Organizing Open Innovation in Distributed Network:
A Socioeconomic Analysis of the Networked Production Models

HUANG, Hao
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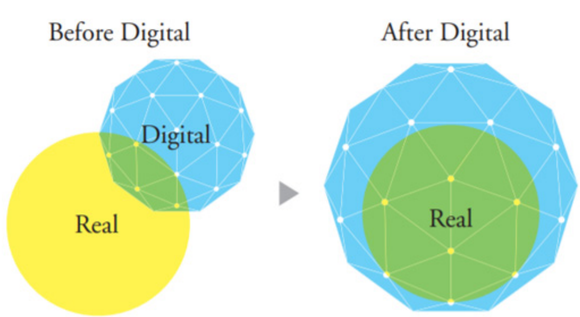
The Emergence of a Globalized Open Economy

1.1 The Motivation

The globalized economy is so different from the traditional ones. With the development of information and communication technologies, we are heading into a brand-new networked economy that is connecting all human beings together (Jemielniak & Przegalinska, 2020). The changes are not limited to the scale or the pace. As shown in Figure 1, the digital world is now merging with the physical world (Fujii & Obara, 2019). In the new age of human civilization, everyone is always online. It is a paradigm shift affecting every corner of the human society, definitely including the economy.

Figure 1. Before and after the digitalization



Source: Fujii & Obara, 2019, p. 46.

For instance, the marginal cost can become as low as zero in the networked economy. Reproducing a painting will request a set of instruments and materials, as well as a well-trained artist when it is on paper. However, copying a picture file needs only a few mouse clicks or a few commands with the computer. The digital production of ICT industries can get rid of the capacity constraints we found in the traditional industries. Since the rational price equals the marginal cost in a perfect competitive market, the rational price for digital goods can also be as low as zero. Therefore, sales, revenues, profits, and GDPs are all become an astonishing zero in this sense.

On the contrary, the fixed cost of advanced manufacturing can be extremely high. In semiconductor manufacturing, a typical case of globalized modern industry, it costs more than 2 billion dollars to build a factory with the most advanced EUV fabrication systems. Moreover, the price is still increasing year by year. As a result, fixed cost degression is very complicated in such industrial sectors.

These two opposite trends have led to a similar approach: <u>open innovation</u>. In Schumpeterian innovation theory, innovations are either created by the entrepreneurs ("creative destruction", or "Mark I", 1912/1934) or created by the large companies' "creative accumulation" ("Mark II", 1942). In both cases, innovations are leaded by the market leader internally ("closed innovation" in Chesbrough (2003)'s words). However, the paradigm of innovation is shifting. Nowadays, more and more companies are shifting to an open innovation strategy. The trend of open innovation forces firms to use "external ideas" and "external paths" (Chesbrough, 2003). As a result, the firms have to keep "reassessing their leadership position" (Chesbrough & Appleyard, 2007). Open innovation happens collaboratively and is often not led by a certain market leader.

In the semiconductor manufacturing industry, all firms are either extremely asset-light “fabless” manufacturers, or extremely asset-heavy IDMs (integrated device manufacturers) and “pure play” foundries. Except for a handful of cases, these firms are collaborating very deeply together. In fact, 7 out of the top 15 semiconductor suppliers have all their revenues from collaborated productions (IC Insights, 2020). In this industrial sector, even rivals are cooperating together. Apple and Qualcomm have filed a couple of lawsuits against each other in recent years (Apple, 2019). However, they rely on the same foundry (TSMC) to produce their similar products (mobile SoCs), and even work on the same production engineering (fabrication processes) together at the same foundry. Similarly, while Samsung Electronics is working with Nvidia on graphic processing technologies (Nvidia, 2020), it is also the partner of Nvidia’s rival AMD sharing the similar graphic technologies (AMD, 2019). More interestingly, AMD is one of the top customers of Samsung’s rival TSMC (Castellano, 2021). Definitely, each pair of these companies are fierce rivals. But at the same time, they are partners altogether.

As Adler (2001) puts it, trust is the central construct in knowledge-intensive activities (semiconductor manufacturing is definitely a knowledge-intensive industry). How can a group of trustless players gather together to promote collective knowledge creations? The answer could be open innovation.

Similar “irrational” phenomena can be found in other ICT industrial sectors. The software industry is the first adopter of open innovation and is now shifting to an open source paradigm (Von Krogh & Von Hippel, 2006). According to Synopsys (2021)’s report, more than 98% of software products contain open source based codes. Due to its high quality and free distribution, open source software has been widely used on the Earth – and even on the Mars (Friedman, 2021). As a term originated from the computer world, the concept of “open source” herein can be explained as “assuring rights to make and distribute copies of computer programs, to access to the software's source code and a necessary preliminary to change it, and to make improvements to the program" (Perens, 1998). To put it more understandable, for a software company, adopting an open source strategy means that anybody, including its customers and rivals, can access the source codes – the core competence – of its products. Not only the risk-taking start-up companies, but also the software giants such as Microsoft and Google have shown their motivations in the open source movement (Huang, 2016). According to GitHub's "open source survey" (2018), nearly half (47%) of the commercial software companies are permissive to contribute their source codes outside. Furthermore, some commercial companies are playing even more aggressively, giving out their intellectual properties such as the patents to the open source community. In 2018, the alliance of open media (AOMedia) was founded by technology titans including Amazon, Apple, Facebook, Google, and Microsoft. All the members of AOMedia agreed to abandon their related patents for the open source codecs developed by AOMedia (AOMedia, 2019). For the participants of AOMedia, giving up the royalty fee business means a potential loss of billions of U.S. dollars per year. Nevertheless, a company opened all its intellectual property (in other words, a company without "exclusively protected" core competence) can achieve great success in the software industry: Founded in 1993, Red Hat, Inc. recorded the eighth-biggest first-day gain in the Wall-Street history during its initial public offering in 1999, surpassed one billion U.S. dollars revenue in 2012 and two billion in 2015, and was acquired by IBM for 34 billion U.S. dollars in 2018 (Red Hat, Inc., 2020).

For the knowledge-intensive industries, intellectual property is generally considered as "the central resource for creating wealth" (Smith & Parr, 2000). How do software companies "abandoning" their intellectual property succeed in business? The answer could be open innovation.

The comprehensive acceptance of open innovation in the capitalist economies suggests that we need to reconsider the theoretical framework of economics and management science in the networked era. Evidently, phenomena such as the abundance of core competence protection and the zero-trust collaboration found in these open innovation attempts are not compatible with traditional innovation management and innovation theories. The traditional theories are facing more and more problems in solving the globalized, collaborative production issues (Rifkin, 2014). We need to introduce a new methodology and develop a new mechanism for open innovation management.

1.2 The Objectives

From the discussion of the previous section, we can conclude three characteristics of the globalized networked economy:

1) The dynamic and plural economic landscape of the globalized society requires flexible and responsive productions. The comprehensive interconnections in the networked world generate an evolving globalized economy. Today's productions, particularly the digital productions in the global network, have to be highly agile and interoperative.
2) The complexities of science, technology, and business force innovation processes to be collective and distributed. To satisfy the intensive demands and requirements in a globalized business context, firms have to make full use of the global supply chain, control all the resources and information flows. A

"closed" corporate or a "dedicated" individual is no longer able to survive in the globalized era.

3) A typical competition in the global network should not be a zero-sum game. Instead, an innovation network can form a win-win relationship between the participants.

To survive in the era of globalization and comprehensive interconnections, we have to 1) understand the intra-organizational, and extra-organizational mechanism of participatory inter-personal activities in the global business context; 2) understand the organizational and inter-organizational mechanism of the global network settings. Furthermore, we need to answer the following important questions: What drives individuals and corporates (firms) to participate in collaborations (especially those "altruistic" ones)? How can individuals and corporates trust each other in global distributed network? What network settings and typologies are fit for the responsive and cooperative global business?

We aim to solve these research questions by investigating and analyzing the following issues.

The conditions and restraining factors of open innovation in the distributed networks

Granovetter, one of the most important scholars in the network analysis, identified four economic outcomes that the network has a significant impact on: hiring, pricing, productivity, and *innovation* (2005, p. 33). The management of innovation in the networked economy, particularly in the distributed networks, is much different from the traditional innovation management.

This research aims to understand the managerial mechanism of a more collaborative, globalized world economy: the "trust" and "motives" for members from every corner of the world to join the open innovation. Furthermore, this research is concerning with the necessary relationship between market structure and innovation process in the modern market economy, especially the globalized economy.

The dependencies and routines for the commercialization of open innovation

On the other hand, innovation cannot be elicited on request (Kamien & Schwartz, 1982). As long as innovation "is what capitalism consists in and what every capitalist concern has got to live in" (Schumpeter, 1942, p. 82), we must recognize the potential business implication of the new open innovation paradigm.

From the business perspective, open innovation is a distinctive concept comparing to the traditional innovation management. Traditionally, investors assess "the competitive advantage of any given company and the durability of that advantage" rather than "how much an industry is going to affect society, or how much it will grow" (Buffett & Loomis, 1999). To the contrary, the open innovation paradigm seems to be focusing more on involving extensive interactions and interactors, keeping sustainable growth, and building an ecosystem. With the traditional due-diligence methods, we can only treat open innovation as a negative factor that will neglect and even abandon the competitive advantage of a company.

However, the open innovation theory is initially implicated with the business model for entrepreneurs as well as large companies to achieve greater returns (Chesbrough, 2003), employ markets (West, 2007), and improve productivity (Ito &

Tanaka, 2013). It is crucial to find the path dependencies, the necessary routines, and the sufficient environmental variables for open innovation business models to raise money and realize a profit.

Therefore, this research aims to investigate the business applicability of the open innovation paradigm. This research will analyze a number of business cases adopting the open innovation paradigm in different types of productions, different industrial sectors, and different innovation networks. Some cases have succeeded, some have failed. This research will compare the different implementations of the open innovation paradigm in these empirical cases. From the comparison of different business approaches, this research aims to come out with some implications for business adoptions of the open innovation paradigm. Besides, this research will investigate and evaluate "the mechanisms of open innovation in searching and promoting new combinations" (Yonekura & Shimizu, 2015, pp. 89-100) in the distributed business networks.

1.3 The Structure of this Research

This research is composed of six chapters that can be roughly divided into four parts: Part 1) Chapter 1 and Chapter 2, the introduction and the background of open innovation. Part 2) Chapter 3, the literature review on the previous theoretical implications and empirical studies of the open innovation implementations. Part 3) Chapter 4 and Chapter 5, the original analyses of various empirical implementations of open innovation in different industrial sectors. After the three parts, part 4) Chapter 6 concludes this research and discusses the impact and implications of the open innovation paradigm in the globalized business context.

In this chapter, we have discussed the emergence of open innovation in the networked society. We started by comparing the differences between the physical, discrete, "real" economy and the digital, networked, "augmented" economy. After the digital revolution, the new era of the human economy has some different properties than the traditional productions: the marginal cost of digital production can be as low as zero, but the fixed cost of advanced manufacturing can sometimes be extremely high. Innovation causes the response from the system (Schumpeter, 1939, p. 172), and innovation is the answer to response to the systematic changes. In this chapter, we reviewed a bundle of "strange" business strategies in both the digital production industries and the advanced manufacturing industries. We have pointed out that the open business strategies are based on an updated innovation paradigm. The opened business strategies can better response to the dynamic and plural markets, can possibly create the complex innovation, and can form win-win relationships in order to survive in the globalized economy. Therefore, we need to understand the mechanism of "open" innovation in the globalized and networked economy. At the end of this chapter, we addressed the objectives of this research: 1) to understand the conditions and restraining factors of adopting open innovation; 2) to understand the dependencies and routines for implementing open innovation.

Since open innovation is an extended paradigm with a root of the traditional innovation theory, we need to go over the Schumpeterian innovation theory and the existing innovation managerial mechanisms before we can discuss the implementation and management of open innovation. In Chapter 2, we will first introduce the history of innovation and particularly the Schumpeterian innovation theory. We will then discuss the evolution from the "closed" in-house innovation model to the open innovation paradigm. We will investigate the new institutional economics, the open source movement in the software industry, and other distributed innovation methodologies that related to the development of open innovation paradigm. We will also introduce several innovation management theories from different academic and practical backgrounds with a cross-disciplinary view.

After the introduction and the background, we will survey the existing literature to have a basic understanding of the current research status of open innovation. In Chapter 3, we will first distinguish the various definitions of open innovation. After comparing the different conceptualizations of open innovation, we will review the available implementations, the possible approaches and mechanisms, as well as the potential benefits and challenges of the open innovation paradigm in a globalized network context. We will then survey and review the previous theoretical research and the empirical studies of open innovation. At the end of Chapter 3, we will conclude the research status of open innovation, and address the remaining problems of the previous research.

The next part is the original research of this dissertation. Chapter 4 is about the methodology and research design. In the first section, we will define the term "open innovation" used in this research. From the definition and the remaining problems of the existing literature, we will then set the research questions based on the objectives of this research: 1) To understand the intra-organizational and extra-organizational mechanism of peer participation in distributed open innovation networks in the individual level of analysis; 2) To understand the organizational and inter-organizational mechanism of the distributed open innovation network in the collective level of analysis. To answer these two questions and four sub-research questions, we will introduce the analytical frameworks in the latter part of Section 4.2. We will then discuss the theoretical background of the analytical frameworks in Section 4.3 with the game theory. At last, Section 4.4 will conclude the analytical tools in this research and introduce the research methodology we adopt in the comparative case studies.

In Chapter 5, we will comparatively analyze seven commercial companies representing different types of productions and implementing different open innovation approaches. Particularly, we will survey four capital-intensive and labor-intensive firms from the manufacturing and service industrial sectors, which are underresearched in the existing literature. By comparing the successful cases with the failed cases, we will identify the conditions, path dependencies, and the necessary and sufficient factors to implement open innovation in different innovation types and different production networks. The comparative case studies will give us an empirical understanding of the influence, the applicability, and the limitation of the open innovation paradigm in the context of a globalized business. We will also discuss the appropriate open innovation managerial methods from the experiences of the successful cases, and the known bad practices of open innovation implementation that we find in the failed cases.

After the introduction, the literature review, and the original analyses, we will have a conclusion of this research in Chapter 6. Firstly, we will provide a summary of this dissertation in Section 6.1. We will present the key insights from our original analyses in Section 6.2. We will further discuss the potential impacts and implications of open innovation from our findings. In Section 6.3, we will clarify the limitation and remaining problems of this research. At last, we will share some recommendations for the future research in the theme of open innovation in the distributed networks.

Chapter 2

Innovation and Management: The Background

In this chapter, we discuss the history of innovation theory, the management of innovation, and the importance of innovation for economic development. In section 2.1, we introduce the concept of the Schumpeterian innovation theory, and the related concepts before the "innovation" was introduced by Joseph Alois Schumpeter. In Section 2.2, we introduce the limitation of the Schumpeterian innovation. We then introduce open innovation and other "novel" innovation concepts developed by different scholars to suit the modern globalized and networked economies. In Section 2.3, we discuss the background of open innovation: the digital production and the open source movement in the software industry. In Section 2.4, we introduce the implicit theoretical roots of open innovation management: the new institutional economics. In Section 2.5, we introduce some visionary innovation management theories that have also been widely accepted and applied in the research of open innovation.

2.1 Innovation: The Key Factor of Modern Economic Development

Innovation is a relatively recent concept: The concept of innovation is initially introduced by Joseph Alois Schumpeter (1912/1934). However, only a few studies concerning the technical advance as an economic phenomenon were done before the end of World War II. Nevertheless, "innovation" as well as its concept has long been considered and implicated applied as the driven power of the development of human society in the previous research. Since the rise of the capitalist economy from 1760, firms have always been innovating to maintain their profitability (Schumpeter, 1942, p. 83). In fact, the discontinuous emergence of innovations accounted for 75% of GDP growth in the US since World War II (Ezell & Atkinson, 2010). According to OECD's report, innovation is now the top factor of economic growth in developed countries (Curley & Salmelin, 2018).

Schumpeter highlights the discontinuous changes that displace the old economic equilibria and create new conditions as the critical factor of economic development (1912/1934). In his three famous books, *The Theory of Economic Development* (1912/1934), *Business Cycles* (1939), and *Capitalism, Socialism and Democracy* (1942), Schumpeter coined the concept of innovation[1] and discovered its role in the economic development of the capitalism. In *Business Cycles*, Schumpeter uses the term "innovation" for the first time to distinguish the discontinuous "*neue kombination* [new combination]" from other similar concepts (such as technological change, invention, etc.) (1939, p. 80). He defines innovation "as the setting up of a new production function" (1939, p. 84). Schumpeter further defines the innovation process as a "process of creative destruction", which "incessantly revolutionizes the economic structure from within, incessantly destroying the old one, incessantly creating a new one" (1942, p. 83). As shown in Figure 2, the concept of innovation is the strategic stimulus to economic development in Schumpeter's works, which covers the cases of 1) Product innovation: "the introduction of a new good" or "of a new quality of a good"; 2) Process innovation: "the introduction

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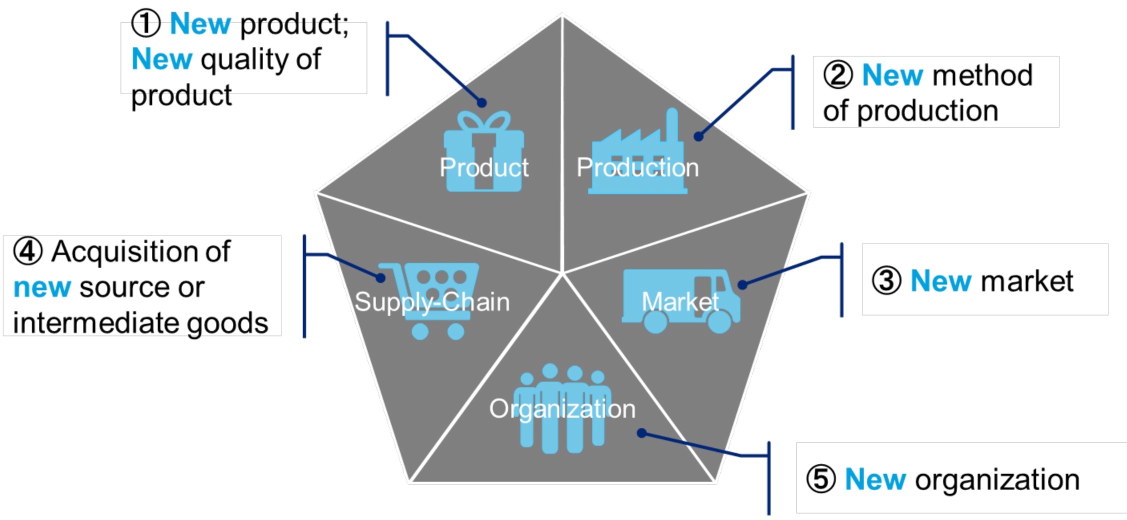
[1] Note that Schumpeter did not use the word "innovation" in his early books. Instead, he used the phrase "*neue kombination* [new combination]". Schumpeter has later confirmed that "innovation" means "*durchsetzung neuer kombinationen* [fulfillment of new combinations]". Therefore, most scholars are treating "new combination" that appeared in Schumpeter's earlier works as a synonym of "innovation" (Yashiro, 2016).

of a new method of production"; 3) Market innovation: "the opening of a new market"; 4) Input innovation: "the conquest of a new source of supply of raw materials or half-manufactured (intermediate) good"; 5) Organizational innovation: "the carrying out of the new organization of any industry" (1912/1934, p. 66). Such cases should be a commercial or industrial implementation of something "new" or "unfamiliar" to the consumer (product innovation), to the branch of manufacture in a particular region (process innovation, market innovation, and input innovation), or to the market or industrial structure (organizational innovation).

Figure 2. Five types of Schumpeterian innovation



Source: Made by the author.

In the first two books (1912/1934, 1939), Schumpeter has picked up the *entrepreneur* as the critical role played in such discontinuous changes. An entrepreneur is one who explores the new market or technological opportunity and creates "*neue kombinationen* [new combinations]", either 1) to fulfill the unsatisfied needs or 2) to present a more efficient means of production. In this sense, there are two major differences between the classical economic theory and Schumpeterian innovation theory: 1) In Schumpeterian innovation theory, the reason of economic development is not the "sovereign consumer" (classical and neoclassical school) but the "entrepreneur" (Schumpeterian school); 2) In Schumpeterian innovation theory, the source of such new combinations does not need to be something exactly "new" (for instance, an invention). An entrepreneur is not an inventor: Invention is not a necessarily factor to induce innovation (Schumpeter, 1939, p. 80). An entrepreneur indicates the existence of a new combination in the current economy and tries to implement such a new combination. An entrepreneur is rewarded with extraordinary profit from the innovation. However, an innovation "calls forth imitation that eventually erodes the extraordinary profit" (Kamien & Schwartz, 1982, p. 8). As Schumpeter puts, an entrepreneur "is an entrepreneur only when he actually 'carries out new combinations,' and loses that character as soon as he has built up his business, when he settles down to running it as other people run their businesses" (1912/1934, p. 78).

In his third book (1942), Schumpeter has also paid attention to the roles that very large firms played in economic development. In Chapter 3 (Schumpeter, Ibid.), Schumpeter distinguishes the entrepreneur (or small and micro firms)-based "creative destruction" with the "monopolistic practice". Through the process of "creative destruction", entrepreneurs challenge the existing firms and capitalistic system (Chapter 7, Schumpeter, Ibid.). By applying the "monopolistic practice" of innovation, large firms (such as multinational corporations) carry out innovation along their established technological trajectories (Pavitt, 1984) to both keep their monopoly and prevent the entrance of newcomers. The "monopolistic practice" is later been labelled as the Mark II of Schumpeterian innovation – the "creative accumulation" – to distinguish from the Mark I, "creative destruction".

It is worth mentioning that the effects of technology, market, and management improvement in economic development have long been recognized but somewhat ignored by scholars before the findings of Joseph Alois Schumpeter. For instance, Adam Smith, one of the earliest economists in the rise of capitalism, has observed the role of technology in economic progress during the industrial revolution in his famous book *The Wealth of Nations* (1776). Adam Smith indicates that the division of labor improves the methods of production as each worker grew more expert at their own work. Adam Smith has also recognized that the limiting factor of the division of labor is the market structure. Thomas Malthus and David Ricardo have also been concerned with the influence of technical advance and the global trade in the economic equilibrium system. While the early classical economists have almost identified all the factors of innovation, they are ignoring the dynamic changes. Smith, Malthus, Ricardo, and other early scholars' viewpoints were based on the "stationary state" equilibrium, in which "all the economic variables are fixed relative to each other" (Kamien & Schwartz, 1982, p. 5). To the contrary, the creative destruction and creative accumulation are highly relying on the dynamic equilibrium of economic development.

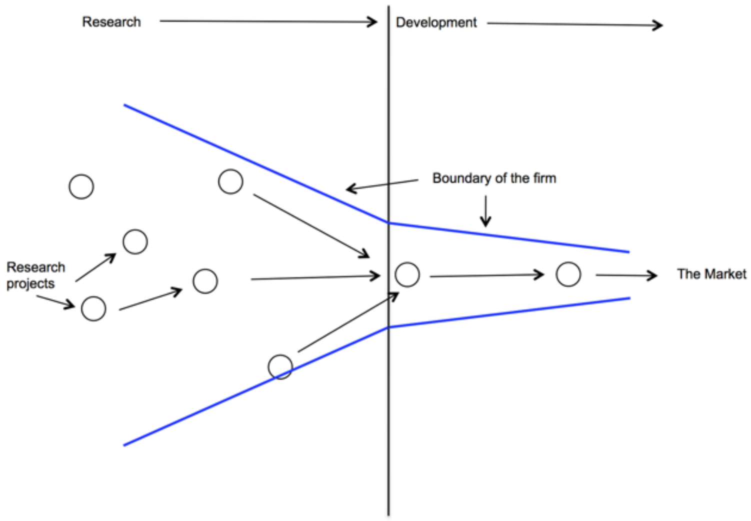
2.2 Innovating "Innovation": The Route to the Open Innovation

Joseph Alois Schumpeter has suggested that the economy is dynamically changing all the time. As its result, "innovation" itself is innovating in parallel (Curley & Salmelin, 2018). After a century when Schumpeter has come up with the idea "*neue* *kombination* [new combination]", the current conditions (discontinuous change of economic development) and processes of innovation are much different from the concept in Schumpeter's three classical books. The changes of production, market, and lifestyle in the networked society require a more inclusive and decentralized paradigm of innovation.

