the locus of its technology platforms to product system level. The Chinese cases give emblematic cases (Marukawa, 2007). A total solution vendor, such as Mediatek and Spreadtrum, encapsulates a large portion of product functions into solution chipsets and bundles essential components in order to shorten customer manufacturers' product development lead time to market. Yet, at the same time, these manufactures may face serious difficulties to differentiate and/or evolve their products.

The fact would imply that in modularized interfirm development networks, how to manage the balance between the locus of proprietary system integration and that of external standardized platforms should be a critical issue for a product developer: product developers need to consider their ranges of proprietary hardware and software. While the expanded locus of an external standardized platforms reduces handset development cost and leadtime, the restricted locus of an external standardized platforms increases handset design flexibility to extend product functions. The balance between the locus of product developers' system integration and that covered by external standard platforms can largely influence not only the developer's competitiveness but even industrial dynamism under vertical disintegration.

5. Conclusion

The study shows that technology/product development processes have been modularized into relatively independent interfirm processes. Accordingly, vendors specialized to their focused processes each prepare a part of system knowledge in the form of a standardized platform according to the level of a system of nested modules. The data implies that such multiple-platforms provided in modularized product development processes collectively enhance the dissemination of system knowledge to allow new entrants to develop products.

In modularized product development processes, firms can mutually offer complementary knowledge (*i.e.,* different levels of system knowledge) in order to overcome their insufficiency of system knowledge[19] and speed up product development. More vertically integrated/enclosing firms (*e.g.,* Nokia) have accumulated knowledge on communication technologies and handset systems. Compared to such firms, modular-architecture-oriented firms, particularly new entrants, without sufficient system knowledge will face modularity trap in technological changes (Chesbrough and Kusunoki, 2001). These firms are assumed to have difficulties to integrate a variety of components/technologies into a product when core technologies change.

However, especially in Taiwan, Korea and China, the dissemination of system knowledge takes place of a large portion of system knowledge which had been nurtured in vertically integrated/enclosing firms. The case indicates that even leading manufacturers exploit standardized technology platforms from specialized vendors. Such interfirm networks for the dissemination of system knowledge may imply that technological changes would not necessarily decay modular-architecture-oriented firms without sufficient system knowledge (Chesbrough and Kusunoki, 2001).

On the other hand, leading manufacturers primarily invest in their local system knowledge, architectural knowledge, developing their proprietary product platforms and/or products. Also the locus of such knowledge may range over core technologies beyond the locus of these firms' product development tasks (Brusnoi, et al., 2001; Takeishi, 2002). These manufacturers are not simply reactive to design rules set by predominant technology platform vendors.

The study shows that the examination of the determinants of the loci of task and knowledge of product developers' system integration should be required in future researches. The determinants of the loci are relevant to how a firm explore and exploits its knowledge in modularized interfirm development processes. In relation to such knowledge exploration and exploitation, development processes for system integration (*i.e.,* how a variety of elements are integrated based on a core technology system) should be also explicated in detail.

Architectural knowledge and relevant development processes of distinctive manufacturers are still worth of examination. These research issues extracted from the proposed perspective will help us approach the nature of manufacturers' product development capabilities in open environments.

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[1] Marukawa, et al. (2007).

[2] A total solution reduces integration cost in product development facilitating the integration of components and technologies (Iansiti and Levien, 2004; Sakakibara and Koyama, 2006). However, such monotonous encapsulation should sacrifice systems' extensiveness and progress, as is shown in the case of the Chinese industries (Marukawa, 2007). As a result, encapsulation may hinder bilateral mutual learning between firms.

[3] From the late 1990s, chipset vendors started to provide their chipsets with RTOS and standardized communication protocol stacks which specialized vendors developed.

[4] See Nikkei Electronics (2004; 2006b; 2006c; 2007).

[5] The information of software platform is from news releases of the related foundations and manufacturers in 2007 and 2008.

[6] See Merrill Lynch (2007).

[7] 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.

[8] Also see Citi Industry Research (2008), IDC (2007), Nikkei Electronics (2004; 2006b; 2006c; 2007).

[9] Estimated based on Citigroup (2006). Yet, the estimated ratio might be overestimated as the estimation is based on the assumption that all the handset models of ODMs' production are also designed by ODMs.

[10] For instance, see Nikkei Electronics (2006a) and Ueda (2007). Our interviews also confirmed that these Korean

firms primarily invest in handset development.

[11] These chipsets and software are virtually developed within group firms.

[12] Also see Nikkei Electronics (2007). NTT DoCoMo attempts to replace DoCoMo proprietary Symban/Linux OS (MOAP S/L) with the combination of standardized OS and the operator pack. On the other hand, the Japanese CDMA manufacturers for KDDI have exploited Qualcomm's hardware and software platforms as is the case of the Korean manufacturers. Yet, these CDMA manufacturers also started to exploit standardized software modules/platforms (KCP/KCP+), including a large part of upper layers (*e.g.,* applications, API, UI), which have been developed led by their customer operator: KDDI.

[13] While being the most popular platform for smartphones, Windows Mobile is not necessarily common open platforms as it is developed and licensed simply by Microsoft. Windows Mobile originating from PC software is reported to go behind other mobile platforms in terms of functional expansion according to operators' and manufacturers' applications, realtime multiple application operation, and power management.

[14] Interviews with two Japanese manufacturers (Dec, 2008).

[15] Interview with NTT DoCoMo (Dec, 2008). Also see corporate home pages of NTT DoCoMo and Access (access in Oct, 2008).

[16] Interviews with manufacturers, ODMs, and design offices from 2006 to 2008.

[17] Vendors renew their technology platforms every 2 years and application parts in less than a year, depending on the evolution of technologies and applications.

[18] Even the Chinese local mobile phone handset manufacturers and IDHs take advantage of technical information and supports from core chip vendors in order to solve their systemic problems. For instance, one of the top local mobile phone handset manufacturer, Amoi, has also worked with Spreadtrum, China's local technology platform vendor, in order to develop GSM/GPRS mobile phone handsets and the Chinese 3G standard TD-SCDMA handsets.

[19] The Chinese 3G TD-SCDMA development may support the prediction. The Chinese digital product industries mostly rely on product modularity. However, in the TD-SCDMA development collaborative networks, the insufficiency of system knowledge of the Chinese local firms are compensated for by major global technology platform vendors (*e.g.,* ADI, TI, Infineon, NXP) and brand manufacturers (*e.g.,* Nokia, Motorola, Samsung, LG). These firms are indirectly involved in networks through partnerships with local firms.