Before the world becomes vastly connected, research and development were hindered from being processed outside the firm. Firms tend to see the innovation process as an internal activity. According to the Schumpeterian innovation theory, an innovation process "has to engage in monopolistic practices designed to retard imitation in order to reap the profits from its investment" (Kamien & Schwartz, 1982, p. 9). Similarly, other management theories also suggest a strictly exclusive and controllable innovation process. For instance, the traditional knowledge management strategy that sharing the tacit and knowledge only in a small group (inside the firm) is an effective method to create new knowledge (Nonaka & Takeuchi, 1995). It is straightforward that creativity benefits from sharing knowledge with more people. In contrast, it is also straightforward that the more accesses to the knowledge, the more risks it will be leaked. Therefore, firms have to build their walled garden of differentiation by neatly exclude rivals' participation using patents, copyrights, or confidentiality agreements. From the conventional view of knowledge management and innovation management, promoting innovation openly is a risky and irrational business strategy. Conservative business strategy guides firms to develop defensible positions against the forces of competition and power in the value chain, implying the importance of constructing barriers to competition, rather than promoting openness (Chesbrough & Appleyard, 2007).

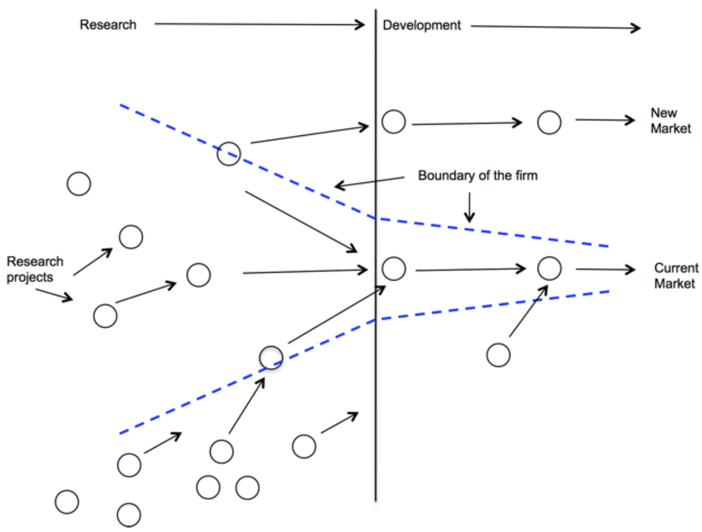
Nevertheless, management of innovation becomes more and more challenging in the era of globalization: the spotlight of innovation transitioned from process-based to value-oriented (Porter, 1985), from product-centered to service-focused (Gummesson, 1994), from supply-side driven to demand-side driven and eventually to network guided (Tapscott, 1997/2014; Shapiro & Varian, 1998). However, these “innovated” innovations can still be covered by the Schumpeterian five types of innovation and his concepts of “creative destruction” and “creative accumulation”. The motives and activities of such innovation are still limited, either inside the entrepreneurial firm or in a monopoly market position. In either way (“creative destruction” or “creative accumulation”), the market should always be sacrificed to allow innovation (and thus, the economic growth) when the entrepreneurial activity conflicts with the competition, according to the traditional Schumpeterian innovation theory. Generally speaking, Joseph Alois Schumpeter and the traditional Schumpeterian scholars of innovation never believe the concept of competitive market: “Perfect competition is impossible under modern industrial conditions” and “the large-scale establishment or unit of control must be accepted as a necessary evil inseparable from the economic progress which it is prevented from sabotaging by the force inherent in its productive apparatus” (Schumpeter, 1942, p. 106).

Figure 3. A closed innovation model



Source: Chesbrough, 2003, p. xxii.

Figure 4. An open innovation paradigm



Source: Chesbrough, 2003, p. xxv.

Whilst the networked economies growing, the paradigm of innovation is shifting: from the "closed", "exclusive", "restricted", "monopolistic" innovation (Figure 3) to an open innovation paradigm (Figure 4). According to Henry Chesbrough, the father of open innovation, "open innovation is a paradigm that assumes that firms can and should use external ideas as well as internal ideas, and internal and external paths to market, as the firms look to advance their technology" (Chesbrough, 2003, p. xxiv). Similar as the Schumpeterian innovation theory, open innovation is forcing firms to reassess their leadership position (Chesbrough & Appleyard, 2007). However, the new breed of innovation requires firms to "increasingly" collaborate (Bogers, et al., 2017) with "high variety" of "partners" and "phases of innovation" (Lazzarotti & Manzini, 2009) to acquire "external and internal resources" and "knowledge" for "new product and service development" (Tidd, 2014). The open and collaborative characteristics of open innovation make it absolutely different from the traditional Schumpeterian innovation theory.

According to Chesbrough (2003), the key difference between open and traditional innovation is the requirement of "control", such as "internal R&D", "dedicated marketing departments", and "closely guarded intellectual property". This system "worked well in the 20th century" but "eroded" since World War II. The open innovation theory will be further introduced in Section 3.1.

The early development of the ICT industry was an awakening of the open innovation. Many scholars (e.g., Shapiro & Varian, 1998; Lessig, 2008; Nishino, et al., 2008; etc.) have cited the case of VCR war (a.k.a. Video war, Videotape format war; in Japanese, *Video Sensou*) in their works as the very first case of "inclusive" innovation on the topics of network theory (e.g., network effects, network externalities). During the 1970s, there were many analog video cassette recorder (VCR) systems in the consumer market: Betamax (Sony), VHS (JVC), and many other competitors. Despite the fact that Sony's Betamax is the first VCR system appeared in the consumer market and the most superior format in terms of video technology at that time, JVC's VHS eventually becomes the winner of the VCR war (Lardner, 1987). Shapiro & Varian (1998) refers to network effects to explain the success of the VHS: JVC issued licenses to Hitachi, Mitsubishi, Sharp, and Matsushita as soon as VHS was standardized in 1976. The list of VHS partner kept increasing. On the contrary, Betamax was a trademark of Sony. Although Sony eventually started to issue licenses to a few hardware manufacturers (Toshiba, Sanyo, Aiwa, and NEC), those licensed makers had to use other names (*Beta-houshiki*) when selling their Betamax systems. The variety of names confused not only the customers but also the content providers. Consumers could easily buy VHS in the shops, but had to distinguish from a lot of "Betas". As more and more users chose the VHS system, content providers switched to produce VHS cassettes instead of Betamax in the expectation that VHS has a larger market. Whereas, the more contents available in VHS format, the more consumers would choose to buy the VHS recorders. Sony buried its first-mover advantages as well as its technical advantages with its "closed" and "exclusive" innovation management mechanism.

However, the case of VHS is not really an example of open innovation. While the innovator (JVC) relieved the restriction to include more competitors in its promotion of VHS, the innovation process of VHS as well as its external uses are still controlled by the firm. The "exclusibility" and the "controllability" are the key points that distinguish a conventional innovation from the open innovation.

On the contrary, "open-sourcing" in the software industry is widely accepted to be a typical case of open innovation. In the next section, we will introduce the open source model of open innovation found in the software industry.

2.3 The Headstream of Open Innovation: Open Source Model in Software Industry

The concept of open innovation, as well as its implementations, is highly inspired by the open source movement in the software industry. Many scholars[2] have initially observed the application of open innovation paradigm in software development processes. Therefore, it is worth introducing the history and background of the open source model in software development.

Open innovation fits the networked production well. And software development is a typical networked production – this is why open innovation becomes so common in the software industry. The software industry is a knowledge-intensive industry that involves a large amount of labor forces. This makes software development "a cooperative game of invention and communication" (Cockburn, 2006). Furthermore, modern information and communication technologies such as artificial intelligence and computer vision are much more complicated than the previous ones, and thus requires larger-scale cross-sectional collaborations (Lyu & Huang, 2019). The requirements of modern software development force the companies in the software industry to look for new models that fit for the networked production environment. The open source model, as a decentralized production model, fits the open and trustless collaboration in software development well.

As mentioned in Chapter 1, open source is an unconventional model comparing

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[2] For instance, West & Gallagher (Chap. 5 in Chesbrough, et al., 2006), Benkler (2002).

to the "ordinary" software business models: anyone, who contributes to the development of open source software, deliberately refrains from using patent and other exclusive institutions[3] to protect the source codes' property rights. The Open Source Initiative, a non-profit organization that promotes the "open source definition" (OSD) for the good of the community, defines open source software as software that: 1) allows free redistribution; 2) openly distributes its source code; 3) allows derived works; 4) respects the author[4]'s rights of claiming an open source license; 5) does not discriminate against other persons or groups; 6) does not discriminate against fields of endeavor; 7) attaches the rights to all parts of the software; 8) has no commercial restrictions; 9) has no proprietary additions; 10) is technologically neutral (Open Source Initiative, 2007). Since the Open Source Initiative is the organization that certifies open source software certifications, its "open source definition" is considered as the official definition of open source.

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[3] Note that open-source software and other open-sourced stuff (APIs, documents, etc.) do use an open-source licensing system to protect the use, modification, and distribution rights. While such licenses are neither proprietary nor public-domain-equivalent, they have their enforceability approved by the U.S. court (Robert Jacobsen v. Matthew Katzer and Kamind Associates, Inc., 2008).

[4] Including the author(s) and the author(s) of the dependencies.

Table 1. The history of open source software

Year	Event
1977	The first open sourced software package, BSD (Berkeley Software Distribution), was released by its developer, Computer System Research Group of the University of California, Berkeley.
1984	Richard Stallman set up the GNU (later becomes the Free Software Foundation, Inc. in 1985) to support the free software movement.
1989	The Free Software Foundation, Inc. released the first copyleft license "General Public License" (GPL).
1991	The first version of Linux was released by Linus Torvalds.
1992	UNIX System Laboratories filed a series of lawsuits against BSD and the University of California, Berkeley.
1994	UNIX System Laboratories reached a settlement with BSD after being acquired by Novell. While the settlement approves and permits the open source model of BSD, the University of California, Berkeley stopped the development of BSD after releasing the final version 4.4BSD-Lite.
1997	Tim O'Reilly (the founder of publisher O'Reilly Media) used the term "open source" for the first time in his paper. Bruce Perens composed the original draft of open source definition.
1998	Netscape Communications Corporation opened the source codes of its browser software "Netscape Navigator" under the name of "open source software" for the first time. The Open Source Initiative was founded to support the open source movement and the collaborative development.

Source: Tsunekawa, 2008, p. 14. Translated and revised by the author.

While being used earlier than open innovation, the term "open source" is also a relatively new one. As shown in Table 1, the first open sourced software was released in

1977. However, the term "free software"[5] did not exist until 1984. The first open source license GPL did not available until 1989. And the definition of "open source" was composed in 1997, 20 years after BSD's release. The academic concerns over open source software in economics come even later in the new century (Benkler, 2002; Von Hippel & Von Krogh, 2003; Bauwens, 2006; etc.).

The massive success of Linux in the late 1990s had drawn a lot of attentions from the industry as well as the academic scholars. In 1998, the ICT giant IBM decided to replace its own web server software with the open source alternative Apache in its commercial server products (Moody, 2001). As IBM was one of the biggest commercial server providers at that time, the market share of open source software in the web server category soon reached 60%. Around the same time, Eric Raymond presented the first open source software development model (the Bazaar model) in 1999. The Bazaar model is highly inspired by the Linux kernel development. Raymond attributed the success of Linux to the openness of the source codes, thus the open source model of development. Linus Torvalds, the original developer of Linux, also claimed that the success of Linux is from "open" rather than "free": the source codes of Linux are "openly available" instead of free for "no money" (Torvalds, 2021). By opening the source codes, Linux attracts the attention of users with different motivations: using it for free, learning from it for free, modifying and customizing it freely, and so on (Lakhani & Von Hippel, 2003). The users test the software and find bugs, then report it to the developer, or even fix and improve it

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[5] Free software, Libre software, and Open-source software (often be summarized as FLOSS) are three different movements in the software industry that promoting similar development and business models. While the characteristics of these movements are not exactly the same, we do not distinguish them in this research.

themselves. The network effect from a large userbase is very critical in software development. In Raymond's words, "given enough eyeballs, all bugs are shallow" (Raymond, 1999, p. 29).

Researchers on the innovation theory did not ignore the open source movement. Eric von Hippel, who was focusing on user-innovation models, present the first academic paper on the innovation model of open source software in 2003 with Georg von Krogh. In their paper, they recognized the "Private-Collective" model in the open source software development, which deviates and denies both the private investment model of innovation (Demsetz, 1967) and the collective action model of public goods (Olson, 1965). Their work indicates that the open source model is the first step towards a collective innovation model (Von Hippel & Von Krogh, 2003, p. 213).

2.4 Production Management: New Institutional Economics Approaches

As one of the most fundamental processes in economics, management of production has long been discussed and researched by economists. According to the classical and neoclassical school of economics, any kind of organization in production is meaningless: the market is the most ideal, most effective place for production (Coase, 1937). With its price mechanism, the market has the highest ability to distribute production factors such as resources, labor, and capital across the whole market. Therefore, cooperative production that takes place in a smaller organization (such as a firm) is not as efficient as the market. However, the neoclassical economists assume that every player in the market has the perfect rationality as well as the perfect information, and is always seeking profit maximization. The assumption itself is not established in the real world.

Herbert Simon has examined the mismatch in the neoclassical assumption. In Simon's decision-making theory, he comes out with the concept of "bounded rationality" (Simon, 1961): While each agent wants to make fully rational decisions, the profit maximization may not be accomplished because of lack of perfect information. Therefore, agents can only make the most satisfying decision within their limited abilities of collecting, processing, and exchanging information.

Based on Simon's theory, cooperative economic activities in the production becomes understandable. Cyert and March (1963) claim that any production organization will distribute incentives to its participants. If the incentive is larger than the input of a participant, the participant will continue to take part in the organization. However, the interests of participants may vary and conflict from each other. The incentive cannot always meet all participants' needs. Therefore, a more complicated form is needed to solve the conflicts.

The new institutional school has developed a series of theories to explain why a formal production organization (generally, the firm production) is superior to the price mechanism-based market production. The new institutional economists keep the same assumptions: every agent is an opportunist that always wants to maximize his utility while only has bounded rationality. Under this assumption, the superiority of organized firm production can be explained with its lower transaction costs (Williamson, 1975), being a better "nexus of contracts" (Jensen & Meckling, 1976), and more efficient distribution of property rights (Demsetz, 1967).

The new institutional economics also involves in the research of innovation. Unlike the classical economists, the new institutional school recognizes the role "entrepreneur" played in the economic development: An entrepreneur is an individual with contracts that combines all the production factors (inputs), that helps the resources allocating in a decentralized economic system. Furthermore, Demsetz (1967, p. 353) assumes that innovation should be supported by private investment to acquire private returns in his private investment model. By co-ownership of the innovation's property, both parties involved (the innovator and the investor) should be able to get more profit from the innovation. Therefore, this model supports the protection of intellectual property through patent, copyright, and other legal methods (Demsetz, 1967, p. 359).

2.4.1 The Property Rights Theory

Among the theories of the new institutional school, the property rights theory provides a possible approach to understand the open innovation management in the networked productions. Originally suggested by Ronald Coase (1960), initiated by Harold Demsetz (1967), and further developed by Oliver Hart (1995), the property rights theory focuses on the efficient allocation and transfer (distribution) of property rights to maximize the beneficial effects and minimize the harmful effects of such rights. The property rights theory defines the "internalization of externalities" as "a primary function of property rights" (Demsetz, 1967, p. 348). It is very similar to the "internal and external use of ideas" in the open innovation paradigm.

The basic concept of the property rights theory starts from the economic meaning of ownership: "Why it matters *who* owns a piece of private property" (Hart, 1995, p. 5). Coase (1960) introduces his transaction cost theory to solve the problems of public goods, the economic externalities, and the social costs. As long as the bounded rationality assumption is tenable, the property rights (as a bundle of rights) of goods or service cannot be fully identified and understood. Therefore, the use of goods or service will generate positive or negative effects on not only the holder of its property rights, but also the irrelevant parties. This is the “externality” of property rights.

Similar to other new institutional economics approaches, the property rights theory is based on the following two assumptions: 1) all agents in an economic activity are rational, that want to maximize their utilities; 2) agents in an economic activity has its bounded rationality, that their abilities to collect, process, and communicate information is limited. The market transactions between players in an economic activity are under the condition of bounded rationality. While all agents are opportunistic and rational and seeking for the utility-maximizing, they cannot always make the most efficient decisions due to the bounded rationality. Therefore, sometimes we have a diseconomy in the transaction of goods.

The property rights theory further explains the diseconomy with the concept of property rights. Practically, we do not exchange physical commodities or services themselves through a transaction in the marketplace. Instead, we trade the property rights – the identities, the functions, or the features – of the goods. “Property rights”, as defined in the property rights theory of the new institutional school, is “a bundle of rights” (Demsetz, 1967, p. 347) including: 1) The right to exclusively use (control) a specific feature of a goods; 2) The right to claim the values generated by the specific function of a goods; 3) The right to sell (transfer) such property rights.

The definition of “property rights” in the new institutional economics is much more flexible than the legal concept (Kikuzawa, 2006, pp. 178-179). Take the innovation process as an example: The intellectual property such as a patent is definitely a property right; however, the right to apply an idea, the right to use a tacit knowledge, and the right to access to a knowledge network are all "property rights" in the new institutional economics. Therefore, it is possible for scholars to link the concept of property rights with the production management.

Table 2. Allocation of property rights in different types of firms

Perspectives	***static***			***dynamic***
	Allocation of property rights			Transferability of property rights
Type of firm	Control	Residual claim	Sale	
Enterprise with single ownership	Entrepreneur	Entrepreneur	Entrepreneur	Unlimited
Corporation without workers' codetermination (e.g., stock corporation)	Management	Shareholders	Shareholders	Unlimited
Corporation with statutory codetermination (e.g., *die partnerschaft* in Germany)	Management / Employees	Shareholders	Shareholders	Limited
Non-Profit-Organization	Representative of members	-	-	Limited
State-owned firm	State	State	State	Limited
Public administration	State / Public servants	-	-	Non-transferable

Source: Picot & Wolff, 1994, p. 218. Revised by the author.

Alchian & Demsetz (1972) apply the property rights theory in their research on different types of production management, which also becomes the root of the agency theory as well. Picot & Wolff (1994) summarizes the types of firms (organizations) in Table 2 under the "bundle of rights" in the property rights theory.

Table 3. The structure of property rights assignment in an organization

	Formal organization	**Flexible organization**
The property rights assigned to	Individual	Position (job / role)
The content of assignment	Explicit in detail	Implicit and unclear
The length of assignment	Long term	Short term
The validity of assignment	Public assignment	Private assignment
Advantages	High profitability in a static business environment	High productivity in a dynamic business environment
Disadvantages	Difficult to adapt a dynamic business environment	Low efficiency in a static business environment

Source: Kikuzawa, 2006, p. 207 & 209.

The different allocation and transferability of property rights affect the efficiency of an organization. As shown in Table 3, Kikuzawa (2006) analyzes the advantages and disadvantages of different production organization under the following four perspectives: 1) The institutionalization of property rights assignment; 2) The distinctness of property rights assignment; 3) The length of property rights assignment; 4) The validity of property rights assignment. A formal and rigid organization often has its property rights assigned to certain individuals (persons) distinctively and in long terms. The assignments are public, explicit, and clear in written documents. To the contrary, the property rights in a flexible and informal organization are often assigned to short-term positions instead of a particular person. The property rights are assigned by oral statements in private communications in flexible organizations.

As the results of such property rights assignments:

1) If the property rights are clearly assigned to an individual, the member will actively make use of the property rights to maximize its utility. If the property rights are assigned to a position, it is able to transfer the property rights without the change of organizational structure. Therefore, a formal organization is effective, while a flexible organization is agile to changes.
2) If the property rights are explicit and well divided in detail, the members of such formal organizations are able to identify and acknowledge each other's rights. Thus, they can make full use of beneficial externalities while avoiding harmful externalities. On the contrary, the adjustment of assignments is very challenging. Even the slightest adjustment requires a reconstruction of the whole documents of rules and affects the entire organization. Therefore, an implicit and unclear assignment is more flexible, thus better in a dynamic business environment.
3) Similar to 2), if the assignments are in long terms, the manipulations of property rights are more efficient; if the assignments are in short terms, the organization is more elastic.
4) If the assignments (to persons) are based on the public knowledge, such as the certificates and the experiences of the individuals, the assignments are more valid and trustworthy. However, in a dynamic business environment that keeps changing every day, it is difficult to find the appropriate certificates or experiences that a job requires. For a flexible organization, it is more efficient

to keep the assignments in a private and unofficial manner.

According to Kikuzawa's analyses, a flexible organization deals better with the environmental changes, and has higher efficiency in innovation processes. This is similar to the opinions of the open innovation theory.

Hart (1995) further develops the concept of "residual control rights" in the property rights theory. The residual control rights can be defined as the rights to assign the usage of an asset that is not explicitly assigned to other parties. The firm is not only a set of property rights but also an ensemble of residual control rights according to Hart's theory. The external assignments of the residual control rights are very common in open innovation implementations, which will be introduced in the following chapters.

2.5 Innovation Management Theories

According to the Schumpeterian innovation theory, it is critical to control the innovation process under appropriate innovation management (Harrington & Voehl, 2020). In this section, we will introduce several academic approaches to innovation management that are applicable in both the "closed" traditional Schumpeterian innovation theoretical approach and the open innovation approach.

2.5.1 Typology of Innovation: The Henderson-Clark Model

Traditional different types of innovation are divided in a dichotomy manner: the incremental innovation and the radical innovation.

Also known as the niche innovation, the incremental innovation is to continuously improve and engineer an existing product, intermediate goods, process, or production.

While the incremental innovation itself is not really a Schumpeterian “innovation”, the niche improvements can be considered as the parts to form a “creative accumulation”. To the contrary, the radical innovation is a discontinuous innovation on creating a “creative destruction”.

However, both the incremental innovation and the radical innovation focus on the technology or mechanism rather than the human beings. To include the human architecture in the typology of innovation, Henderson & Clark (1990) develop a new typology model of innovation in their research on the semiconductor photolithographic alignment equipment industry.

Figure 5. Henderson-Clark model of innovation typology

		Core concepts	
		Reinforced	Overturned
Linkage between core concepts and components	Unchanged	Incremental Innovation	Modular Innovation
	Changed	Architectural Innovation	Radical Innovation

Source: Made by the author, based on Henderson & Clark, 1990, p. 12.

As shown in Figure 5, the Henderson-Clark model adds an additional metric to the typology of innovation. When there is both a conceptual evolution and an architecture reformation, it is a radical innovation. Similarly, incremental innovation is an improvement to the core concepts and the combination between the core concepts and the components rather than a "destructive" change. The two new types Henderson & Clark add are located between the incremental innovation and radical innovation: architectural innovation which focuses on the reformation of architecture without destructively changing the modular; modular innovation is the innovation that destructs an existing component but does not change the architecture.

The Henderson-Clark model has become the most commonly used model in distinguishing different types of innovation. In this research, we will also adopt the Henderson-Clark model in the discussion of the applicability of open innovation.

2.5.2 "Networked" Innovation Management: Innovation Process Management

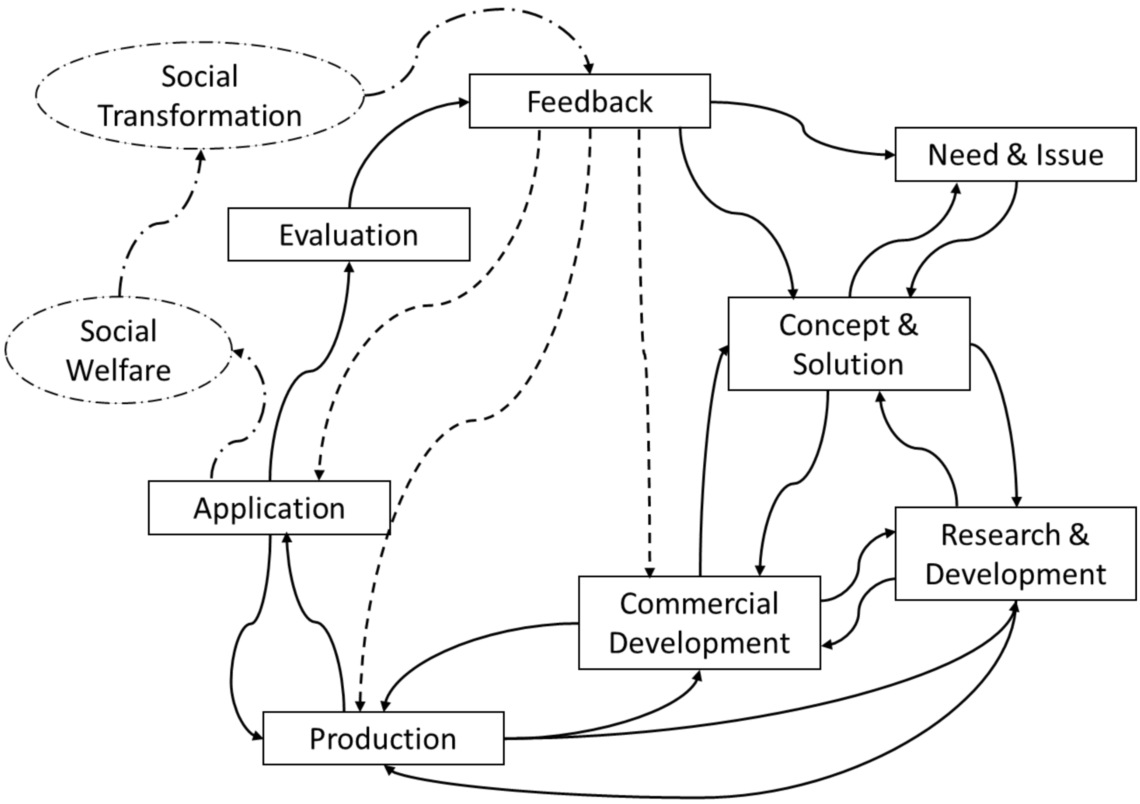
Many scholars have assumed that larger firms perform better in innovation. The reason lays in the Schumpeterian innovation theory. There are two explicit hypotheses based on the Schumpeterian innovation theory: 1) There is a positive relationship between innovation and monopoly; 2) There is a non-linear positive relationship between the size of a firm and its ability of innovation (Kamien & Schwartz, 1982). These two hypotheses suggest that larger firms in a monopolistic market position are more innovative than smaller firms in a competitive market.

However, we are heading to a much more distributed economy in the networked era. After the development of information communication technologies during the third industrial revolution, the innovation has been changed largely from the time of Joseph Alois Schumpeter. In the modern economy, there are more types than the Schumpeterian "creative destructions" and "creative accumulation" (Yashiro, 2016, p. 16). The size of the network as well as the network centrality of the nodes start to play a substitutional role in the management of innovation.

Therefore, the innovation management in the current networked economic context has to deal with the following new situations (Yashiro, 2016, pp. 16-17):

1) The further division of labor from the advanced and complex technological and systematic development.
2) The development of ICT and other technologies makes the system of human economy more and more complex and complicated. As a result, it is more and more difficult for an individual company to develop, operate, or apply a technology or a system itself. In order to procure the necessary knowledge and resources for an innovation, the innovator has to construct a network that includes experts and professional organizations from different academic and business fields. The future division of labor will be "in the global level", suggested by Yashiro (2016, p. 17).
3) The further development of distributed and collaborative innovation among the diverse organizations and peers.
4) In addition of the difficulties in the complex technologies and systems, the relation between supplier, wholesaler, and the end-users also becomes more and more complicated. In order to improve the social welfare as well as the social sustainability, a diversity of people and organization will join the innovation processes. The modern innovation management has to make full use of the external knowledge and resources from the collaborations with the other nodes in the network.

Figure 6. The innovation process model



Legend:
A square block: A *node* of an activities or actions.
A rounded block: A *node* of a result or effect.
A solid line with arrow (⟶): A knowledge, information, or resource *flow* carrying the achievements from the originated node to the pointed end.
A dotted line with arrow (- - - ▸): A knowledge, information, or resource *flow* carrying the feedback from the originated node to the pointed end.
A broken line with arrow (— · ▸): A *flow* of accumulated social welfare created by the innovation process.

Source: Made by the author, based on Yashiro, 2016, p. 20.

To systematically design a managerial mechanism for such "networked" innovation, Yashiro (2016, p. 19) has suggested a network-based innovation model: the innovation process model (Figure 6).

Yashiro has also introduced the network theory in his development of the innovation process model. In his model, there are eight types of *nodes* in the innovation network (Yashiro, 2016, p. 21):

1) Need / Issue: This type of nodes identifies and defines both the explicit and implicit issues in the innovation network, and converts them into the needs for innovation.
2) Concept / Solution: This type of nodes defines the basic concept and architecture of an "artefact" (the achievement of innovation process).
3) Scientific Research / Technological Development: This type of nodes does research or development to find a new scientific fact / technology or redefine an existing technology.
4) Development of Product / Service / Organization: This type of nodes develops a new product (hardware or software), a new service, a new business model, or a new organizational mechanism.
5) Production: This type of nodes performs the mass-production of a product or a service.
6) Application: This type of nodes provides, promotes, and sells the new product / service / business model.
7) Evaluation: This type of nodes evaluates the social welfare generated by the "artefact".
8) Feedback: This type of nodes manages and processes the knowledge from the evaluation, and finds which nodes can be improved in the process.

Yashiro's approach is a network-based innovation managerial mechanism.

Yashiro adopts the network theory to explain his model: the more knowledge flows inside a firm or between different firms, the more chances to create new connections and new combinations in the innovation process (Ibid., 2016, p. 19). However, the innovation process management model focuses more on a local or a restricted network rather than a distributed open network. Although Yashiro has put components such as the social welfare and social transformation into the model, he has neither explained the meaning of such nodes nor discussed how the innovation process can achieve such social influences in his research. Furthermore, the innovation processes in his model are more "in-house" rather than a networked innovation situation. Therefore, we define Yashiro's innovation process model as a "networked" in-house "closed" innovation managerial mechanism.

2.5.3 "Cross-network" Innovation Management: Innovation Intermediary

The innovation intermediary theory is another methodology in connecting and constructing potential "*neue kombinationen* [new combinations]" inside a network. While being a traditional innovation management method, the concept "innovation intermediary" has also been highly respected in the open innovation management theory: the innovation intermediary has the ability to connect nodes not only inside a network but also beyond the network boundary. It is worth introducing the innovation intermediary both in an innovation process management manner and an open innovation management approach.

The innovation intermediary has been actively researched by a vast number of researchers. Generally speaking, the innovation intermediary is an organization that promotes the innovation activities as well as the innovation factors by intermediate different parties of the innovation process in an innovation community (Yashiro, 2016, p. 281). The core characteristic for the innovation intermediary is to connect, rather than create, the potential "*neue kombinationen* [new combinations]". In an information network, there are always different requirements and different supplies. The innovation intermediary is to find 1) the exact needs of requirement; 2) the exact technology of the supplies; and 3) the appropriate connection or a necessary path dependency between the requirement and the supply.

While sharing a common goal of bridging the information communication and the knowledge transfer between the parties in need, the innovation intermediary has different roles in different processes, different communities, and different networks. Furthermore, innovation intermediaries also considered being the ones who connect necessary ideas, knowledge, information between parties to create complementary capabilities inside the community.

Howell (2006) claims that the concept of innovation intermediary can be dated back to the middleman during the first industrial revolution. During the past four centuries, there have been different types of innovation intermediary. According to Howell, there are ten functions of the innovation intermediaries: 1) foresight and diagnose the problem; 2) scanning and information processing; 3) knowledge processing, generating, and (re)combination; 4) gatekeeping and brokering; 5) testing, validation, and education; 6) accreditation and standardization; 7) validation and regulation; 8) protecting the results; 9) commercialization; and 10) evaluation and assessment (2006, p. 720). As shown in Table 4, the functions of innovation intermediary connect almost all innovation related resources.

Table 4. Typology of intermediation in the innovation process

Type	Function
Foresight and diagnostics	
Technology foresight and forecasting Articulation of needs and requirements	*Foresight, forecasting and technology road mapping*
Scanning and information processing	
Scanning and technology intelligence	*Information scanning and technology intelligence*
Scoping and filtering	*Selection and clearing function*
Knowledge processing, generation and combination	
Combinatorial	*Helping to combine knowledge of two or more partners*
Generation and recombination	*Generating in-house research and technical knowledge to combine with partner knowledge*
Gatekeeping and brokering	
Matchmaking and brokering	*Negotiation and deal making*
Contractual advice	*Finalizing the contract*
Testing, validation and training	
Testing, diagnostics, analysis and inspection	
Prototyping and pilot facilities	
Scale-up	
Validation	
Training	
Accreditation and standards	
Specification setter or providing standards advice	
Formal standards setting and verification	
Voluntary and de facto standards setter	
Regulation and arbitration	
Regulation	*Formal regulation*

Self-regulation	*Quasi-formal basis as an agency involved in self-regulation*
Informal regulation and arbitration	*Informal arbiter between different groups, for example, between consumers and producers*
Intellectual property: protecting the results	
Intellectual property rights advice	*Protecting the outcomes of collaboration*
Intellectual property management for clients	
Commercialization: exploiting the outcomes	
Marketing, support and planning	*Market research and business planning*
Sales network and selling	*Support in the selling and commercialization process*
Finding potential capital funding and organizing funding or offerings	*Early stage capital*
Venture capital	*'Follow on' funding*
Initial Public Offering	
Assessment and evaluation	
Technology assessment	*General assessment of performance and technologies*
Technology evaluation	

Source: Howell, 2006, p. 721-722.

The innovation intermediary theory, like the concept of itself, is a bridge "intermediating" the traditional innovation theory and the more collective and distributed open innovation theory.

2.6 Conclusion: The History of Innovation and its Management

In this chapter, we have discussed the history of innovation theories, the different approaches in management of innovation, and the sources of open innovation in the theoretical and practical development of innovation management theories.

This chapter has two parts: 1) the introduction and background of different innovation theories; and 2) the introduction and background of different innovation management theories. Section 2.1 to 2.3 are dedicated to the first part, the innovation theories. Section 2.4 and 2.5 are aiming to provide a comprehensive vision of the management theories on innovation processes.

In section 2.1, we have focused on the Schumpeterian innovation theory. We have introduced the concept of innovation coined by Joseph Alois Schumpeter, and particularly the reason why innovation is important for the modern economic development. We have also introduced some similar concepts of "innovation" before it was introduced by Schumpeter. In Section 2.2, we have introduced the limitation of traditional Schumpeterian innovation: it is a "closed" in-house process focusing on either the entrepreneurs (creative destruction) or the large corporations (creative accumulation). To solve the limitation of the Schumpeterian innovation theory, we have then introduced the initial concept of open innovation and other "novel" innovation concepts by several scholars in the research of innovation theory in Section 2.3. We have claimed that these concepts are developed to suit the modern globalized and networked economies. In this section, we have also discussed the empirical headstream and the theoretical background of open innovation: the digital production and the open source movement in the software industry.

In the coming two sections, we have discussed the innovation management theories. In Section 2.4, we have introduced the implicit theoretical roots of open innovation management: the new institutional economics, and particularly the property rights theory. In Section 2.5, we introduce some visionary innovation management theories that have also been widely accepted and applied in the research of open innovation, including the Henderson-Clark model, the innovation process model, and the innovation intermediary theory.

Chapter 2 has given a historical and theoretical background of the open innovation in the globalized networked economy.

Chapter 3

Literature Review: Open Innovation and Its Implementations

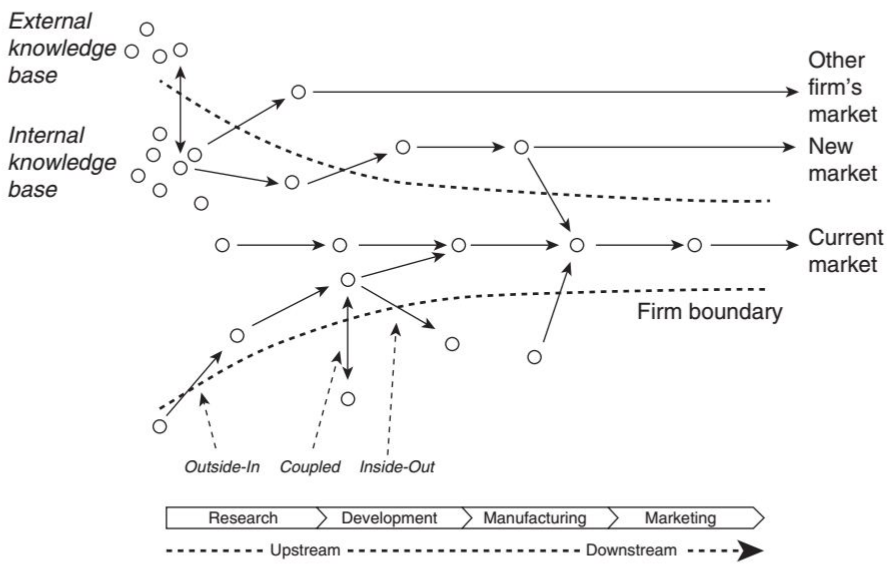
This chapter introduces the open innovation theory and reviews the previous theoretical and empirical research related to the open innovation management. In Section 3.1, we investigate and discuss the different theoretical buildings of the open innovation paradigm. We also review the theoretical literature regarding the definitions of open innovation, the conditions of open innovation, and the open innovation in the networked economy circumstances in the first section of this chapter. Section 3.2 introduces a typical open innovation implementation: the common-based peer production model. The related literatures on the theoretical explanation and empirical application of the peer production model are also reviewed in Section 3.2. We then review the previous empirical studies of open innovation in different industrial sectors in Section 3.3. After finishing the literature review of the open innovation paradigm, we take a look at other modern economic phenomena in Section 3.4. We will distinguish open innovation from other concepts, including the user innovation, knowledge management, and platform economy. Finally, this chapter concludes the current status and the remaining problems of the open innovation management, particularly the problems in the networked economy context, in Section 3.5.

3.1 The Open Innovation Theory

As introduced in Section 2.2, open innovation is a new paradigm for the management of innovation: innovation without the requirement of "control".

Open innovation is initially defined as "a paradigm that … firms can and should use external ideas as well as internal ideas, and internal and external paths to market … to advance their technology" (Chesbrough, 2003). Chesbrough made a more generic definition, that "open innovation is the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation" (Chesbrough, 2006a, p. 17). According to the definitions, open innovation focuses on loosening the control of properties to make better use of both internal and external innovative efforts, particularly to employ new markets. The key points of open innovation are: 1) purposive utilization (input) of the external knowledge; 2) purposive utilization (output) of the internal knowledge (Yonekura & Shimizu, 2015, p. 4).

Figure 7. The open innovation model



Source: Chesbrough, et al., 2014, p. 18.

As stated in Section 3.4, open innovation aims to yield same results as the traditional Schumpeterian innovation in the sense of "*neue kombination* [new combination]" (in Figure 7, where an idea reaches another idea or a market). However, the inclusion of external interactions and utilizations is a different manner from the conventional innovation management. As Chesbrough & Bogers put, open innovation is "a *distributed* innovation process" "across organizational *boundaries*" (Chap. 1 in Chesbrough, Vanhaverbeke, & West, 2014, p. 17).

3.1.1 Different Typologies of Open Innovation

Chesbrough's original definitions of open innovation (2003, 2006a) is rather academic and conceptual. Later scholars concerning the business models for open innovation have come up with a varies of applicable definitions for open innovation implementations (Table 5).

Table 5. Comparison of different definitions of open innovation

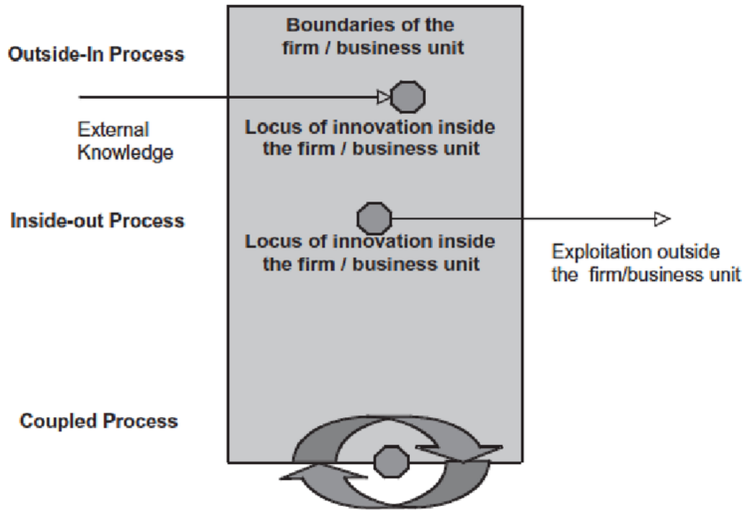
Author	**Definition**
Enkel, et al., 2009	Open innovation can be implied with the three core processes: the *outside-in process*, the *inside-out process*, and the *coupled process*.
Lazzarotti & Manzini, 2009	A collaboration with high variety of partners and high count of partners.
Dahlander & Gann, 2010	*Non-pecuniary outbound innovation:* how internal resources are revealed to the external environment. *Pecuniary outbound innovation:* firms commercialize their inventions and technologies through selling or licensing out resources developed in other organizations. *Non-pecuniary inbound innovation:* firms use external sources of innovation. *Pecuniary inbound innovation:* firms license-in and acquire expertise from outside.

Wallin & Krogh, 2010	Process that covers the creation and use of knowledge for the development and introduction of something new and useful.
Tidd, 2014	Firms should acquire valuable resources from external firms and share internal resources for new product/service development.
Banu et.al., 2016	Government, research organizations, clients and consumers, suppliers, business actors, aiming at linking human, financial, material resources, information, and knowledge for the purpose of obtaining shared-value innovation.
Curley & Salmelin, 2017	Open Innovation 2.0 is a new paradigm based on principles of integrated collaboration, co-created shared value, cultivated innovation ecosystems, unleashed exponential technologies, and extraordinarily rapid adoption.
Bogers, et.al., 2017	Firms make greater use of external knowledge and increasingly collaborate with a variety of external partners.

Source: Tynnhammar, 2017, p. 3; revised by the author.

Enkel et al. (2009) co-work with Chesbrough and identify three unique processes of open innovation that is distributed across the boundaries: 1) The outside-in process: Apply open innovation by "enriching the company's own knowledge base through the integration of suppliers, customers, and external knowledge sourcing". This is also known as the inbound open innovation. 2) The inside-out process: Apply open innovation by "transferring ideas to the outside environment" for profit. For instance, selling one's intellectual property in the market, licensing one's patent to other firms. This is also known as the outbound open innovation. 3) The coupled process: Combing the outside-in and inside-out to co-create innovation through "give and take". A typical implementation of this type of open innovation is the peer production, which will be introduced later in this chapter. As shown in Figure 8, Enkel et al.'s typology is based on the direction of knowledge flow.

Figure 8. The outside-in, inside-out, and coupled processes of open innovation



Source: Conboy & Morgan, 2011, p. 539.

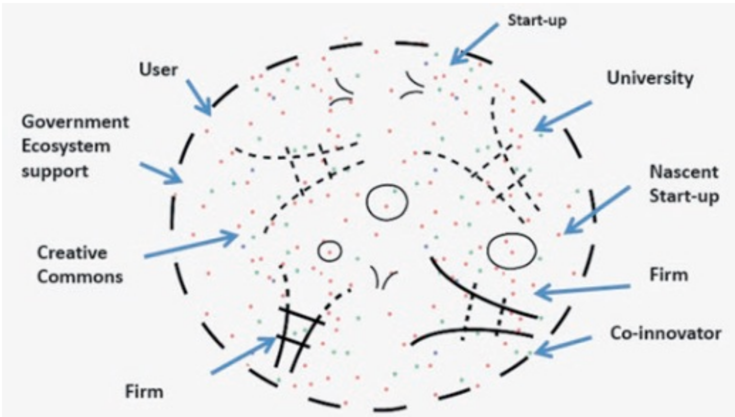
Table 6. Dahlander and Gann (2010)'s typology of open innovation

	Inbound innovation	***Outbound innovation***
Pecuniary	Acquiring *e.g.,* Licensing (acquiring)	Selling *e.g.,* Out-licensing
Non-pecuniary	Sourcing *e.g.,* Consortium, university-industry collaboration	Revealing *e.g.,* Crown-sourcing

Source: Dahlander & Gann, 2010, p. 702. Examples are from Ibid., p. 706.

In a similar manner, Dahlander & Gann (2010) develop the inbound and outbound classification of open innovation. In their research based on systematic content analysis, they conclude two inbound processes (sourcing and acquiring) and two outbound processes (revealing and selling). To better classify and apply the open innovation processes, they claim that different openness levels fit for different practices (see examples in Table 6). Their two-dimensional typology employs money flow (pecuniary and non-pecuniary) in addition to the knowledge flow (inbound and outbound), which makes it more applicable to empirical research as well as the practical commercializing efforts of open innovation.

Figure 9. Open innovation 2.0: A new milieu



Source: Curley & Salmelin, 2018, p. 4.

Curley & Salmelin (2018) from the EU Open Innovation Strategy and Policy Group (OISPG) come up with an updated version of the open innovation paradigm: open innovation 2.0 (henceforth, OI2). By introducing the concept of "network" and "ecosystem", OI2 omits the "boundary" and combines the "inbound innovation" and "outbound innovation" altogether (see Figure 9). OI2 is "all about an openness to innovation that does not resist change, but embraces it." Therefore, OI2 is available not only for businesses but also for governments and communities. Curley & Salmelin and other scholars have applied the open innovation paradigm to test some latest phenomena including agile software development and data-mining, and have proven the capability and sustainability of the network-based innovation paradigm.

3.1.2 Open Innovation in Networked Production

As stated by Dahlander & Gann (2010), Curley & Salmelin (2018) and many other scholars, the open innovation theory has a good compatibility with the network theory. Therefore, the open innovation paradigm is a promising approach to manage today's networked production, especially in the large-scale distributed networks.

The network theory in the economics perspective derives from the social network theory. The network theory is interdisciplinary research that focuses on the structural relationship between nodes in a social network. Nodes in the network theory are defined as "highly interdependent decision makers whose preferences and behaviors mutually influence one another to varying degrees through their network connections" (Knoke, 2012, p. 21). Nodes can be individuals, firms, organizations, or other social units involved in the social network.

The network theory, along with the progress of the ICT industry and the networked society, becomes more and more important. The network theory provides the essential concepts and methods for initializing and operationalizing trust, order, and the "embeddedness" in an economy (Granovetter, 1985). Network theory is also a comprehensive model to analyze the closed social organizations (e.g., closed network inside a firm, a community, or a market), the interactions between social units, as well as the large-scale global distributed network. Granovetter (2005, pp. 34-35) has identified four "core principles" of the network theory: 1) norms and network density; 2) the strength of weak ties[6]; 3) the importance of structural holes; 4) the interpenetration of economic and noneconomic action.

The network theory is important to innovation management. The social structure and networks has a powerful impact on the extent and source of innovation and its diffusion (Granovetter, 2005, p. 43). In the following paragraphs, we will introduce some common network theoretical approaches in the previous explanations and implementations of the open innovation paradigm.

Innovation intermediary is one of the network theoretical concepts adopted in the open innovation theory to explain the diffusion of innovation. According to Chesbrough (2006a), the intermediary plays a critical role in the open innovation network. From a business perspective, Morris Chang, the founder of TSMC, has also stressed the importance of intermediary in the diffusion of open business models (Yin, 2021).

To understand the innovation intermediary, we need to look into different types of nodes in the network theory. The connectivity of nodes is measured with their *degree centralities*, *closeness centralities*, and *betweenness centralities*. The higher “degree centrality” means the node has more direct ties with the other nodes. The “closeness centrality” indicates the length (pace) a node can contact another. The “betweenness centrality” measures the frequency that a node lies on the geodesic shortest path of the ties between any other nodes. Nodes with higher network centralities are able to create, control, or mediate the connections between the other pairs of nodes. Therefore, they are

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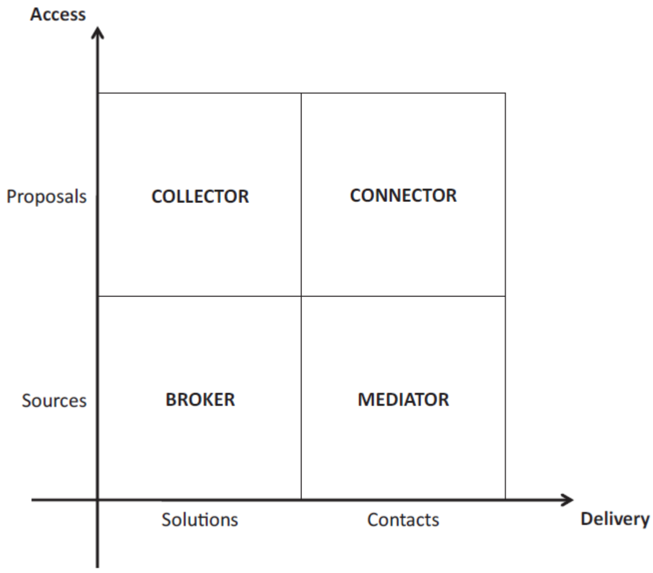
[6] A tie is an interpersonal connection between two nodes in a network. The strength of ties is “a probably linear combination of the amount of time, the emotional intensity, the intimacy (mutual confiding), and the reciprocal services which characterize the tie” (Granovetter, 1973, p. 1361).

the intermediary in the network.

Figure 10. Typology of innovation intermediaries



Source: Colombo, Dell'Era, & Frattini, 2015, p. 129.

Colombo, Dell'Era, & Frattini (2015) take the intermediary approach in their research on the innovation network. They have identified four types of innovation intermediaries in the new product development process: The collector, the broker, the mediator, and the connector (Figure 10). The four types of innovation intermediaries depend on each network position and offer their clients with 1) *know-who*, the knowledge about who knows what in the network; and 2) *know-how*, the knowledge regarding the ability to access and recombine different sources of knowledge to propose a solution to a specific problem. *Collectors* own know-who of potential solvers, and provide their clients the delivery of solution by connecting each client to an appropriate solver. *Brokers* are similar to collectors but provide solutions directly based on their know-how. *Mediators* have the know-how of identifying the source of knowledge that their clients need, and establish a connection between an external network and the appropriate client. *Connecters* own know-who of the network of solvers, and disclose themselves as partners in the collective innovation process.

Sakai (2017) adopts a similar approach in his comparative analyses of open innovation related governances and policies. He also proposes that promoting the innovation intermediary inside the industrial networks is important in open innovation-related policy-making.

On the other hand, the open innovation paradigm deals with these new norms of the networked economies. Elsner, Heinrich, & Schwardt (2015, pp. 476-479) has summarized the differences between the traditional innovation characteristics and the networked innovation characteristics as Table 7.

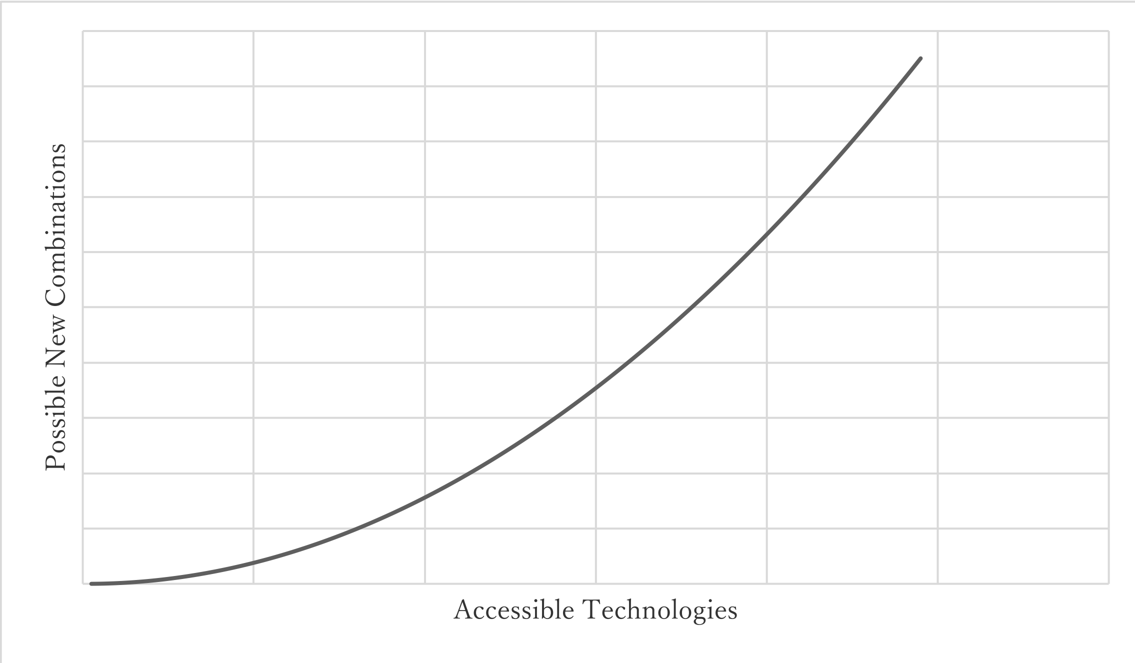
Table 7. Different understandings of critical aspects concerning innovation

Traditional innovation characteristics	Networked innovation characteristics
Linear view	Iterative loops
Frictionless knowledge transfer	Tacit knowledge
Adopting others' innovation directly	Developing absorptive capabilities
Known innovation space: Risk management	Unknown innovation space: Uncertainty
Cost-benefit analysis in investment	Open-ended process, creation of immaterial demands
Focuses on the market mechanism	Focuses on capacity building, communication, knowledge transfer, interaction, and cooperation

Source: Elsner, Heinrich, & Schwardt, 2015, p. 478; revised by the author.

Traditionally, innovation is a linear process that emphasizing the effects and incentives from the supply side to the demand side: pushing the supply side and pulling from the demand side (Elsner, Heinrich, & Schwardt, 2015, p. 477). The direction of innovation is fixed from one way to the other. However, no innovation can be made without the related "coordination" in "information and communication dimension" under the networked economy circumstances (Ibid., p. 69). In the networked economies, there is no longer the dichotomy of supply side and demand side. Instead, innovation becomes an "outcome of cooperative efforts" (Ibid., p. 478). All nodes in an innovation network can both input and output ideas, knowledge, demands, and incentives. Innovation under the networked condition has to be compatible and interoperable with each other in either way, in order to accumulate capacities and knowledge to create new "*neue kombinationen* [new combinations]" as many as possible.

Figure 11. The explosion of combinations



Source: Yonekura & Shimizu, 2015, p. 85; translated by the author.

Yonekura & Shimizu (2015) propose a network-based explanation of the combination explosion problem found in open innovation. According to their theoretical and empirical studies, a more open network will provide more chances of combination (network effect, see Figure 11). Theoretically, open innovation still outputs "*neue kombinationen* [new combinations]" as defined by Schumpeter. With the traditional innovation management theory, firms are encouraged to explore and exploit new combinations as many as possible. However, in the networked circumstance, the number of such combinations are too big to be examined. How to restrain the transaction cost for potential innovation, which is also mentioned in the next section, is one of the major challenges in the open innovation management.

3.1.3 Benefits and Challenges of Open Innovation: Management is Critical

Theoretical research has also indicated the benefits and risks of open innovation.

Tidd (2014, pp. 8-9) has summarized the principles of open innovation along with its potential benefits and challenges (Table 8).

Table 8. Principles, potential benefits, and the challenges of open innovation

Principles	Potential benefits	Challenges
Tap into external idea	Increase the knowledge base; Reduce the reliance on limited internal knowledge.	Search and identify the relevant knowledge sources; Share or transfer tacit and systemic knowledge.
Capture value from external R&D	Reduce the cost and uncertainty associated with internal R&D; Increase the depth and width of R&D.	Differentiate with distinctive capabilities in competitions.
No need to originate research in profitability	Reduce R&D cost; Access to more resources with different research strategies.	Have sufficient R&D capability to identify, evaluate, and adapt external R&D.
Build a better business model before entering the market	Capture rather than create value *(latecomer advantage).*	Lose any first-mover advantage; Take time before entering the market.
***Use* (instead of *generate*) ideas**	Reduce the unnecessary R&D *(reinventing the wheel).*	Cost a lot to evaluate and develop the unproved ideas.
Allow inbound and outbound use of intellectual property	Create value from the complementary capabilities of both parties.	Conflict with commercial interest or strategic direction.

Source: Tidd, 2014, pp. 8-9; revised by the author.

Yonekura & Shimizu (2015, pp. 24-28) also summarize the merits and demerits of open innovation (Table 9). While their findings are generally similar to Tidd's, Yonekura & Shimizu disagree with the idea that open innovation adopter needs a lot of time to evaluate and develop the external ideas, thus loses the first-mover position. Their empirical results show that the new product developments with open innovation are about 20% faster than those with conventional in-house innovation methods. Therefore, they believe that there are more chances to claim a first-mover advantage with the open innovation approaches.

Table 9. The merits and demerits of open innovation

Merit	Detail
Speeding-up and first-mover advantages	Adopting open innovation can pick up the pace of new product development, and thus claim a first-mover advantage for its adopter.
Reappraisal of the adopter's internal assets	Firms can re-evaluate their internal assets with the open innovation approach. Therefore, they can make use of the unused assets.
Optimizing adopter's own R&D strategy	Firms can acknowledge competitors' R&D strategies from the open innovation processes. Therefore, they can revise their own strategies.
Boosting the adopter's internal R&D	Adopting open innovation will put positive pressure on the internal R&D department to boost the productivity.
Demerit	**Detail**
Costs of open innovation management	Open innovation employs external R&D resources and accesses to new markets at the cost of higher internal management expenses.
Risks of technology drains	Adopting open innovation increases the risk of technology drain and human resource outflow.
Loss of core competence and internal capability of long-term R&D	Acquiring external R&D resources may decrease the motives of internal R&D. As a result, the creation and accumulation of strategic assets are more challenging for open innovation adopters.

Source: Made by the author, based on Yonekura & Shimizu, 2015, pp. 24-28.

According to Tidd and Yonekura & Shimizu's findings shown in Table 9, we can see that the benefits of open innovation are mainly from the improvement of organizational capabilities, the reduction of costs, and the optimization of business model. In contrary, most of the potential risks from open innovation adoption can be related to the knowledge management approaches, the competitive advantages, the internal and external managerial mechanism, and the cost-benefit management. Most of these potential benefits and risks rely on the management of open innovation.

In fact, most previous research on the innovation management as well as open innovation management has suggested that innovation models are very sensitive to particular context and contingencies (Tidd, 2014, p. 3). Patterns of innovation differ by the industrial sectors, the business environments, and the strategic pools. Therefore, it is vital to know the conditions and the critical factors to promote and organize a successful open innovation, both academically and empirically.

Yonekura & Shimizu have also emphasized the importance of organization in open innovation management. Since the open innovation cannot be appointed but only be accepted, the structure of a successful open innovation organization must be able to influence the behavior pattern of its members (2015, p. 59). Therefore, they suggest setting a dedicated department in the firm to manage and promote the open innovation.

Iwao (2018) also focuses on the organizational design of the innovation process. After comparatively analyzing the Japanese automobile industry, Iwao finds that the innovation process has to follow a bottom-up manner in an innovation network, which is similar to Yonekura & Shimizu (2015)'s findings.

3.2 Previous Theoretical Implications: Commons-based Peer Production

Commons-based peer production (henceforth, peer production[7]) is a model of socioeconomic production introduced by Yochai Benkler (2002, 2006) and further developed by other scholars (Bauwens, 2006; Siefkes, 2007; etc.).

The term of peer production is first used by Benkler (2002) as a non-professional, not property- or market-based production. In his later book (2006), Benkler compares the peer production with the concept of firm in the new institutional economics, and describe the commons-based peer production as "a new model of socio-economic production in which groups of loosely connected individuals cooperate with each other to produce meaningful products without a traditional hierarchical organization" (Rozas, 2017, p. 53). Bauwens gives another description claim peer production to "produce use-value through the free cooperation of producers who have access to distributed capital" (2006). Siefkes (2007, pp. 13-16) describe peer production differently in a Marxist manner, that a peer production must have "commons, sharing, control over the means of production", be a "free cooperation", and not rely on the "social status".

According to the above explanations, generally speaking, peer production is a collective action that individuals cooperate freely to contribute independently as peers within a distributed, self-organized community in order to reach a common goal.

Peer production fits for open innovation implementation because it "favors openness and sharing", which makes innovation to "spread much faster" (Siefkes, From

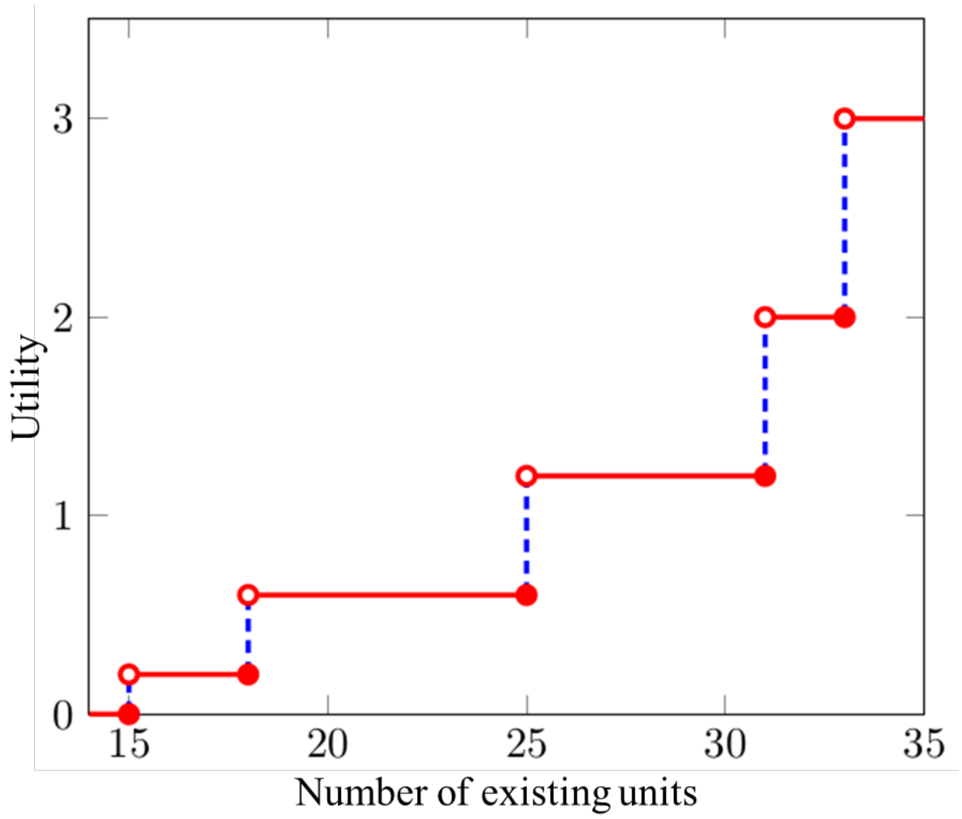
[7] Although Benkler has once defined "peer production" as "a subset of commons-based peer production practices" that is strictly "self-selected and decentralized" without any hierarchies (2006, p. 33), he does not distinguish the two terms strictly in his works.

exchange to contributions generalizing peer production into the physical world, 2007, p. 83). In fact, Chesbrough, the father of open innovation, has confirmed that the peer production model is a possible networked production model for open innovation implementation (Enkel, Gassmann, & Chesbrough, 2009).

To explain why peer production favors openness and sharing, Benkler (2006, pp. 113-115) refers to the “lumpy goods”. In Benkler’s definition, lumpy goods are the goods that can only be produced and purchased “in certain discrete bundles that offer discontinuous amounts of functionality or capacity”. For instance, in order to buy a computer, one must buy a computer processor unit (CPU). CPUs nowadays have dual-, quad-, hexa-, or even more cores. Even one only needs a single core, he has to buy the whole CPU – half a piece of CPU has no utility at all.

According to Benkler’s definition, lumpy goods create an economic surplus that is “shareable”. Such economic surplus can be 1) a surplus of property rights; 2) a surplus of time (Ma, Zhang, Sun, & Cai, 2016, p. 4 & p. 25). Benkler has referred SETI@home (a distributed supercomputer project) as an example of the first surplus, and Wikipedia as an example of the latter. Nevertheless, each case shows that sharing the excess capacity of lumpy goods is definitely a motive to participate the peer production. Shirky has further developed the economic surpluses created by lumpy goods. In Shirky’s two books (2008, 2010), he uses the concept of “cognitive surplus” as the reason that drives people to participate in the open innovation processes voluntarily.

Figure 12. Lumpy goods

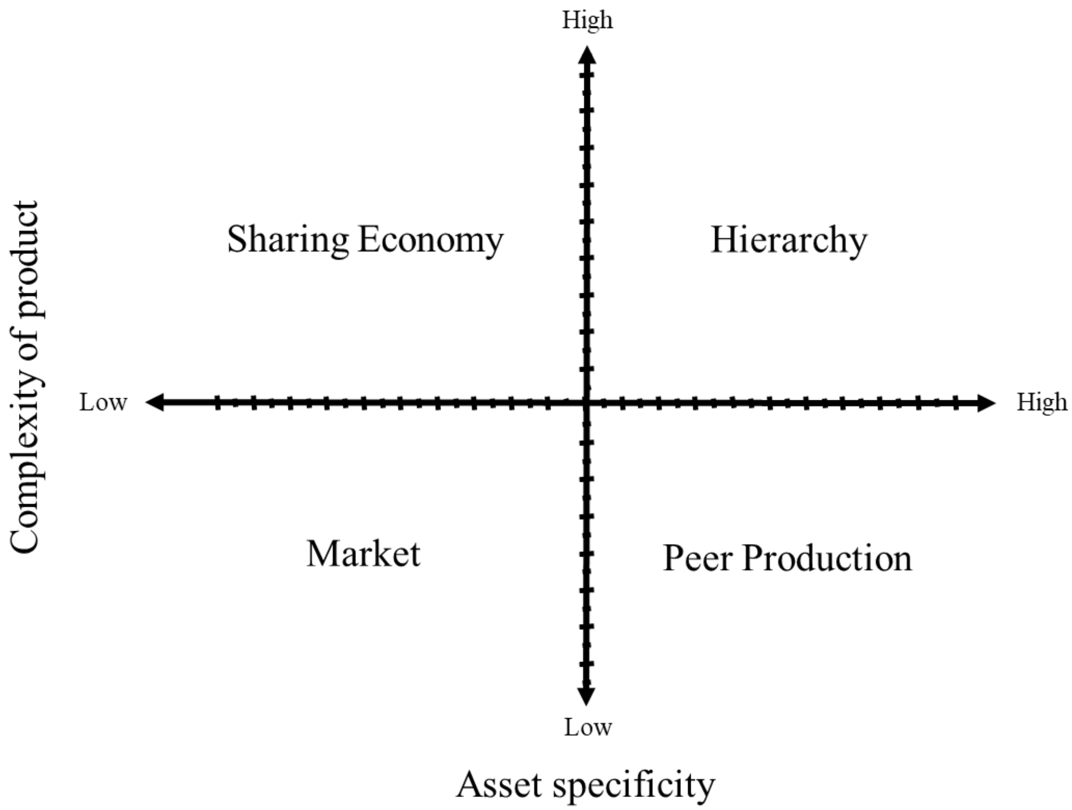


Source: Made by the author.

The concept of lumpy goods is not originally created by Benkler. In economics and game theory (public goods game), lumpiness ("grain size" in Benkler, 2006) is a parameter for the public goods. Thompson defines lumpy goods as a "collective good" that "must be provided in a fixed a fixed amount or quantity to produce positive benefits for contributor" (1987, pp. 433-434). As shown in Figure 12, lumpy goods are defined as public goods whose utility is discretely increasing when more than a certain number of units exist. He explains the lumpy goods with the externality in the new institutional economics (introduced in Section 2.4.1) and refers to Coase's paper on lighthouse (1974) as an example of lumpy goods: Imagine there are several cities on the seaside. Until a certain number of cities have invested and built a lighthouse, a sea route can be established. If more than the specific number of lighthouses are built, the sea route has a higher redundancy and can deal with accidents such as a natural disaster. If a city only builds a bad lighthouse that is not working properly, the sea route becomes dangerous and useless. As long as cities want to trade with each other (to get much larger profits that cover the costs of a lighthouse), they have no reason to refuse building and maintaining lighthouses. Therefore, lumpy goods can be used to explain the rational altruism (Thompson, 1987).

There are also other theoretical explanations on the mechanism of peer production. In his book *The Sharing Economy* (2016), Sundararajan has developed a framework to distinguish different production types based on Malone, Yates, Benjamin (1987)'s model (MYB-model). While Sundararajan does not refer to peer production directly in his schema, he points out that peer production (as a common implementation of open innovation) "is challenging the permeability of these boundaries" (p. 76) and could be placed "between a pure market and a hierarchy" production (p. 77). Comparing to traditional production types and the "sharing-economy", we can locate peer production as another hybrid production shown in Figure 13.

Figure 13. The positions of different production types[8]



Source: Made by the author, based on Sundararajan, 2016, p. 73.

In Malone, Yates, Benjamin (1987)'s model based on the new institutional economics theories[9], hierarchy-based firm production can reduce the cost by a high level

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[8] Complexity of product is defined as the amount of information needed to specify the attribute of a product to consumer (Chandra, Jr., 1993);
Asset specificity is defined as the extent to which the investments made to support a particular transaction have a higher value to that transaction than they would have if they were redeployed for any other purpose (McGuinness, 1991).

[9] Similar approaches can be found in many other new institutional economics works. For

of integration when production is highly complex (Chandra, Jr., 1993) and requires special assets (McGuinness, 1991). Since the peer production and the market production are both distributed productions, the sharing of special assets is impossible for both of them. However, peer production and market production work well when such special assets are not essential for the production. For example, in the software industry, where peer production fits well for, the assets required are only computers and the internet connections – what everybody (at least in the software industry) owns. On the other hand, software development is highly complex. A software development project usually requires a specific team of programmers working for days and nights. As a knowledge creating production, it is difficult to use crowdsourcing or subcontract in the software development. Thus, the market production does not fit the software industry. Peer production fits the technology-oriented revolutionary innovation, which has higher complexity of production and lower asset specificity.

Hoshino (Chap. 3 in Yonekura & Shimuzu, 2015) develops a similar theoretical approach to locate the implementations of open innovation. As shown in Figure 14, he believes that the open innovation performs better with the output management style, where the processes of production do not have to be managed strictly. Furthermore, he distinguishes the platform-style of open innovation implementations, which fit for the horizontal specialized production, with the project-based open innovation implementations that fit the vertical specialized production. His model is compatible with

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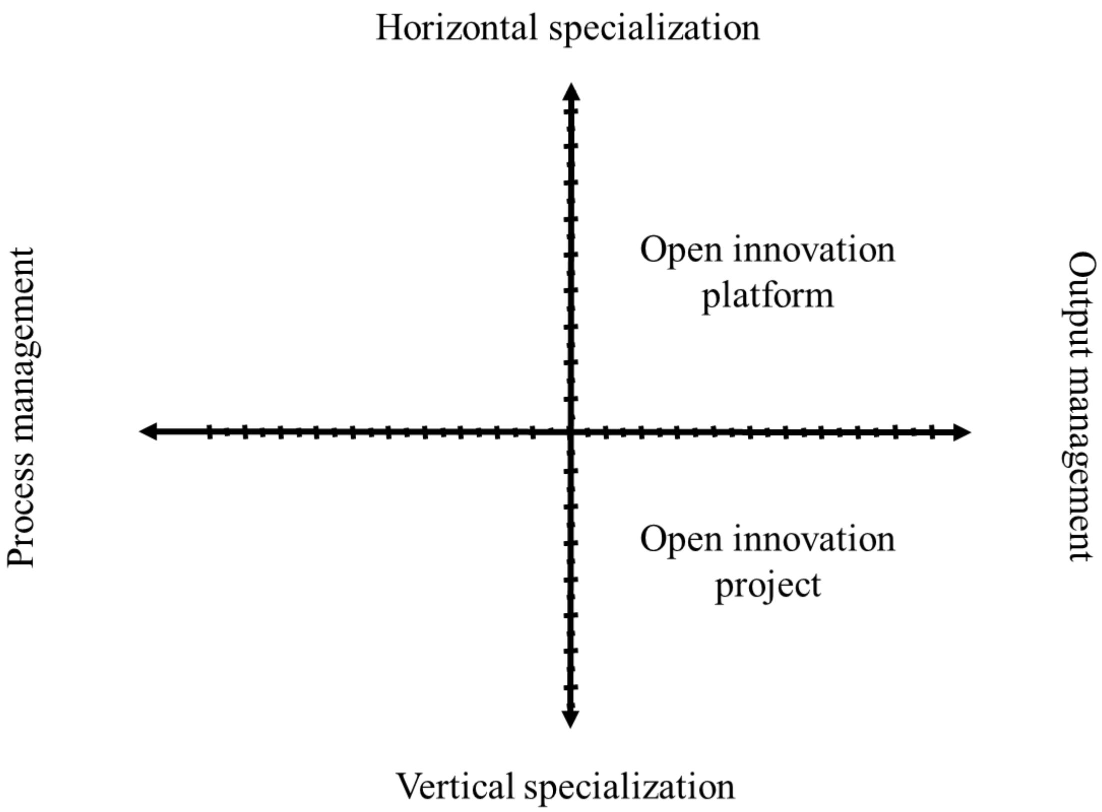
instance, Picot & Wolff designed a similar figure (1994, p. 216) that locates different forms of production organizations with the "specificity of input" and the "strategic relevance of output".

ours as the output management-oriented production should have a lower asset specificity.

Figure 14. The management of different innovation approaches

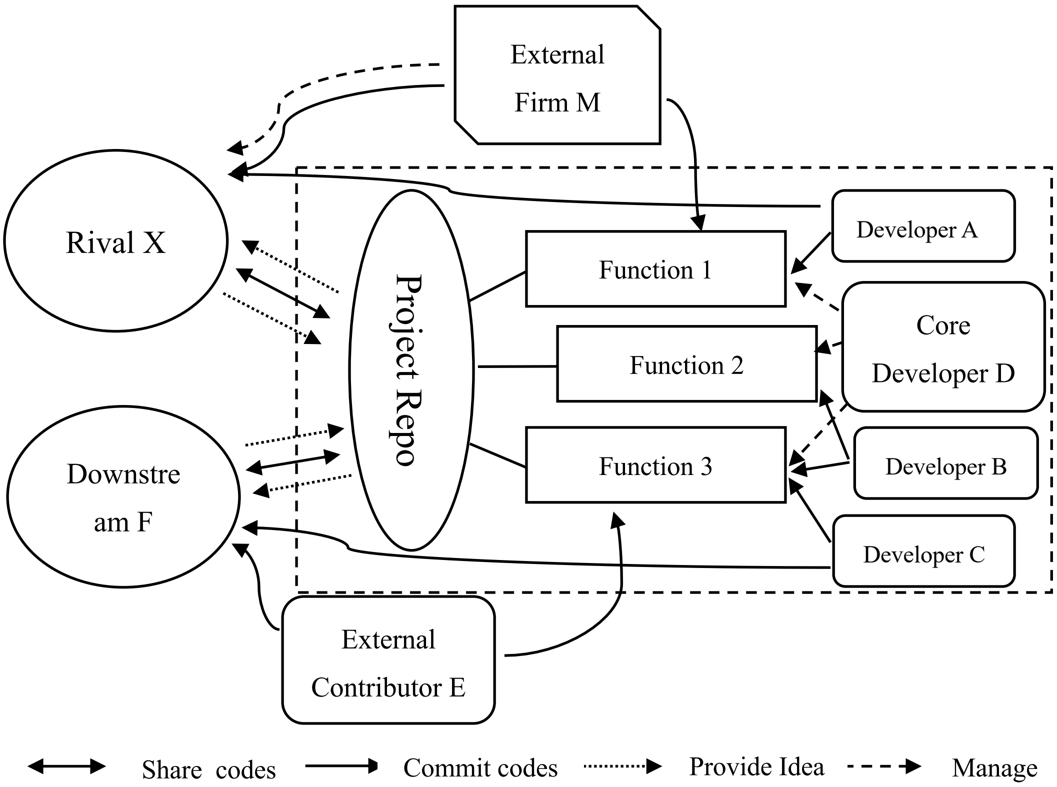


Source: Made by the author, based on Yonekura & Shimizu, 2015, p. 64.

3.2.1 Peer Production Implementation in Software Industry

As a concept summarized from the open source software development practices (Benkler, 2002), peer production has already been a widely adopted open innovation implementation in the software industry (Siefkes, 2012).

Figure 15. The networked workflow in the peer production model



Source: Made by the author.

The workflow of a typical peer production instance in the software industry is shown in Figure 15. The dotted line square in the middle of the schema is the pseudo "boundary" of the project community (or firm, in the firm-based peer production cases). The circle named "project repo" is the repository (usually a distributed version control system in the software development practices) that manages the source codes – the output of software production. The project can be divided into several functions (1, 2, 3), which are shown as the smaller squares inside the "boundary" of the project. In a peer production network, there are several types of peers involved: core developer (or product manager) (D) of the project, community (or firm) member (A, B, C) of the project, external participant (E, M), rival project (X), upstream project that provides the necessary function(s) for the project, and downstream project (F) that depends on the project's function(s).

As an implementation of the open innovation paradigm, the peer production model implemented in the software industry focuses on 1) the utilization of "purposive inflows and outflows of" codes and ideas; 2) "to accelerate internal" development (Chesbrough, 2006a, p. 17). The open source software project allows anyone (members and non-members) to retrieve (get), fork (make a personal copy), and pull request (provide new working codes (*resources*) or conceptual codes (*ideas*)) the source codes. The members of the project can commit (create a new version (*product*)) by permitting a pull request or uploading their own codes.

From the descriptions of peer production (Benkler, 2002, 2006; etc.), an instance of peer production must satisfy the following four delimitation criteria: 1) collaborative production, 2) peer-based, 3) commons-based; 4) favoring reproducibility (Rozas, 2017, p. 54).

Collaborative production

According to the definition, peer production is a cooperative model of production. Different from the hierarchy-based firm production system, peer production is a collective action that allows 1) a group of independent individuals 2) who want to achieve something that cannot be done by a subset of the group 3) to actively work together and produce the common "something" from their interactions. These are the three major differences between the peer production and the traditional firm production.

In the context of software development, the peer production model is also different from the traditional development models designed for the firm production. The traditional waterfall model of software development focuses on the knowledge transfer inside the firm to promote collaborations. However, the team members are assigned to different workflows passively in a hierarchical management manner. Developers have to wait for the next job assignments after finishing their current works, which is considered to be a time lost (Petersen, Wohlin, & Baca, 2009). Recent agile development models accelerate the development by making the development iterative and shortening the developing cycles of each iteration (Sutherland & Schwaber, 2007). This works well for small software developments. However, the agile approaches abandon the chance of open innovation, since the scale of the agile development network is quite limited.

To the contrary, peer production encourages the creation of new values from the "interactions" (Salcedo, Fuster-Morell, Berlinguer, Martinez, & Tebbens, 2014, p. 3) and "integrations" (Benkler, 2002, p. 408) of independent individuals. In this sense, it promotes open innovation.

Unlike those in the traditional social and economic organizations, the interactions and integrations in peer production are neither coordinated by contracts, nor following a hierarchical structure (Benkler, 2002, pp. 408-409). The interactions are structured in a self-managed manner with neither contractual obligations nor forces of coercion (Salcedo, Fuster-Morell, Berlinguer, Martinez, & Tebbens, 2014, p. 3). Therefore, every "peer" in the innovation network is able to participate in peer production, which makes peer production "peer-based".

Peer-based

The term “peer” in the peer production model is similar to the concept of “node” in the network theory. A peer can be an individual, a firm, a community, or even a government of a country (e.g., the federal government of the United States (The White House, Office of Management and Budget, 2016)) in a peer production network.

In the context of open source software development, there are usually three types of peers: 1) voluntary peer, 2) sponsored peer, and 3) employed peer. In addition, the peers can be divided into two groups according to their location in the innovation network: 1) internal peers, 2) external peers.

The voluntary peer is not contributing for profit or other direct and immediate utility. On the contrary, the other two types of peers contribute in order to get some returns (e.g., wage, fees, the interoperability of their own software, etc.). When contributing without the requirement of returns, a commercial firm can also be a voluntary committer in some cases.

From a network theoretical viewpoint, an internal peer is a node that 1) is located inside the controlling firm, community, or society of a peer production network; and 2) is bound to the network controller geographically or with some sorts of (social) contracts.

Hierarchies may exist inside some peers (such as firms, governments). However, there is neither hierarchy nor social status in the peer production processes. Peer production is neither hierarchy- nor market-based. Both the internal peers and external peers are aiming to achieve something “common” by contributing to a “common” place (repository) based on some “common” resources (source codes). Therefore, peer production is commons-based.

Commons-based

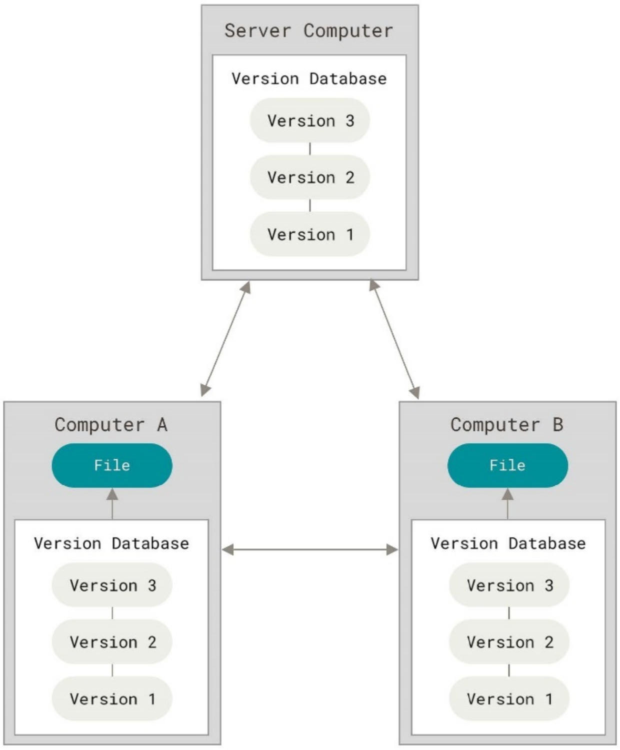
The collective production is driven by a "general interest", and will result in "the creation of a set of commons" (Rozas, 2017, pp. 54-55). The peer production model urges the production process to be always open to embrace external use and participation.

Repository, which plays a central role in the workflow of software development, is a key element of "commons" in the peer production implementation. The repository is a database to store, deploy, and manage the source codes of a software development project. In the practices of software development, the repository (instead of the office) is the actual workplace for the staff. In modern software development, there may be multiple developers working on a same function simultaneously. The repository must be able to manage collaborative workflows: recognize and dissolve conflicts, for instance. Therefore, the software industry has long been using version control systems to serve as the repository.

Categorized by the approaches to version control, there are two types of version control system: 1) centralized version control system, and 2) distributed version control system. Centralized version control systems have been invented and used earlier than the distributed version control systems. "*CVS*" and "*Subversion*" are the most famous centralized version control systems, while distributed version control systems such as "*Git*" and "*Mercurial*" are becoming more and more popular nowadays.

A centralized version control system has a centralized canonical codebase. All developers work against this repository through a checkout taken from the repository with the current status of source codes. All operations perform directly to the central repository. Therefore, only a limited number of developers (often the internal peers) are able to write (*commit*) into the repository. The unauthorized developers have to submit their changes to an authorized one through other media.

Figure 16. Schema of distributed version control system



Source: Chacon & Straub, 2014, p. 13.

Comparing to the centralized version control system, distributed version control system (Figure 16) relaxes the requirement of having a central and master repository. With a distributed version control system, a *checkout* creates a complete repository of your own, with all historical data downloaded. Developer with a distributed version control system can work freely against his own *checkout*, and *push* his changes to others' repositories through a *patch*. A software project using a distributed version control system can give all members write permission to the repository.

While both types of version control systems can serve the collaborative production, the openness of distributed version control system made it possible for peer production in a distributed network. External peers who do not have strong ties (so that they can communicate through “other media”) with the authorized internal peers can also participate in the development. The distributed version control system is the “common” workplace in a peer production implementation.

The concept “commons” here is “a particular institutional form of structuring the rights to access, use, and control resources” (Benkler, 2006, p. 23). Therefore, the final products as well as the intermediate goods of a commons-based peer production must be “reproducible”.

Reproducibility

The peer production model favors “the reproducibility of the goods created” (Rozas, 2017, p. 54). In the open source software development context, developers are always encouraged to build smaller modular programs and write readable codes that can be reused by other programmers (Raymond, 1999). In this sense, the peer production model also favors the open innovation processes. In an open innovation network with a wide variety of peer productions, both the outside-in and the inside-out processes can be achieved smoothly.

The four delimitation criteria of the peer production model make it highly compatible with the open innovation paradigm. In the following section, we will introduce several pieces of literature on how the peer production model accelerates the open innovation processes in the ICT industry through effectively utilizing the globally distributed innovation networks. Though the peer production model is summarized from the software development practices, these characteristics of the peer production model should nevertheless benefit the open innovation in other industrial sectors, particularly from those implementations in distributed networks.

3.3 Previous Empirical Studies: Applications of Open Innovation

3.3.1 Open Innovation in ICT Industry

Among the industrial sectors, implementations of open innovation are most researched in the ICT industry. Many open innovation research papers in this field are based on the peer production model. For instance, the open source model in software development is considered as a typical peer production adopting the open innovation paradigm (Levine & Prietula, 2013). In fact, as Benkler (2002) puts himself, the concept of peer production is retrieved from the practices in the ICT industry (particularly the software industry).

West & Gallagher (2006) did one of the earliest pieces of empirical research on commercial open source software development based on the open innovation paradigm. They analyze the investment (financing) sources, the development processes, and the business (commercialization) models of 10 commercial and non-profitable open source software development projects. They explore and suggest the possibility of applying the open innovation paradigm in commercial companies.

Henkel (2007) is another early research on the commercialization of open source software. He studies how companies (system integrators) embed the Linux kernel in their commercial products, and contribute to the Linux community in return. He applies the game theory on the analyses of global coordination games in open innovation, and builds models for the open innovation games. Besides, he does a large number of interview surveys to the developers and the firms. He concludes 1) the motives of voluntary participants in the open source software development; 2) the advantages and disadvantages of open innovation implementation (Table 10).

Table 10. Advantages and disadvantages of open innovation adoption in the system integrating business

Advantage	**Disadvantage**
Employment of external troubleshooting, bugfixes, codes reviews, and security checks (Low maintenance costs)	Risk of fragmentation (too many different forks of the system) Risk of leaking business strategy to rivals
Low development costs	Uncertainty of the future development (due to the changes in the upstream (Linux))
Low transaction costs (following the same standard)	Difficulty of differentiation (Lack of competitive advantage)
Reduced dependency on proprietary software (Low licensing costs)	Difficulty of intellectual property protection Risk of infringements
Easy expansion to other hardware platform (not depend on hardware suppliers' codes)	Lack of hardware suppliers' supports
Access to community support	Uncertainty of receiving suitable support
Open source software (Linux) has better performance than the proprietary software	Linux requires more storage spaces than the proprietary software
Open source software (Linux) is more stable than the proprietary software	Customers doubt the stability of Linux-embedded system
Open source software (Linux) is highly modularized and configurable (Easier to develop)	Linux lacks Real-Time capability (difficult to develop RT-platform)

Source: Henkel, 2007, p. 83 & p. 107.

Munir et al. (2018) analyze a case of open innovation application with the utilization of open source software in Sony Mobile. Their research has constructed a comprehensive understanding of the determinants, requirements, outcomes, and processes of the open source software-based open innovation approach. They suggest that adopting open innovation can benefit the software development from the following perspectives: 1) flexibility in implementing new features and fixing bugs; 2) optimizing and accelerating the incremental workflow; 3) knowledge retention for better external knowledge transfer; 4) inner source initiative for better internal knowledge transfer (pp. 208-209). They also suggest that using and developing open source software can benefit the diffusion of open innovation inside a firm. However, their analyses are limited in the software engineering level. There is a lack of result in the business perspective.

From a business perspective, West (Chap. 4 in Chesbrough, et al., 2014) investigates several successful and failed cases of open innovation platform strategies in the ICT industry. He starts from a comprehensive case study of Symbian, a failed smartphone operating system developed by Nokia. He has observed that Symbian's open innovation strategy leveraged both outside-in (funding from external companies including Nokia's rivals) and inside-out (bring its technology to external market) processes. However, Symbian doomed to failure due to a critical problem: the conflicting interests of its participants. He then compares Symbian with other successful and failed open innovation cases in the ICT industry from the perspectives of platform strategy, ecosystem structure, and the source of funding. He suggests that the "platform chaining" could be a useful strategy for the R&D-oriented startups to launch a new ecosystem. By applying the platform chaining strategy, an entrepreneur can diversify an existing successful platform from a related industrial sector, extend the platform to the new ecosystem and inherit its explicit and tacit resources from an open innovation approach.

While most previous research of open innovation and peer production adoptions in the ICT industry shows positive results, there are also some different voices.

Conboy & Morgan (2011) discuss the applicability and implications of the open innovation paradigm when it comes to agile software development. As a highly networked development mechanism, agile software development should benefit from the openness and transparency introduced from open innovation approaches (Lyu & Huang, 2019). However, they find that the current implementation of open innovation does not compatible with the agile software development methods. They suggest that we need to further research on the practical application of inter- and intra-organizational open innovation.

Remneland-Wikhamn et al. (2011) also tip that not every ICT company can benefit from open innovation. They combine the peer production model with the open innovation paradigm. They comparatively investigate the smartphone industry, and try to find the differentiation between the close-sourced Apple system (iOS) and the open sourced Google system (Android). They claim that the opened Android system performs worse than the closed iOS system, as a result of the limited capacity on generating creative contents. They suggest that generativity is more important than openness in the platforms' aggregated wealth; while the generative capacity is limited by opening the ecosystem.

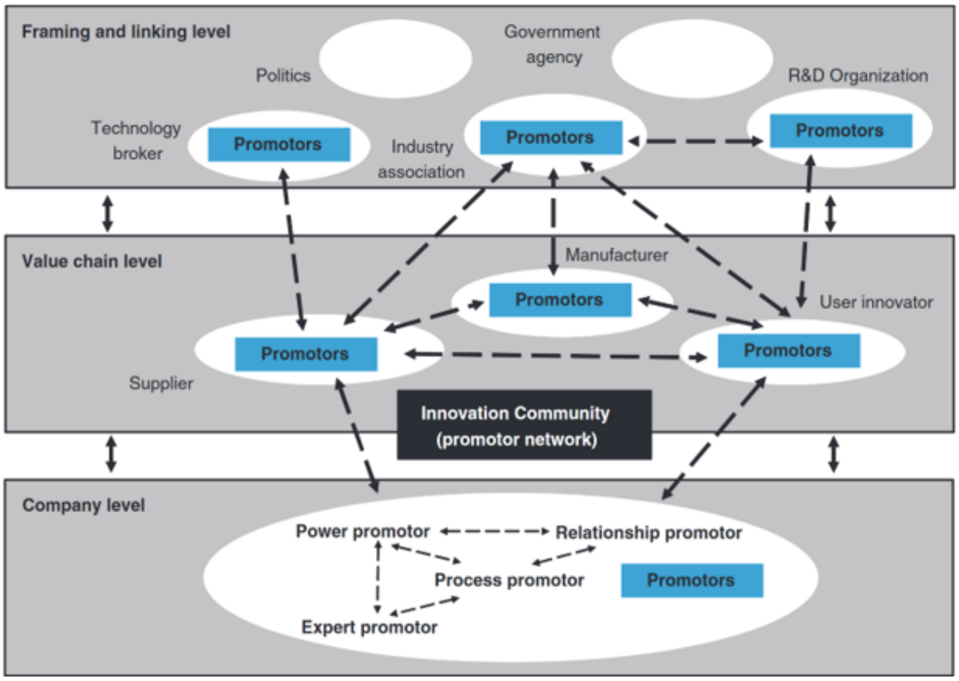
3.3.2 Open Innovation Outside ICT

There are also efforts to apply open innovation outside the ICT industry.

As for the external and collective innovation efforts before the networked economy, Keupp & Gassmann (2009) focus on how and why different firms' performances differ in their innovation activities by adopting the open innovation paradigm. Based on the third Swiss innovation survey in 1996, they recognize that the open innovation efforts at that time were the result of lacking innovative capability. They have identified four archetypes of firms (Scout, Explorer, Isolationist, Professionals) that differ from their width and depth of open innovation activities. They claim that the different behaviors of different archetypes are caused by the firm's internal weaknesses.

From a network theoretical view, Fichter (2009) develops the innovation intermediary theory with his empirical research. According to his case studies, the innovation intermediary (in his words, the promoter network, see Figure 17) plays a key role in the open innovation network.

Figure 17. The promoter network



Source: Fichter, 2009, p. 361.

Raasch, Herstatt, and Balka (2009) explorative examine the applications of peer production model outside the software. They have comparatively studied six cases using open source strategies in the traditional manufacturing industry (OScar, RepRap, and OSGC), the traditional agricultural industry (Free Beer), and the digital manufacturing industry (Open Moko and Neoros OSD). They preliminarily investigate the characteristics of open innovation in different industrial sectors.

Muller-Seitz & Reger (2010) also choose the OScar as their research object. Their case study focus on how to utilize the peer production framework as an open innovation managerial mechanism in the manufacturing industrial sector. They find that the empirical application of open innovation is still very limited. Most current models and frameworks of open innovation implementation, including the peer production, are designed for the software industry.

Ebner, Leimeister, & Krcmar (2010) adopt the concept of open innovation in their research of the education industry. They use the concept of “community engineering for innovation” in a networked and distributed virtual community for SAP training.

Although their research is based on the software industry, Renzel & Klamma (2014) design a large-scale social engineering method with the open innovation paradigm. Their open innovation-based method for the exchange of internal and external ideas can be also applied outside the software industry. Based on their social engineering method and the open innovation theory, they suggest that current open innovation implementation require an open communication and collaboration platform to support all stakeholders in reaching their particular goals.

Researchers of open innovation are also taking trust as a critical factor. Gómez, Olaso, & Zabala-Iturriagagoitia (2016) use the innovation intermediary theory as the source of trust in open innovation processes in their case study in Spain.

Similarly, but in a more sociological approach, Brockman, Khurana, & Zhong (2018) suggest that high societal trust in a country promotes the open innovation, and thus improves the overall innovative efficiency in the specific country. They examine the practical status of patent co-ownership in 29 countries, and find a correlation between the societal factors and the innovation productivities.

While still lacking in number, scholars start to adopt Enkel et al. (2009)'s and Dahlander and Gann (2010)'s models of open innovation process when dealing with tangible goods.

Michelino et al. (2014) focus on the R&D investments of the biotech and pharma industry. They compare the inbound open innovation process with the outbound in the industry, and find that: 1) inbound open innovation practices are substitutive to the internal R&D activities; 2) outbound open innovation practices are complementary to the internal R&D activities. They also find that open innovation can get diffused when more companies start to implement it.

Vanhaverbeke & Chesbrough (Chap. 3 in Chesbrough, et al., 2014) have investigated several typical cases and build open business models based on the use of outside-in and inside-out open innovation processes (Table 11). Their framework illustrates the possibility to apply open innovation in commodity businesses. Furthermore, in their case study of IBM's application of Linux, they suggest the establishment of innovation network may provide a further chance in product and service innovation other than the ICT-based intangible goods.

Table 11. Classification of open innovation and open business models.

	Closed Business Model	Open Business Model
Outside-in Open Innovation	**Use others' knowledge to develop a new offering** Early iPod – Apple Swiffer – P&G	**Use others' knowledge to develop a new business model** iTunes Store – Apple SkyNRG – KLM
Inside-out Open Innovation	**Unused knowledge used by others** Food ingredients – P&G & ConAgra Foods	**Internal knowledge accessible to others to develop a new business model** Linux (used / sponsored by) IBM
Closed Innovation	**In-house innovation** Tide – P&G Nylon – Du Pont	**Search for assets owned by others to develop a new business model** iPhone – Apple

Source: Chesbrough et al., 2014, p. 54.

Wakutsu (Chap. 9 in Yonekura & Shimizu, 2015) also focuses on the open innovation implementations in the biotech and pharma industry. He investigates the challenges of R&D processes and traditional business model (the "blockbuster" model) in the Japanese pharma industry, and summarizes the reasons for accepting open innovation as: 1) The failure of the current business model: The R&D cost to develop a "blockbuster" becomes unaffordable for a single firm; 2) The declining first-mover advantage: The increasing acceptance of generic pharmaceuticals reduce the innovator's profits; 3) The failure of closed R&D model: The R&D of biopharmaceuticals cannot be complete within the pharma industry. It requires participation from different industries. He also claims that the outbound innovation process generates the most profits from the open innovation approaches in the Japanese biotech and pharma industry.

In a microeconomics manner, Ito & Tanaka (2013) analyzes the productivity boost introduced by open innovational R&D activities. Based on a large-scale of Japanese firm data (*Kigyo Katsudo Kihon Chosa*), they find that exporting firms engaged with either inbound or outbound open innovation process are more productive than those are not exporting or not adopting open innovation approach. Furthermore, they find that a mixture of internal and open (external) innovation processes boosts even more productivity.

Takei, Saeki, & Nagae (2019) from Nikkei Business have investigated several open innovation cases in Japan. They categorized three types of open innovation implementations from the empirical cases in Japan: 1) Inbound type: Utilizing the inbound knowledge and resources to generate new combinations. They use Sapporo Beer as a typical case for the inbound type. 2) Outbound type: Disclosing the internal technology and know-hows to attract and accelerate the cooperation outside. They raised Fuji Film as an example for the outbound type. 3) Coordination type: Using activities like "ideation" and start-up business model contest to identify and verify the new ideas, and then investing the entrepreneurs through the Corporate Venture Capital to achieve innovation collaboratively. They have found Panasonic as a model for this type. After analyzing the cases, they have summarized the following key points of successful open innovation implementation: 1) strong trust and deep communication between the partners; 2) actively disclosure of information in the open innovation network; 3) flexible contracts;

4) clear goal setting.

Previous research on open innovation implementations has shown generally positive results in R&D-oriented and knowledge-intensive industries. However, there are fewer pieces of research on open innovation implementations in capital-intensive and labor-intensive industries.

Schweitzer, Gassmann, & Gaubinger (2011) focus on the role of open innovation in dynamic business environment. They analyze more than one hundred manufacturers in the Upper Austria region, measure the external sources firms exploit from the open innovation, the market and technical turbulences, and the result of innovation processes of the samples. They find that open innovation activities are more important in a dynamic environment than the traditional market. Supplier integration is vital when technological turbulence is high; whilst customer integration is critical when market turbulence is high. However, they suggest that new and different knowledge management skills are required to succeed in open innovation management, which are still not clear in their research and the previous research.

Levine & Prietula (2013) suggest that the open innovation paradigm and peer production model is not industry-aware. They design a computational model to analyze how to organize an open collaboration for different productions. Their model is also able to compare the performance of open innovation in different organizational forms. They identify three elements that affect performance: 1) the cooperativeness of participants, 2) the diversity of their needs, and 3) the degree to which the goods are rival (subtractable).

As for the comparative research on firm sizes, Van de Vrande et al. (2009) take a series of long-term surveys to 605 Dutch small and medium-sized enterprises adopting open innovation. While there is no significant difference between the manufacturing industry and the service industry, the small-size firms perform worse than the medium-size ones in open innovation activities.

Ito (Chap. 8 in Yonekura & Shimizu, 2015) also claims the difficulties for small and medium-sized enterprises to adopt an open innovation paradigm. He claims that the Japanese SMEs in the manufacturing sector are less active than the large firms in open innovation activities due to the lack of access to external knowledge. However, he also suggests some possible approaches for SMEs. He analyzes the small and medium-sized manufacturers in the *Koiki Keihin* region of Japan, and finds that the inbound open innovation process is the most promising way for SMEs to acquire external knowledge.

On a different approach, Latouche (2019) provides an alternative way for the start-ups and SMEs to adopt an open innovation paradigm. He suggests that large groups usually have long-practiced pooling of resources and expertise for collaboration and value creation. The large companies are also willing to innovate, but "producing innovation is expensive" for them. The companies often found "corporate incubator" to actively attract and invest internal and external entrepreneurs' project. An entrepreneur with an innovative idea can make use of the large groups' resource pools by accept investment from the corporate incubators. He then provided several French case studies that attempted open innovation through the corporate incubators in different industrial sectors.

3.4 Distinguish Open Innovation and Other Similar Concepts

Besides the open innovation, there are also other theories that focuses on the cooperation and interoperation issues in the modern networked economies. For instance, to involve the external participation in an innovation process, the user innovation theory

(Von Hippel, 2005) as well as the user-driven innovation theory (Wise & Høgenhaven, 2008) are available both in the academic fields and for the business practices; to deal with the knowledge creation and knowledge transfer between different economic organizations, the knowledge management theory (Nonaka & Takeuchi, 1995) is the most common toolkit; to solve the problem of trustless cooperation, the evolutionary game theory is an ideal tool (Yun, Won, & Park, 2016); when taking irrationality into consideration, behavior economics is a promising theory; when considering the cross-boundary cooperation, cross-functional team (CFT) theory is a good choice (Wang, 2017); recently, scholars are trying to adopt a technology-determinist approach that use algorithms such as the blockchain to solve the trustless collaboration problem (Pazaitis, De Filippi, & Kostakis, 2017). Furthermore, the rises of platform economy (Sundararajan, 2016) are often treated as an application of the open innovation paradigm.

The user innovation theory (Von Hippel, 2005) shares a lot of assumptions and precepts with the open innovation paradigm. However, the user innovation theory focuses more on the demand side, presenting a demand-oriented individual innovation process. To the contrary, the open innovation is a firm-centric paradigm that concerns how to improve the firm's economic outcomes through leveraging external ideas and knowledge. Thus, the user innovation is an individual, dyadic innovation process in a more dissociated manner. In contrast, the open innovation is an organizational, cooperative innovation process in an interactive network (Piller & West, Chap. 2 in Chesbrough, et al., 2014). Nevertheless, the user innovation theory is also evolving to embrace the open innovation paradigm. The latest research on user innovation has developed something more "open innovation"-alike, including a "private-collective" model (Von Hippel & Von Krogh, 2003), a user-driven firm innovation model (Wise & Høgenhaven, 2008), and many other models. These models connect the users with the firm, connect the individual innovation efforts with the collective innovation processes, and are incorporated in an integrated user-firm network.

Figure 18. SECI model: the four modes of knowledge creation

From / *To*	Tacit knowledge	Explicit knowledge
Tacit knowledge	(Socialization) **Sympathized Knowledge**	(Externalization) **Conceptual Knowledge**
Explicit knowledge	(Internalization) **Operational Knowledge**	(Combination) **Systemic Knowledge**

Source: Nonaka & Takeuchi, 1995, p. 72.

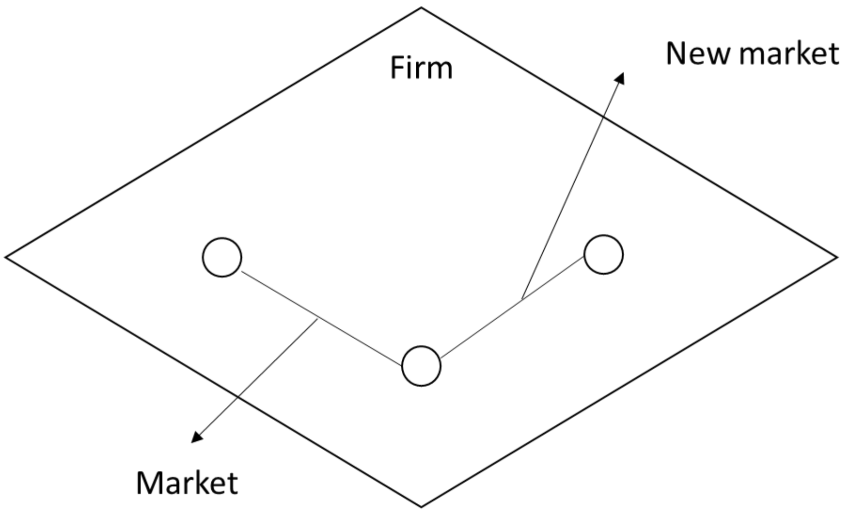
Knowledge management theory (Nonaka & Takeuchi, 1995) lies between the traditional innovation management theory and the open innovation paradigm. As mentioned in section 2.2, the original knowledge management theory focuses on the recognition, use, transfer, and creation of knowledge *inside* a firm's boundary (i.e., knowledge-creating company). However, the knowledge transfer theory and its SECI model (see Figure 18) do not limit the communication of tacit and explicit knowledge in a closed organization: the knowledge management theory only supposes that such knowledge silo is difficult to be transferred across boundaries, even inside an organization. The four modes of knowledge creation, socialization, externalization, combination, and internalization, are still working well in the open innovation contexts. Furthermore, Nonaka, the father of knowledge management theory, suggests that the knowledge created by the open innovation "are able to permeate both inside and outside" of the organizational boundaries (Nonaka, Foreword in Chesbrough, Vanhaverbeke, & West, 2014, p. vii). While Nonaka also raises a lot of remaining problems, the open innovation management theory is a networked evolution of the knowledge management theory in this sense.

The game theory is a series of mathematical models that closely related to the economics research. Game theory (in the non-cooperative game) and the mainstream economics share the rational economic man (homo economicus) presumption. Furthermore, the cooperative game, that is designed in the sight of economic behaviors by Oskar Morgenstern, becomes one of the theoretical roots of the behavior economics. Game theory studies the strategic interaction: which is also what the open innovation paradigm and the network theory focus. Many scholars have adopted game theory in the research of open innovation (Henkel, 2007; Yun, Won, & Park, 2016; etc.), the networked economy (Elsner, Heinrich, & Schwardt, 2015), and other related disciplinaries. This research also uses game theory in the modeling of open innovation.

Blockchain is a peer-to-peer network based technology for distributed and decentralized data storage. Blockchain stores information in "blocks" as "chained" lists to overcome any potential transaction vulnerabilities in the zero-trust network. While the core concept of blockchain is very forward-thinking, the blockchain is not designed for the large-scale systems. The lack of performance with its distributed hash algorithm limits the application of blockchain. However, with the further improvement on the architecture as well as the concepts, blockchain or its successor will definitely benefit the collective autonomous cooperation in the networked economies.

Although many scholars (Chesbrough, Vanhaverbeke, & West, 2014) link the open innovation paradigm with the platform economy, we carefully distinguish the two concepts in this research. In the following paragraphs, we compare and identify the differences between the in-house ("closed") innovation, the platform economy-based innovation, and the open innovation with a network theoretical approach.

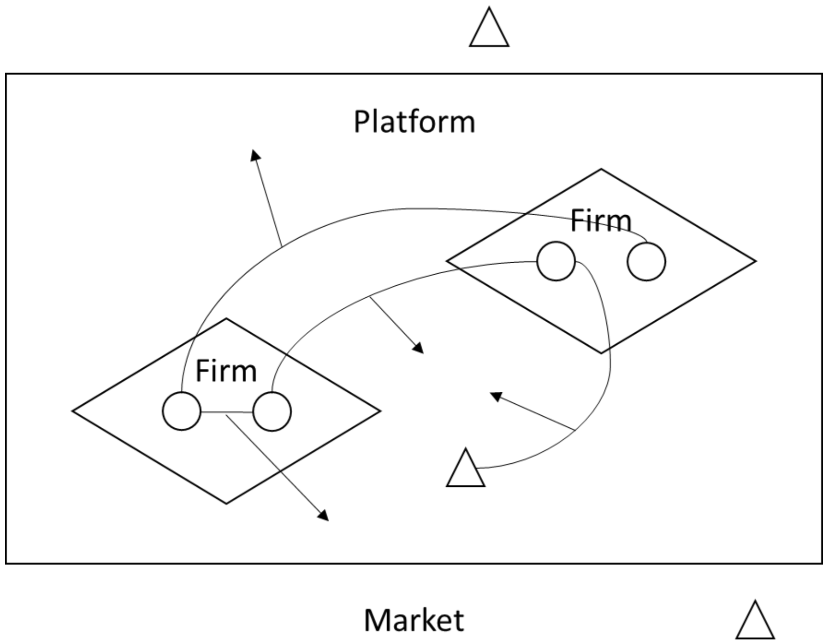
Figure 19. Schema of the in-house innovation



Source: Made by the author.

To distinguish platform economy from the other innovation processes, let us start with the traditional "closed" innovation activities inside a firm. Figure 19 shows an example of a typical in-house innovation situation. According to the conventional innovation theory, innovation happens when two parties meet and get together into a creative idea that carries out something new and disruptive. In Figure 19, we can observe three nodes (the circle dots) inside the boundary of the firm (the diamond square) form two connections (the lines without an arrow), and each combination creates an innovation (the lines with arrow) to an existing market or a new market. Since the innovation processes are completed inside the firm boundary, it is a “closed” innovation.

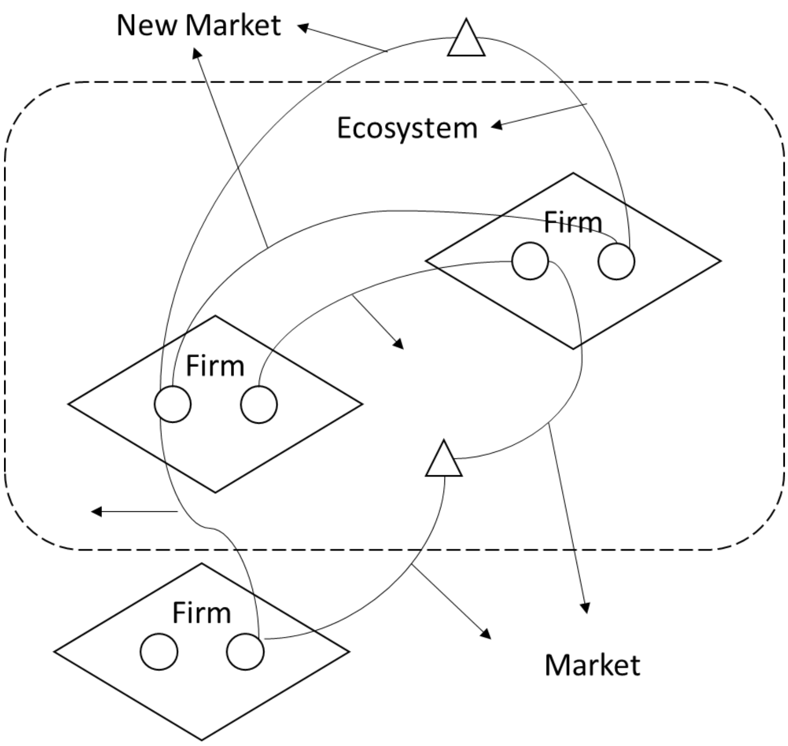
Figure 20. Schema of innovation in a platform economy



Source: Made by the author.

The platform economy relaxes the limitation of the in-house innovation process, and allows more connections (lines) outside the “house” (firm). However, while the platform economy relaxes the boundary of the in-house innovation process, the boundary of platform exists. As shown in Figure 20, the inflows (the lines with inward arrows) are restricted to be inside the platform, and the outflows (the lines with outward arrows) are also not allowed to exceed the boundary (the square around the platform) of the platform. Therefore, while platform economy allows more linkages and thus more “new combinations” in its ecosystem (platform), the implementation of platform economy is still a “closed” innovation.

Figure 21. Schema of innovation in an open innovation ecosystem



Source: Made by the author.

The open innovation, to the contrary, is a borderless open system. The most significant difference between the open innovation ecosystem and the platform economy is the *boundary*. As shown in Figure 21, the connections (the lines with arrows) can be formed between internal and external nodes (the circle and triangle dots), between inside and outside the firms (the diamond square), and between different types of nodes. Furthermore, the innovation can be created both insides and outside the (pseudo) boundary (the dotted square).

In this research, we only focus on the boundaryless open innovation implementations like the ecosystem shown in Figure 21. We do not treat the platform economy as an implementation of open innovation.

3.5 Conclusion of Literature Review

In Chapter 3, we have surveyed and reviewed the following types of existing literatures on open innovation: 1) The theoretical development of open innovation, in Section 3.1; 2) The commons-based peer production theory as a possible implementation of the open innovation paradigm, in Section 3.2; 3) The empirical studies both in and outside the knowledge-intensive ICT industry, in Section 3.3. Furthermore, we have discussed the differences between open innovation and other similar theories in Section 3.4.

According to the classifications of previous theoretical studies (Chesbrough, Vanhaverbeke, & West, 2014, pp. 25-26), the empirical research introduced in this chapter are categorized into the following five levels (Table 12): intra-organizational level, organizational level, extra-organizational level, inter-organizational level, and the innovation system and society level.

As shown in Table 12, the intra-organizational level research focuses on the open innovation functions (e.g., benefits and harms) that motivate and drive business units to take part in. The organizational level research focuses on the construction, maintenance, and management of an open innovation organization or a small-scaled open innovation network. The extra-organizational level also focuses on the individual effects and the organizational effects. However, the research objects of the extra-organizational level are the "external" individual business units and organizational instead of the "internal" open innovation adopters. The inter-organizational level studies the open innovation networks and open innovation ecosystems. The innovation system and society level focuses more on the political economics of open innovation.

Table 12. Levels of analysis of previous open innovation research

Level of analysis	*Research objects*	*Research topics*
Intra-organizational	Individual person Group / Team Project Business unit	Individual-level challenges and coping strategies for open innovation
Organizational	Firm; Non-firm organization Strategy; Business model	Organizational design, practices, and processes for integrating external sources
Extra-organizational	External stakeholders (individual, community, organization)	The role of users and communities for open innovation
Inter-organizational	Alliances Network Ecosystem	How organizations practice open innovation in ecosystems and industrial clusters
Innovation system and society	Local region; Nation Supra-national institution Citizens; Public policy	Applications of open innovation paradigm outside of R&D

Source: Made by the author, based on Bogers, et al., 2017, p. 12.

The five levels, somehow, can be further classified into two wider levels: 1) the individual level, which includes the research on business units and business organizations in the intra-organizational, the organizational, and the extra-organizational levels; 2) the collective level, which includes the research on the open innovation networks, open innovation ecosystems, and the social and political effects of open innovation such as the open governance.

Based on the five levels of analysis, we have summarized and categorized all the open innovation-related literature we have surveyed in this chapter. As shown in Table 13, most pieces of previous research focus on the individual level, especially 1) the motives for a business unit to take the open innovation approach; 2) the organizing or managerial mechanisms for open innovation implementations. There are only a few pieces of research on the network settings and the social impacts of open innovation. Furthermore, most pieces of research are conducted in the software, ICT, or other R&D-oriented industrial sectors. Little research has been done concerning the assets-heavy manufacturing industries and the labor-intensive service industries.

Table 13. Previous research categorized from the level of analysis

Research *(Research method; Industry / region of research)*	***Individual levels***			***Collective levels***	
	Intra-organizational	Organizational	Extra-organizational	Inter-organizational	System and Society
Brockman, Khurana, & Zhong, 2018 *Quantitative comparison; Global.*					◎
Conboy & Morgan, 2011 *Case study; ICT (Software).*	◎				
Ebner, Leimeister, & Krcmar, 2010 *Case study; Education.*		◎			

Fichter, 2009 *Case study; Design.*				◎
Gómez, Olaso, & Zabala-Iturriagagoitia, 2016 *Comparative case studies; Spain.*	○			◎
Henkel, 2007 *Comparative case studies; ICT (Software).*	◎	◎	○	
Ito & Tanaka, 2013 *Quantitative comparison; Japan.*	◎			
Ito, 2015 *Case study; Japan.*	◎			
Iwao, 2018 *Case study; Automobile.*		◎		○
Keupp & Gassmann, 2009 *Quantitative comparison; Switzerland.*	◎			
Latouche, 2019 *Case study; France*	◎		◎	
Levine & Prietula, 2013 *Computational modeling; Global.*		◎		◎
Michelino, et al., 2014 *Quantitative comparison; Biotech & Pharma.*	◎	○		
Munir, et al., 2018 *Case study; ICT (Software).*	◎	○		
Muller-Seitz & Reger, 2010 *Case study; Automobile.*	◎			
Renzel & Klamma, 2014 *Case study; ICT (Software).*		◎		
Remneland-Wikhamn, 2011 *Comparative case studies; ICT (Software).*	◎			
Schweitzer, Gassmann, & Gaubinger, 2011 *Quantitative comparison; Austria.*	◎	○		
Takei, Saeki, & Nagae, 2019 *Case study; Japan.*	◎		○	

Vanhaverbeke & Chesbrough, 2014 *Case study; Chemical, transportation, & ICT.*		◎		○
Van de Vrande, et al., 2009 *Quantitative comparison; Netherlands.*	◎			
Wakutsu, 2015 *Case study; Biotech & Pharma.*	◎			
West, 2014 *Case study; ICT.*		◎	◎	○
West & Gallagher, 2006 *Comparative case studies; ICT (Software).*	◎			

Legend:

◎ – The empirical research was done in this level;

○ – This level is discussed preliminarily, descriptively, or theoretically.

Source: Made by the author.

After reviewing the theoretical and empirical development of open innovation, we have found that the previous research has only done a preliminary investigation on the conditions of open innovation. While Chesbrough has developed a widely accepted concept, there is a shortage of the practical framework and production model of open innovation besides the R&D-oriented and knowledge-intensive industries. As a result, the conditions of the open innovation paradigm are still unknown for 1) a majority of industrial sectors, especially the capital-intensive and labor-intensive industries (e.g., the manufacturing industry); 2) the paths and routines for cross-boundary open innovation.

Furthermore, there is little research on the trust, motives, and other constraining and incentive factors of the collaborative actions and the coordination issues in the implementations of open innovation. Some of the previous literature has tried to apply open innovation to the new phenomena, but not enough work has been done in building a comprehensive analytic model. There is a lack of both theoretical and empirical studies. Particularly, there is no research on the correlation of open innovation adoptions and business successes.

Chapter 4

Research Design

This chapter introduces the research framework and the research methodology of this thesis. In Section 4.1, we define the concept of open innovation used in this research. From the definition, we clarify the research questions, the research perspectives, and the research objectives of this dissertation in Section 4.2. To solve these research questions, we will analyze several cases in the real business context with the game theoretical approach. Before introducing the open innovation games that we will discuss and analyze in the following chapter, Section 4.2.2 provides a basic introduction to the game theory. Section 4.3 introduces two types of open innovation games that can be useful in recognizing and analyzing the organizational-level factors in our research frameworks. Based on the game theoretical development and discussions in Section 4.3, we conclude the applicability of our analytical tools, and design the methodology of our empirical research in Section 4.4.

4.1 Definition of Open Innovation in this Research

As introduced in both Chapter 2 and Chapter 3, this research adopts Chesbrough (2006a)'s definition of open innovation: "open innovation is the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation" (Ibid., p. 17).

According to the definition, open innovation is a paradigm to 1) develop appropriate business models (organizational innovation), 2) enter new markets (market innovation), 3) create and capture new values (product innovation), 4) improve the productivity (process innovation), and 5) reduce costs (input innovation and organizational innovation) for a production organization through the purposive *new combinations* of internal and external ideas, knowledge, and resources.

The research object and the focal player of this research is the production organization. A production organization here not necessarily needs to be a commercial one (generally speaking, a firm). The modern economy involves different business organizations apart from the traditional firms (Weil, 2017, p. 3). We cannot ignore the new forms of production since we are researching the new economy. Nevertheless, every player in a business network should have its business (possibly not monetary) incentives. Furthermore, as defined in the previous paragraph, the objectives and methods of open innovation activities are not always pecuniary. Therefore, a non-profit organization can also utilize the open innovation processes to gain its own incentives. As long as a production organization is doing business in an economic network and adopting some sort of open innovation implementation, we treat it as a player in the open innovation game.

As mentioned in Chapter 3, the original definition of open innovation is somehow too theoretical and not so capable for empirical uses. For the empirical studies in this research, we follow Enkel et al. (2009)'s model of open innovation processes. We define that an open innovation implementation must operate both the *inside-out* (inbound) and *outside-in* (outbound) processes, or at least one *coupled* open innovation process. By this definition, we exclude the platform economy, where the innovation processes are always inside the boundary of the platform, from the concept of open innovation.

In conclusion, the elements (factors and innovation types) of open innovation defined in this research are summarized in Table 14.

Table 14. The open innovation perspectives in this research

	Inbound knowledge	Outbound knowledge	Inbound resource	Outbound resource
Develop new business model (organizational innovation)	(Open innovation implementation in a production organization)			
Enter new market (market innovation)				
Improve productivity (process innovation)				
Create and capture new values (product innovation)				
Reduce costs (input and organizational innovations)				

Source: Made by the author.

4.2 Research Questions

In order to solve the remaining problems, we need to develop a better model of open innovation for simulations and potential implementations. Therefore, we have set the following research questions:

1) **Individual-level:** To understand the intra-organizational and extra-organizational mechanism of peer participation in distributed open innovation networks.

Research Question 1.1: What drives peers to participate in open innovation collaborations? (i.e., What are the sources of motive?)

Research Question 1.2: How can peers trust each other in open innovation collaborations? (i.e., What are the sources of trust?)

2) **Collective-level:** To understand the organizational and inter-organizational mechanism of the distributed open innovation network.

Research Question 2.1: How factors of network settings affect the establishment of an open innovation network?

Research Question 2.2: How to solve the coordination games in different types of open innovation networks?

4.2.1 Analytical Framework for Individual-level Research Questions

The individual-level research questions (RQ 1.1 and RQ 1.2) are aiming to find the sufficient and necessary factors for internal and external peers to take part in open innovation collaborations. The existing literature surveyed in Chapter 3 has given us several possible research objects (see Table 12 in Chapter 3) and potential factors for establishing a successful open innovation collaboration.

According to the findings of the previous research, we designed an analytical framework for the empirical case studies in this research. As shown in Table 15, four types of factors are categorized in the individual-level analytical framework:

1) Sources of "Trust" for an internal peer to participate in open innovation collaborations (intra-organizational participation);
2) Source of "Motives" for an internal peer to participate in open innovation collaborations (intra-organizational participation);
3) "Coordination" factors for an external peer to participate in open innovation collaborations (extra-organizational participation);

4) Factors of "Incentives" for an external peer to participate in open innovation collaborations (extra-organizational participation). We can assign a majority of identified constraining factors, dependencies, routines, and environmental variables from the previous studies into this analytical framework.

Table 15. The individual-level analytical framework and the references

	Trust / Coordination	**Motive / Incentive**
Intra-organizational factors	Interpersonal relationship (Gui & Sugden, 2005)	Profit / cost (Chesbrough, 2003)
	Risk sharing (Keupp & Gassmann, 2009)	New market / market share (West, 2007)
	Contract / cheating cost (Bogers, et al., 2017)	Productivity (Ito & Tanaka, 2013)
Extra-organizational factors	Public ownership (Hart, 1995)	Access to external resources (Chesbrough, 2003)
	Societal trust (reputation) (Brockman, Khurana, & Zhong, 2018)	Ecosystem (West, 2014)
	Innovation intermediaries (Colombo, Dell'Era, & Frattini, 2015)	Sustainability (Chesbrough & Appleyard, 2007)

Source: Made by the author.

4.2.2 Game Theory for Collective-level Research Questions

The collective-level research questions (RQ 2.1 and RQ 2.2) are aiming to find the conditions and dependencies to establish an open innovation organization (particularly, an open innovation network). These organizational and inter-organizational research problems require different research methods. In the conclusion of the literature review (see Section 3.5), we have mentioned that there is less research done in these levels of analysis.

Nevertheless, open innovation is a paradigm focusing on the collective interactions in innovation processes. Gassmann, Enkel, & Chesbrough (2010, p. 216) have suggested the application of game theory in collective-level open innovation studies. However, there is only a pick of previous open innovation research that is based on the game theory (e.g., Henkel, 2007; Yun, et al., 2017). Furthermore, there is a bias of research objects in the current collective-level analyses. Most of the existing collective-level research concerns only the typical industrial sectors of open innovation – the ICT industry, particularly the software industry. There is no proven methodology for the open innovation research on capital-intensive and labor-intensive industries, which this research would like to explore.

To solve the collective-level problems of open innovation analyses, this research develops a game theoretical approach to analyze the open innovation implementations in the next section.

4.3 The Game Theoretical Approach for Open Innovation Analyses

The game theory focuses on optimal strategic decision-making in collective interactions. While the game theory was considered as a branch of mathematical economics, it is now widely accepted and applied in different academic fields to solve the conflict and coordination problems between a group of rational decision-makers.

To solve the collective-level research questions, we will analyze open innovation cases in different business networks with different configurations and environmental variables. This research designs two groups of game settings as the collective-level analytical frameworks for the empirical research:

1) Coordination games in normal form, which are based on the global games methodology (Carlsson & van Damme, 1993; Yoshimi, 2012)
2) The Lumpy signaling game in extensive form, with Harsanyi & Selten (1988)'s payoff dominance and risk dominance equilibrium selection methodology.

The coordination games aim to test the applicability of open innovation in different types of innovation. For each type of innovation, we have a global game group.

The lumpy goods signaling game is designed to verify the mechanism of "lumpy goods" in the peer production model, particularly in the zero-trust conditions. The game is set as a two-stage coordination game with the payoff and risk dominance equilibrium selection.

In this section, we will discuss the game theoretical approaches for analyzing the open innovation networks in the collective level of analysis. Firstly, we will explain the basic concepts of game theory in Sections 4.3.1 and 4.3.2. We will apply these concepts to design and solve the game models in Sections 4.3.3 and 4.3.4. For the boundaries and configurations of an open innovation network (RQ 2.1), we will develop a Henderson-Clark model-based analytical framework in Section 4.3.3. We will apply game theory to simulate the framework on different open innovation network settings, and then develop a set of hypotheses for both RQ 2.1 and RQ 2.2. Furthermore, we will provide a potential mechanism based on the concept of "lumpy public goods" for inter-organizational open innovation coordination games. After the introductions of the game theoretical framework and mechanism, we will discuss how these findings can be applied in an extended scale of distributed networks in Section 4.3.5.

4.3.1 Basic Concepts of the Game Theory

The concept of “game” is fundamental to the game theoretical simulations in the following sections. A “game” in the game theory contains the following three elements:

1) A set of players: $P = \{A, B, \dots, N\}$, when it is an N-player game.

A “player” is a decision-maker in the game theoretical context. Similar to the concept of “peer” in peer production model (discussed in Section 3.2), a player in game theory can be an individual, a firm, a community, or even a country. In the following sections, we assign capital letters A, B, ... to the players in a game.

2) A set of pure strategies for every player I: $S_I = \{s_1, s_2, \dots, s_m\}$, where $I \in \mathbb{N}; I < N$.

The decision-making process in a game theory is to decide the “strategy” for the particular player in a game. In the following sections, we use the strategy name (e.g., “open”) when discussing the specific strategy in a game.

3) A payoff function for player I, which is determined by the combination of strategies of all the N players: $U_I = v_I(s_A, s_B, \dots, s_N)$, where each $s_I \in S_I$.

The result of the decision for the player in a game is the “payoff”. The payoff is not limited to the monetary return. For instance, a payoff function is a utility function in a von Neumann-Morgenstern game. In a two-player game in the following sections, we use I_{xy} for the payoff of player I when the first player chooses strategy s_x and the second player chooses strategy s_y. We use I_{xyz} for the payoff in a three-player game, in the same manner.

Nash equilibrium is the most common solution to solve a non-cooperative game. A Nash equilibrium is a strategy profile, in which no player can get a higher payoff by changing his strategy unilaterally. In other words, every player has his best strategy given the other player's choice.

A strategy in a Nash equilibrium can be either a pure strategy or a mixed strategy. A pure strategy is a specific choice from the strategy set S_I. A mixed strategy is a distribution of probability on the strategy set S_I. Thus, a player pursuing a mixed strategy will randomly choose from two or more pure strategies with the specific probability. If a game has a mixed strategy Nash equilibrium, the expected payoff for each player is a weighted mean of all the probability of players with a mixed strategy.

Furthermore, we use subgame perfect Nash equilibrium to solve the extensive form of dynamic games. A subgame perfect Nash equilibrium is a strategy profile that represents a Nash equilibrium in every subgame of the dynamic game.

4.3.2 Types of Games and the Solutions

Two types of games will be set in the following models: the normal form game (also known as the simultaneous game and the strategic game) and the extensive form game (also known as the sequential game). To reflect the characteristics of open innovation, all the games are set in the following conditions: 1) perfect information: each player knows the player set as well as the strategy sets and payoff functions of all players in the game (open); 2) non-cooperative: players are not allowed to communicate with others *directly* (zero-trust cooperation, without control).

In a normal form game, every player makes decision at the same time (simultaneously). Figure 22 shows an example of two-player normal form game:

Figure 22. Two-player normal form game payoff matrix

		Player B	
		Strategy x	Strategy y
Player A	Strategy X	A_{Xx}, B_{Xx}	A_{Xy}, B_{Xy}
	Strategy Y	A_{Yx}, B_{Yx}	A_{Yy}, B_{Yy}

Source: Made by the author.

This game can be defined as $G = \{S_A, S_B; U_A, U_B\}$. Player A's strategy set $S_A = \{X, Y\}$, means A can choose from X and Y in the decision-making process. Similarly, player B's strategy set is $S_B = \{x, y\}$, and B has two strategies x and y to choose.

In the normal form game, player A and B make their decisions at the same time and get their payoffs based on the combination of A and B's strategies. For instance, if player A decides to play strategy X and player B decides to play strategy y, A will get A_{Xy} while B will get B_{Xy}.

In order to solve the Nash equilibrium of a normal form game, we need to identify the strategic dominances in the game. Here we introduce two special strategic dominances: the dominant strategy and the dominated strategy. A dominant strategy is a strategy that is better than any other strategy available to the player, no matter what the other players decide. In contrast, a dominated strategy is a strategy that is worse than any other strategy available to the player, regardless to the other players' choices. Let us take the famous prisoner's dilemma as an example (Figure 23).

Figure 23. Prisoner's dilemma

		Prisoner B	
		Confess	Not to confess
Prisoner A	Confess	$-\beta, -\beta$	$0, -\gamma$
	Not to confess	$-\gamma, 0$	$-\alpha, -\alpha$

Notes:
In the setting of prisoner's dilemma, α, β, γ are the length of time served in prison. Here, $\alpha, \beta, \gamma \in \mathbb{N}$; $0 < \alpha < \beta < \gamma$. For each prisoner, $-\gamma$ is the worst case (longest incarceration) and 0 is the best case (immediate liberation).

Source: Made by the author.

In the prisoner's dilemma, two criminals are arrested. While the prosecutors do not have the sufficient evidence to convict them on the principal charge that will get them imprisoned for 10 years, they are able to put criminals in prison for 1 year. The prosecutors offer each prisoner a chance to cooperate with them and betray the other criminal: If both of them betray and confess to the prosecutors, they will serve 5 years in prison (-5); if only one betrays and the other does not, the traitor will be set free (0) and the other will serve 10 years in prison (-10); if both of them keep silent, they will both serve 1 year in prison (-1). The criminals are not allowed to communicate with each other (non-cooperative game).

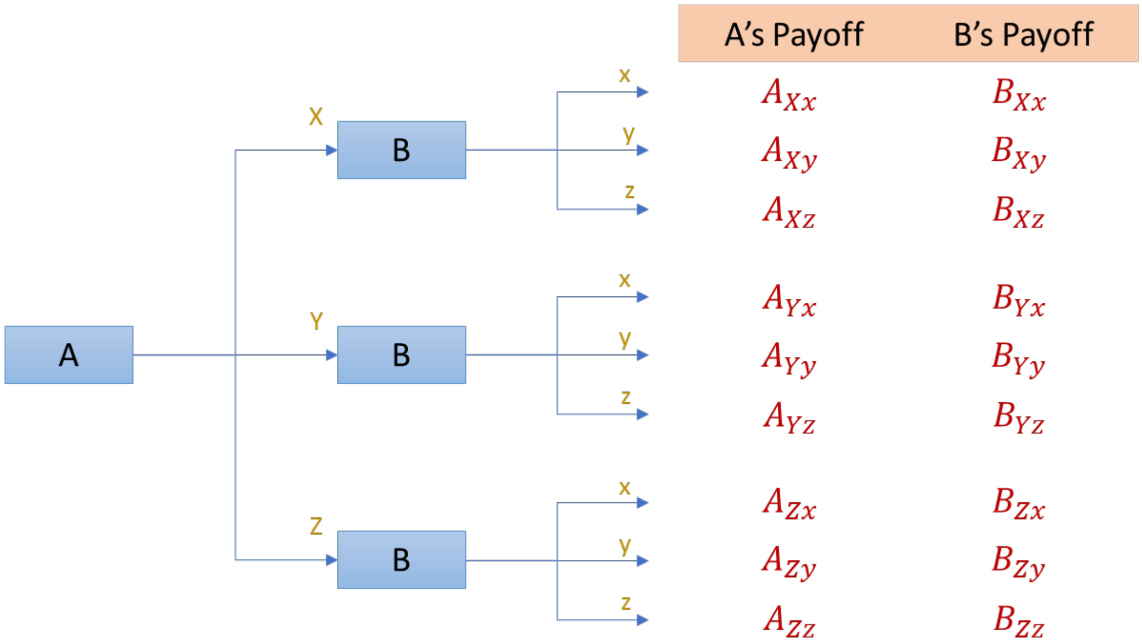
Suppose you are prisoner A: If B confesses, then your best choice is to confess, because 5 years (-5) in prison is better than 10 years (-10); if B does not confess, then your best choice is to confess, since free (0) is better than 1 year in prison (-1). In the two-strategy set, "confess" strictly dominates "not to confess" for A. Therefore, A has a dominant strategy "confess". Since it is a symmetric game (will be introduced later), "confess" is also the dominant strategy for B. There is a pure strategy Nash equilibrium (confess, confess) for this game.

More generally, if every player has a dominant strategy in a normal form game, then the combination of dominant strategy is the pure strategy Nash equilibrium of the game. If there is no dominant strategy for a player in a normal form game, we should investigate whether the other players have. We can eliminate the dominated strategies of the other players to simplify the payoff matrix. If no player has a dominant strategy, we should check whether dominated strategies exist, and then eliminate them from the payoff matrix. After all the eliminations, we can look for the cell(s) where players best responses meet, then they are the pure strategy Nash equilibrium (equilibria). Even if there is no pure strategy Nash equilibrium, there may be a mixed strategy Nash equilibrium.

When the strategy sets and the payoff functions are exactly the same in a normal form game (in our two-player game example, when $S_A = S_B = \{X, Y\} = \{x, y\}, A_{Xx} = B_{Xx}, A_{Xy} = B_{Yx}, A_{Yx} = B_{Xy}, A_{Yy} = B_{Yy}$), we call it a symmetric game. The prisoner's dilemma, for instance, is a symmetric game. Nash (1951) has proven that every finite symmetric game has a symmetric Nash equilibrium. Particularly, two-strategy finite symmetric game has a symmetric pure strategy Nash equilibrium.

To the contrary, an extensive form game is a game that one player (the first mover) takes an action before the others (in sequential order). According to the perfect information assumption, a player in the later stage knows the choices made in the previous stages. As the example shown in Figure 24, we use the decision tree to represent an extensive form game instead of the payoff matrix.

Figure 24. Two-stage extensive form game decision tree



Source: Made by the author.

This example of extensive form game can be defined as G= $\{S_A, S_B; U_A, U_B\}$. The first-mover A's strategy set $S_A = \{X, Y, Z\}$, means A can choose from X, Y, and Z in the first stage. A knows B's strategy set S_B and payoff function U_B when making his own decision (according to the perfect information assumption). Similarly, player B's strategy set is $S_B = \{x, y, z\}$. B can choose from x, y, and z in the second stage after knowing A's choice. After B makes his decision, A and B get their payoffs.

In order to solve the extensive form game, we use the backward induction method to find a subgame perfect Nash equilibrium. We will introduce this method with the two-stage extensive form game. Let $B_{Xz} > B_{Xy} > B_{Xx}, B_{Yy} > B_{Yz} > B_{Yx}, B_{Zx} > B_{Zy} > B_{Zz}$ in the game presented. First, we examine the B's best response: If A chose X, then B should choose z; If A chose Y, then B should choose y; If A chose Z, then B should choose x. Then we consider A's best move: If A choose X, his payoff will be A_{Xz} since B will choose z; If A choose Y, his payoff will be A_{Yy} since B will choose y; If A choose Z, his payoff will be A_{Zx} since B will choose x. As (X, x), (X, y), (Y, x), (Y, z), (Z, y), and (Z, z) have already been elimated from the decision tree, A should choose the strategy to get the best payoff $Max(A_{Xz}, A_{Yy}, A_{Zx})$. If $Max\left(A_{Xz}, A_{Yy}, A_{Zx}\right) = A_{Xz}$, the subgame perfect Nash equilibrium is (X, z).

4.3.3 Networked Open Innovation Games in Normal Form

In order to verify the applicability of the open innovation paradigm in different situations, we have designed four normal form open innovation games and a lumpy signaling open innovation game in a networked context. We would like to apply these games in our empirical case studies to recognize and analyze the boundaries and the sufficient environmental thresholds of the open innovation networks, as well as the path dependencies and the necessary routines of the open innovation strategies in the real business implementations.

As many previous research (Chesbrough, Vanhaverbeke, & West, 2006, p. 38) suggested, the Henderson-Clark model, which we have discussed in Section 2.5.1, is a typical framework to distinguish innovation types with different combinations of internal and external linkages, especially in the real business context of open innovation (West & Gallagher, 2006, p. 329). Although the original Henderson-Clark model is originally designed to explain the innovation in the semiconductor equipment industry, Yashiro (2016, pp. 88-95) claims that the Henderson-Clark typology is a possible model to analyze any innovation activity in an innovation network. In Yashiro's Innovation Process Management model (introduced in Section 2.5.2), the "core concepts" in the Henderson-Clark model are the technologies adopted in the innovation process (Ibid., pp. 90-91); while the "linkages between core concepts and components" are the links between the technologies and the value network, which is the market in the business context (Ibid., p. 97).

Therefore, we adopt Henderson & Clark (1990)'s typology for the types of innovation networks in our empirical research on the business implementations of open innovation. According to the Henderson-Clark model, innovation can be categorized into 1) incremental innovation, 2) modular innovation, 3) architectural innovation, and 4) radical innovation. We will develop four game theoretical models to test each type of innovation.

In the following open innovation games, we set the contexts based on a simplified definition of the Henderson-Clark model (Figure 25): If we need to redesign the core concepts (to an overturned one), we need to develop new technology (product innovation); otherwise (to reinforce the core concepts), we do not have to develop new technology. If we need to change the linkage between core concepts and components, we need to enter a new market (market innovation); otherwise (no change to the linkage), we do not have to enter a new market.

Figure 25. Henderson-Clark model in the open innovation games

		Technology: Existing	Technology: New
Market	Existing	Incremental Innovation	Modular Innovation
	New	Architectural Innovation	Radical Innovation

Source: Made by the author, based on Henderson & Clark, 1990, p. 12.

4.3.3.1 Game Settings

To minimize the influences from the irrelevant factors other than the type of innovation, we set the following idealized assumptions for the open innovation games.

We define a game $G = \{S_A, S_B; U_A, U_B\}$ with two players A and B. The strategy sets of player A and player B are $S_A = S_B = \{Open, Not\ open\}$. Since we are aiming to solve the applicability and the acceptance of a cooperative strategy "open innovation", we set it as a two-player simultaneous coordination game (often referred as the "stag hunt" game in the game theory). The payoff matrix is set as Figure 26.

Figure 26. Payoff matrix of the open innovation games (Game 1.1-1.4)

		Player B Open	Not open
Player A	Open	γ, γ	$-\alpha, \alpha$
	Not open	$\beta, -\beta$	0, 0

Source: Made by the author.

In the open innovation games, players have to choose from multiple Nash equilibria with the perfect but incomplete information. Yoshimi (2012) suggests that the global games methodology (Carlsson & Van Damme, 1993) is a possible solution to select from multiple Nash equilibria in coordination games. As we deal with a similar problem (whether a firm should adopt open innovation in a certain condition) as Yoshimi's research (whether a company should adopt telework in a certain condition), we adopt the same equilibrium selection method in our open innovation game settings.

We set the following conditions to all the following open innovation games.

- Players A and B are two firms producing homogeneous products in a duopoly market.
- Both player A and player B have to choose from the same strategy set: "Open (adopting open innovation)" or "Not open (not adopting open innovation)".
- Players A and B have perfect incomplete information:

The value of γ is the public information that both players know:

$$\gamma \in \mathbb{Z}$$

To the contrary, the payoff α is the private information of player A;

symmetrically, the payoffs β is the private information of player B. However, both players know the range of β and α:

$$\alpha, \beta \in [\lambda, \mu] \quad (\lambda < \mu;\ \ \lambda, \mu \in \mathbb{Z})$$

The probability of $[\lambda, \mu]$ is rectangularly distributed (Yoshimi, 2012, p. 57)[10].

From the above settings, the information that both players have is 1) the player set $P = \{A, B\}$; 2) both players' strategy set $S_A = S_B = \{Open, Not\ open\}$; 3) the values of γ, λ, μ (the payoffs of (Open, Open), (Not open, Not open) and the payoff ranges of (Open, Not open), (Not open, open)).

The information that only one player has is its own payoff of (Open, Not open) and (Not open, open) situations.

Therefore, they have to make decision with the bounded rationality.

In the following games, we will assign each type of innovation a dedicated global game setting group of $\{\alpha, \beta, \gamma, \lambda, \mu\}$.

Game 1.1: Radical Innovation Game

Assumptions

In the context of radical innovation, we assume:

Players A and B are companies that want to develop a new product to enter a brand-new hi-tech market (a radical innovation). For instance, the private aerospace

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[10] According to Yoshimi, the probability distribution does not affect the selection of equilibrium in global game settings.

industry is such a marketplace for radical innovation.

If a company chooses to adopt the open innovation paradigm, the company can cooperate with the other company (if also opened) and the external research institutions in the field to speed up the R&D process. Therefore, payoffs α, β, γ are positive values:

$$\alpha, \beta, \gamma \in \mathbb{Z}^+$$

However, if only one company chooses to adopt open innovation, the open company's core competence will be leaked. The other player can benefit from the leaked core competence. In the brand-new hi-tech innovation context, one's gain is the other's loss. Therefore, all the payoffs (α, β, γ) are limited[11] and predictable.

$$\alpha, \beta, \gamma \in [\lambda, \mu] \quad \lambda, \mu \in \mathbb{Z}^+$$

Solution

Since each player knows its own payoffs and the range of α, β, γ, we adopt the Bayesian Nash equilibrium to solve the game.

If player B knows player A chooses "Open", player B will also choose "Open" if $\gamma > \alpha$. Player B cannot recognize α but knows its range $\alpha \in [\lambda, \mu]$. Since $[\lambda, \mu]$ is rectangularly distributed and $\lambda, \mu \in \mathbb{Z}^+$, the probability that player B will also choose "Open" is $p_{OO} = \frac{\gamma-\lambda+1}{\mu-\lambda+1}$.

Similarly, if player B knows player A chooses "Not open", player B will choose "Open" if $-\beta > 0$. Since $\beta \in \mathbb{Z}^+$, the probability that player B will choose "Open" is $p_{NO} = 0$.

Therefore, for player A, the expected payoff for choosing "Open" is $E_{A_O} =$

[11] Note that γ cannot exceed the range $[\lambda, \mu]$ in Game 1.1's setting.

$p_{OO}\gamma - (1 - p_{OO})\alpha$; and the expected payoff for choosing "Not open" is $E_{A_N} = p_{NO}\beta + 0 = 0$.

Player A should choose "Open" when $E_{A_O} > E_{A_N}$, which means $p_{OO}\gamma - (1 - p_{OO})\alpha > 0$. The inequality can be simplified into $\alpha < \frac{\gamma^2 + (1-\lambda)\gamma}{\mu - \gamma}$. Therefore, the switching signal for the radical innovation game is:

$$\alpha^* = \frac{\gamma^2 + (1-\lambda)\gamma}{\mu - \gamma}$$

When $\alpha < \alpha^*$, player A should choose "Open"; when $\alpha > \alpha^*$, player A should choose "Not open".

Since all the variables $\alpha, \gamma, \lambda, \mu$ in the function are known for player A, the coordination game can be solved without knowing the other player's private information: For instance, when $\gamma = 5$, $\alpha, \beta \in [1, 10]$, $\alpha^* = \frac{\gamma^2 + (1-\lambda)\gamma}{\mu - \gamma} = 5$. If player A has a payoff $\alpha < 5$, it will choose "Open"; If $\alpha > 5$, it will choose "Not open"; If $\alpha = 5$, it will have a mixed strategy Nash equilibrium.

In a real business context, if the complementary capabilities can create extra value (Tidd, 2014) for both parties ($\mu > \gamma \gg \alpha, \beta > \lambda$), $\alpha < \alpha^*$ should establish, and the players in such a radical innovation game should open and collaborate together. To the contrary, if the market is limited (Yonekura & Shimizu, 2015), there is no significant benefit but more harms to cooperate ($\mu > \alpha, \beta \gg \gamma > \lambda$), $\alpha > \alpha^*$ should establish, the players in such a radical innovation game should not adopt open innovation.

Game 1.2: Architectural Innovation Game

Assumptions

In the context of architectural innovation, we assume:

Players A and B are companies that want to expand their existing technology to enter a new market (an architectural innovation). For instance, the social media platform is typical case of architectural innovation.

If both companies choose to adopt the open innovation paradigm, their platforms are interoperable to each other. They can increase the perceived utilities by sharing the services and functions embedded in each other's platform. Therefore, γ is a positive number:

$$\gamma \in \mathbb{Z}^{+}$$

However, if only one company chooses to open up its platform, it will attract more developers and increase its platform's perceived utility. The other player will lose users due to lack of competitive advantage. Therefore, payoffs α, β are negative.

$$\alpha, \beta \in [\lambda, \mu] \quad \lambda, \mu \in \mathbb{Z}^{-}$$

Solution

If player B knows player A chooses "Open", player B will also choose "Open" if $\gamma > \alpha$. Since $\gamma \in \mathbb{Z}^{+}$ is positive while $\alpha \in \mathbb{Z}^{-}$ is negative, player B will definitely choose "Open". The probability that player B will also choose "Open" is $p_{OO} = 1$.

If player B knows player A chooses "Not open", player B will choose "Open" if $-\beta > 0$. Since $\beta \in \mathbb{Z}^{-}$ is negative, the probability that player B will choose "Open" is $p_{NO} = 1$.

Therefore, for player A, the expected payoff for choosing "Open" is $E_{A_O} = \gamma$; and the expected payoff for choosing “Not open” is $E_{A_N} = \beta$.

Player A should choose “Open” when $E_{A_O} > E_{A_N}$. Since $\gamma \in \mathbb{Z}^+$, $\beta \in \mathbb{Z}^-$, $E_{Ao} > E_{AN}$ always establish. Therefore, player A should always choose “Open”.

Symmetrically, player B should choose “Open” when $\gamma > \alpha$. Player B will also choose “Open” constantly.

Therefore, (“Open”, “Open”) is a pure strategy Nash equilibrium of the architectural innovation game. The Nash equilibrium is shown in the payoff matrix in Figure 27.

Figure 27. Payoff matrix of the architectural innovation game

		Player B	
		Open	Not open
Player A	Open	*γ, γ*	*-α, α*
	Not open	*β, -β*	0, 0

Legend:
Cell in grey: The Nash equilibrium of this game.

Source: Made by the author.

In fact, there are many successful open innovation business cases in the architectural innovation category. The open innovation is a dominant strategy for the architectural innovation games.

Game 1.3: Modular Innovation Game

Assumptions

In the context of modular innovation, we assume:

Players A and B are two start-up companies that want to develop a new product to challenge an existing market (a modular innovation).

If a company chooses to adopt the open innovation paradigm, the design of its new product will leak out to the current firms in the existing market. As a result, the new product will be imitated by the current firms with higher market competitiveness. The start-up company loses its competitive advantages. Therefore, γ is a negative value while α, β are positive:

$$\gamma \in \mathbb{Z}^-$$

$$\alpha, \beta \in [\lambda, \mu] \quad \lambda, \mu \in \mathbb{Z}^+$$

Solution

If player B knows player A chooses "Open", player B will also choose "Open" if $\gamma > \alpha$. Since $\gamma \in \mathbb{Z}^-$ is negative while $\alpha \in \mathbb{Z}^+$ is positive, player B will never choose "Open". The probability that player B will also choose "Open" is $p_{OO} = 0$.

If player B knows player A chooses "Not open", player B will choose "Open" if $-\beta > 0$. Since $\beta \in \mathbb{Z}^+$ is positive, the probability that player B will choose "Open" is $p_{NO} = 0$.

Therefore, for player A, the expected payoff for choosing "Open" is $E_{A_O} = -\alpha$, a negative value; and the expected payoff for choosing "Not open" is $E_{A_N} = 0$.

Therefore, $E_{Ao} < E_{AN}$ always establish. Therefore, player A should always choose "Not open".

Symmetrically, player B should choose "Open" when $\gamma > \alpha$. Player B will also choose "Not open" constantly.

Therefore, ("Not open", "Not open") is a pure strategy Nash equilibrium of the modular innovation game. The Nash equilibrium is shown in the payoff matrix in Figure 28.

Figure 28. Payoff matrix of the modular innovation game

		Player B	
		Open	Not open
Player A	*Open*	*γ, γ*	*-α, α*
	Not open	*β, -β*	0, 0

Legend:
Cell in grey: The Nash equilibrium of this game.

Source: Made by the author.

Game 1.4: Incremental Innovation Game

Assumptions

In the context of incremental innovation, we assume:

Players A and B are the only two companies in a mature, high-return, and low-growth market (a cash cow in the BCG-matrix).

While it is difficult to imagine the application of open innovation in a cash cow business, we assume that open up one's product would attract the other company's consumers. As a result, the rival company would lose more revenue. There is a chance that it will quit the market and leave a monopolistic position to the opened one.

According to the assumption, if both companies choose to open up their product, both will lose a certain number of sales:

$$\gamma \in \mathbb{Z}^-$$

However, if only one company open, the other will abandon its business in the market:

$$\alpha, \beta \in \mathbb{Z}^-$$

$$\alpha, \beta, \gamma \in [\lambda, \mu],\ \gamma > \alpha,\ \gamma > \beta$$[12]

Solution

If player B knows player A chooses "Open", player B will also choose "Open" if $\gamma > \alpha$. Player B cannot recognize α but knows its range $\alpha \in [\lambda, \mu]$. Since $[\lambda, \mu]$ is rectangularly distributed and $\lambda, \mu \in \mathbb{Z}^-$, the probability that player B will also choose "Open" is $p_{OO} = \frac{\gamma-\lambda+1}{\mu-\lambda+1}$.

If player B knows player A chooses "Not open", player B will choose "Open" if $-\beta > 0$. Since $\beta \in \mathbb{Z}^-$, the probability that player B will choose "Open" is $p_{NO} = 1$.

Therefore, for player A, the expected payoff for choosing "Open" is $E_{A_O} = p_{OO}\gamma - (1 - p_{OO})\alpha$; and the expected payoff for choosing "Not open" is $E_{A_N} = p_{NO}\beta + 0 = \beta$.

Since β is unknown to player A, there is no pure strategy Nash equilibrium for the incremental innovation game. But it is possible to solve out a mixed strategy Nash equilibrium.

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[12] $\gamma \in [\lambda, \mu],\ \gamma > \alpha,\ \gamma > \beta$ are the additional conditions in Game 1.4.

For instance, let $\gamma = -5,\ \alpha, \beta \in [-5,\ -1],\ \alpha = -4,\ \beta\ = -3$. Then we can calculate the expected payoffs values of player A and player B:

$$E_{A_O} = -4.2;\ E_{A_N} = \beta$$

$$E_{B_O} = -3.4;\ E_{B_N} = \alpha$$

Therefore, we can have the expected probability from the range of α, β: The probability of $E_{Ao} > E_{AN}$ is 0.2; The probability of $E_{Bo} > E_{BN}$ is 0.4.

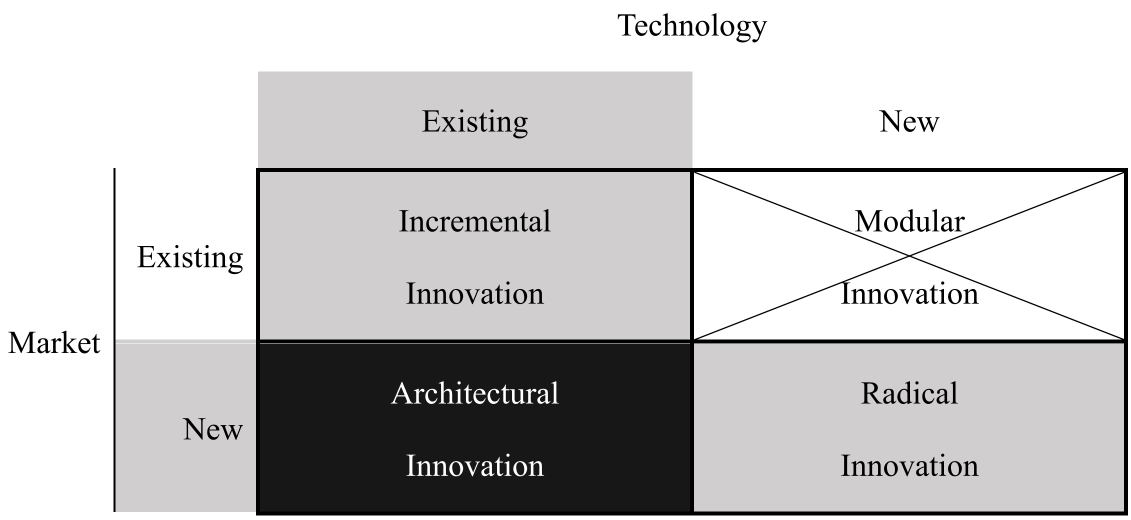
In this setting, the game has a mixed strategy Nash equilibrium (20% “Open” & 80% “Not open”, 40% “Open” & 60% “Not open”).

According to the analysis above, the incremental innovation game has no pure strategy Nash equilibrium but only a mixed strategy Nash equilibrium.

4.3.3.2 Open Innovation Typology

According to the simulation results of the four simplified models of different innovation types, we are able to locate open innovation in the Henderson-Clark model (Figure 29).

Figure 29. Result of the open innovation games



Legend:
Cell in black: The open innovation paradigm can be applied to this type of innovation.
Cell in grey: The open innovation methods can be implemented in this type of innovation under some conditions.
Cell with a cross: The open innovation does not fit for this type of innovation.

Source: Made by the author, based on Henderson & Clark, 1990, p. 12.

The pure strategy Nash equilibrium ("Open", "Open") of the architectural innovation game suggests that open innovation should be a dominant strategy to apply in an architectural innovation game. Furthermore, open innovation should get diffused in such a situation. If one player starts open innovation, the others will also take part in the open innovation. After the companies started to adopt the open innovation paradigm, other companies in the industry are willing to follow them through a collaborative innovation manner.

To the contrary, the pure strategy Nash equilibrium ("Not open", "Not open") of the modular innovation game suggests that open innovation is not applicable in modular innovation. The modular innovation is more a technological invention rather than the "creative destruction". The modular innovation focuses on changing the core design concepts of the products, while still using the existing architecture. The modular innovation requires the innovator to hold a leading position in the market or the innovation network. Therefore, it does not fit the small- and medium-sized firms. This result supports and further explains the propositions of several previous research (Van de Vrande, et al., 2009; Ito, 2015; Takei, Saeki, & Nagae, 2019, p. 40; etc.).

The incremental innovation game has a mixed strategy Nash equilibrium. Generally speaking, we seldom found incremental innovation with an open innovation processing approach (especially the coupled open innovation process as defined in this research) both in the literature and the empirical cases. The incremental innovation does not require a vast majority of external ideas and resources; thus, it can rarely benefit from the open innovation. However, as the game theoretical simulation cannot completely deny the possibilities of incremental open innovation approaches, it is still worth evaluating the possibility of implementing open innovation in the incremental innovation situations.

The radical innovation game has a similar Nash equilibrium with the incremental innovation game that is related to the environmental variables in our game theoretical simulation. However, we have seen a lot of cases that successfully achieved the radical innovation with an open innovation approach. Furthermore, previous literature has suggested that traditional innovation models are not efficient enough or even not suitable for such radical or disruptive innovations (Chesbrough, Vanhaverbeke, & West, 2006, p. 245). It is highly recommended to attempt open innovation in such radical innovation situations. The environmental settings such as network centralities, as well as other factors such as the management and communication methods, should be important in constructing a successful radical innovation network.

According to the simulation results and the discussions of the normal-form networked open innovation games, we can set the following hypotheses concerning the applicability of open innovation in different innovation types:

H1. Open innovation is applicable in architectural innovation, radical innovation, and incremental innovation.

H1.1. Open innovation is one of the state-of-the-art mechanisms in architectural innovation.

H2. Open innovation is not applicable in modular innovation.

We will test these theoretical hypotheses in the case studies in Chapter 5.

4.3.4 Lumpy Signaling Open Innovation Game

The lumpy signaling open innovation game is designed to solve one of the most essential problems in the research of open innovation: How open innovation network establishes without explicit sources of trust?

The two-stage signaling game is designed to verify the mechanism of "lumpy goods" in the peer production model presented in Section 3.2. While the concepts "lumpy public goods" and "lumpiness" seem to be a promising mechanism to explain the collective-level factors of an open innovation network, the existing literature is quite limited and not very persuasive. Furthermore, such collective factors of trust and coordination are often implicit and difficult to be observed from the data analyses.

In this section, we would like to design a signaling game model to explain the mechanism of "lumpiness" in the network configuration of open innovation. We would like to use this model to recognize and analyze the implicit sources of trust and coordination factors in the case studies of this research.

4.3.4.1 Hybrid Sequential Game Setting

The lumpy signaling game is set as a two-stage coordination game, combining the extensive form and the normal form games. Based on Benkler (2006, pp. 113-115)'s given examples on the lumpy goods, we set the context of the lumpy signaling game as the following:

Player A, player B, and player C are the only three companies producing digital goods in a niche market.

Players can reduce its costs if and only if it can access to all the three companies' core competencies. Therefore, the "lumpiness" (Thompson, 1987, p. 433) is 3 against the lumpy public goods (core competencies) in the game settings. All players have strong incentives to achieve the "lumpiness" (increase the amount of the collective public goods).

Player A wants to cooperate with B and C by opening its own core competence. However, player A fears that player B and player C will refuse to open and only take a free ride.

According to the context, we set the game $G = \{S_A, S_B, S_C; U_A, U_B, U_c\}$ as a three-player signaling game: player A is the sender, and it moves first; player B and player C are the receivers and move simultaneously at a spatial subgame in the second step.

$$S = \{O, N \,\&\, N, N \,\&\, F\}$$

$$S_A \in S, S_B \in S, S_B \in S$$

$S =$ {*O*pen, *N*ot open & *N*ever free ride, *N*ot open & *F*ree ride if possible} is the superset of player A, player B, and player C's strategy sets S_A, S_B, S_C.

We assume the perfect incomplete information in the game: 1) player A, player B, and player C know the payoff functions U_A, U_B, U_c and the superset S of each player's strategy set; 2) player A, player B, and player C do not know the other players' strategy sets as well as their profiles (the prior probabilities of $O, N \,\&\, N, N \,\&\, F$).

While the game is set in a general form, to simplify the explanation we assume player A, player B, and player C have the same payoff function:

$$U_A = U_B = U_c = \begin{cases} L \\ 0 \\ -c \end{cases} \quad L \in \mathbb{N}, c \in \mathbb{N}$$

If and only if one player can get all the three players' core competencies, the player can get the lumpy utility L.

If all players choose "Open", their utilities are all L.

If only two players choose "Open", and the other one chooses "Not open & Free ride", then the utility of the free rider is L, and utilities of the other two is $-c$.

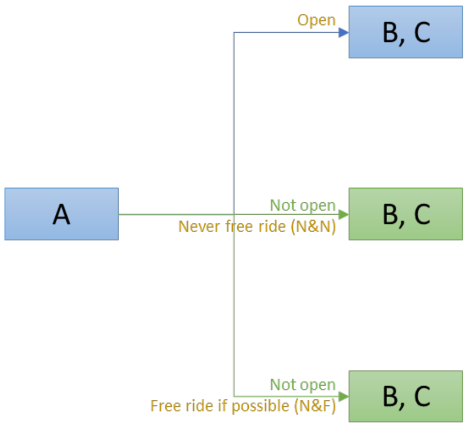
If only two players choose "Open", and the other one chooses "Not open & Not free ride", their utilities are all 0.

If no more than one player chooses "Open", no matter the other players choose their utilities are all 0 (because taking a free ride does not achieve the lumpiness).

Game 2: Lumpy Signaling Game

According to game settings, we can generate the game tree of Lumpy signaling game as Figure 30.

Figure 30. Game 2: Lumpy signaling game



B \ C	O	N&N	N&F
O	L, L, L	0, 0, 0	-c, -c, L
N&N	0, 0, 0	0, 0, 0	0, 0, 0
N&F	-c, L, -c	0, 0, 0	0, 0, 0

B \ C	Open	Not open*
Open	L, -c, -c or 0, 0, 0	0, 0, 0
Not open*	0, 0, 0	0, 0, 0

Note: $L, c \in \mathbb{R},\ L > 0 > -c$

Source: Made by the author.

The Game 2 is set as a two-stage signaling game. The first stage is shown as the left part of Figure 30. The first stage is a sequential extensive form game where A moves first. The second stage is a simultaneous game where B and C moves together as the second-movers. According to the signal of A in the first stage, we have two situations in the second stage. The blue game table in the right side of Figure 30 is the situation when A has chosen "Open" in the first stage; and the green game table is the situation when A has chosen "Not open", respectively. If A's signal is "Open", then the situation is very clear. However, if A has given a signal of "Not open", B and C have to consider whether A will "Free ride" or not. Therefore, in the green game table, we have two sets of possible outcomes.

Solution

First, let us try the standard backward induction to solve the extensive form game.

If player A chooses "Not open", "Not open" is the dominant strategy for both player B and player C. Therefore, "Not open" is meaningless for A as a signal and will be excluded in the game tree.

If player A chooses "Open", there are two Nash equilibria in the normal form subgame: ("Open", "Open") and ("Not open", "Not open"). There is no pure strategy Nash equilibrium in this game.

Nevertheless, we can still solve the subgame with the payoff and risk dominance equilibrium selections methodology (Harsanyi & Selten, 1988).

Firstly, we compare the two Nash equilibria with the risk dominance equilibrium selection. If at least one of player B and player C "Free rides", ("Not open", "Not open") risk dominates ("Open", "Open") weakly since:

$$[U_B(O,O,\ N\&F) - U_B(O,N\&F,N\&F)] \cdot [U_c(O,N\&F,\ O) - U_c(O,N\&F,N\&F)] = 0$$
$$= [U_B(O,N\&F,O) - U_B(O,O,O)] \cdot [U_c(O,O,N\&F) - U_c(O,O,O)]$$
$$[U_B(O,O,\ N\&N) - U_B(O,N\&N,N\&N)] \cdot [U_c(O,N\&F,\ O) - U_c(O,N\&F,N\&F)] = 0$$
$$= [U_B(O,N\&N,O) - U_B(O,O,O)] \cdot [U_c(O,O,N\&F) - U_c(O,O,O)]$$

In the best circumstance (player B and player C never "Free ride"), ("Not open", "Not open") does not risk dominate ("Open", "Open"):

$$0 = [U_B(O, O,\ N\&N) - U_B(O, N\&N, N\&N)] \cdot [U_c(O, N\&N, O) - U_c(O, N\&N, N\&N)]$$
$$< [U_B(O, N\&N, O) - U_B(O, O, O)] \cdot [U_c(O, O, N\&N) - U_c(O, O, O)]$$
$$= L^2$$

Secondly, with the payoff dominance equilibrium selection:

As long as $L > 0 > -c$, (“Open”, “Open”, “Open”) is the payoff dominant. Since $L \in \mathbb{N}, c \in \mathbb{N}$, this inequity is always true.

Therefore, in the subgame player A “Opened”, (“Open”, “Open”) is selected by both risk dominance equilibrium selection and the payoff dominance equilibrium selection. As the result, (“Open”, “Open”, “Open”) is the subgame perfect Nash equilibrium.

4.3.4.2 “Lumpiness” and the Diffusion of Open Innovation

According to the definition of “lumpy public goods” (Benkler, 2006 and Thompson, 1987), the collaborative action itself is a “motive” for participating in the collaboration. As long as the “lumpiness” is not zero, we can achieve a win-win game. If the “lumpiness” (“grain size” in Benkler, 2006) is a larger number close to the number of players in a potential collaboration, all the players have no reason to betray and take a free ride.

In our lumpy signaling game, the subgame perfect Nash equilibrium of Game 2 has also shown that if the lumpiness of the lumpy goods is large enough, the first-mover can use an open signal to trigger the cooperation. In the case lumpiness equals the player number, one cooperative signal provides enough trust in the open innovation network.

Furthermore, players will always cooperate without any other trust (besides the first collaborative signal) in an extended network with a lumpiness slightly less than the player number, as long as the lumpy utility is larger or equals the payoff of taking a free ride.

Therefore, the concept "lumpy public goods" is a potential mechanism to explain the zero-trust collaboration phenomena in open innovation networks. In an open innovation network with a high lumpiness lumpy public goods, trust should not be the constraining factor of the network. If the lumpiness is the common knowledge or an explicit signal in the network, the participation of open innovation can be diffused without any external dependencies. On the contrary, in an open innovation network with a low or zero lumpiness lumpy public goods, the adoption of open innovation should require some external path dependencies. In the low lumpiness open innovation network, we should be able to identify the importance of trust, reputation, co-ownership, public contract, and other limiting factors. Besides, "when costs of participation are low enough, any motivation may be sufficient to lead to a contribution" (Feldstein, 2007). Even a low lumpiness should trigger an open innovation network when the costs are also low enough.

4.3.5 Scalability of the Open Innovation Games

Although the open innovation games presented in the previous sections are modeled with small *N*-player games, the open innovation games almost never happen within a small number of players. It is even more impossible for the open innovation game in the distributed network, where near-infinite players are involving dynamically.

However, we can still apply the findings from the small *N*-player models. The normal form games are easily to be expended with more players. The results of such *N*-player normal form games are often similar to our small *N* settings. Large scale *N*-player extensive form games are usually a bundle of several repeated small *N*-player extensive form games. And we could still apply the "lumpiness" in large *N* settings.

Nevertheless, large *N*-player games should also have Nash equilibria. Nash (1950) has proven that an *N*-player game with a finite strategy set has an equilibrium with the Kakutani fixed-point theorem. In our open innovation game settings, the strategy sets are always infinite. However, the calculation of Nash equilibrium in a large-scale game is very challenging[13]. Therefore, we need some approximate equilibrium to deal with the innovation games in the large-scale distributed networks.

The epsilon Nash equilibrium (ε-equilibrium) is often used as an alternative solution for solving large-*N* games in the computational algorithms[14]. An ε-equilibrium can be treated as an approximate Nash equilibrium. In a Nash equilibrium, no player can

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[13] While this research is not dealing with the computational complexity problems, it is worth mentioning that the exhaustive search for a Nash equilibrium is generally considered as an NP-complete (nondeterministic polynomial-time complete) problem (some potential proves can be found in Chen & Deng, 2006; Daskalakis, et al., 2009; etc.). NP-complete problems are the most complex problems for current computers (Turing machines) and computational theories. There is no algorithm to simplify the Nash equilibrium solution in polynomial-time. This means a large-scale game is almost impossible to be solved in a meaningfully short time (for a business strategical decision-making, for instance).

[14] Daskalakis, et al. (2009) have proven that the ε-equilibrium has a PTAS (polynomial-time approximation scheme) in computational complexity theory. This means that the ε-equilibrium is solvable with Turing machines.

improve his payoff by deviating unilaterally; while in an ε-equilibrium, a player may have a small incentive (ε) to change his strategy. According to this definition, Nash equilibrium is a special condition of the ε-equilibrium: the incentive $\varepsilon = 0$. In a behavioral economics approach, ε-equilibrium is acceptable due to other emotional biases (for instance, the status quo).

The epsilon Nash equilibrium is a potential solution to deal with the continuous (not simply repeated) open innovation games. A general open innovation game can be modeled as a stochastic game Γ_n with a finite set of players P and a finite set of strategy S based on a stage space M. Because of the openness and perfect information assumption, a player i is able to observe the current m_t at a certain stage t, and choose a strategy $s_t^i \in S^i$. After the action, all players in the stage t are able to observe the current strategy profile $s_t = \sum_i s_t^i$ and decide the next stage space m_{t+1}. When the stage space M is finite ($n \in \mathbb{R}$), the stochastic game Γ_n has been proven to have a Nash equilibrium. However, if $n \to \infty$, the ε-equilibrium might be the only available equilibrium[15].

Mean-field game theory is another theory for solving the dynamic large-scale open innovation games. The mean-field game theory is developed to solve the *N*-player game when $N \to +\infty$ (Lasry & Lions, 2007), which is very similar to the conditions for an open innovation game in a distributed network. The mean-field game assumes the usability of a further simplified Nash equilibrium: A player need not go over the complete strategy set before he can make a decision. Let us consider the famous efficient-market hypothesis (EMH) with the mean-field game theory: In a market with perfect information

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[15] Currently, there is no prove on the *N*-player stochastic game when $N > 2$.

and rational investors, the asset price has already reflected all the available information in the market. In that sense, the price is the "mean" price in the "field" of market. In the real business world, consumers cannot and will never investigate all sellers' prices before making their purchasing decisions. The mean-field game theory is a promising mechanism in explaining the diffusion of open innovation.

4.4 Analytical Frameworks and Research Design

In this chapter, we have introduced the definition of open innovation, the research questions, the theoretical background, and the analytical approaches of this research. In this section, we will summarize the analytical frameworks, and introduce the research design of the original analysis in the next chapter.

In Section 4.1, we have first defined "open innovation" as "the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation" (Chesbrough, 2006a, p. 17). Then we have further explained that open innovation is a paradigm to 1) develop appropriate business models (organizational innovation), 2) enter new markets (market innovation), 3) create and capture new values (product innovation), 4) improve the productivity (process innovation), and 5) reduce costs (input innovation and organizational innovation) for a production organization through the purposive new combinations of internal and external ideas, knowledge, and resources. Based on the definition of open innovation as well as the Schumpeterian innovation theory introduced in Chapter 2, we have set a comprehensive research framework (Table 16) for the empirical case studies.

Table 16. The analytical framework of open innovation implementations in the case studies

	Inbound knowledge	Outbound knowledge	Inbound resource	Outbound resource
Develop new business model (organizational innovation) Enter new market (market innovation) Improve productivity (process innovation) Create and capture new values (product innovation) Reduce costs (input and organizational innovations)	(Knowledge or resource flows involved in the open innovation implementation of the case)			

Source: Made by the author.

Based on the definition and the research objectives we set in Section 1.2, we have raised two research questions and four sub-research questions from both the individual level and the collective level in Section 4.2.

After we have set the research questions of this dissertation, we have discussed the theoretical background of our research design. In Section 4.2.1, we have discussed the individual-level factors found in the previous research. To answer the individual-level research questions, we have designed an analytical framework (Table 17) based on the already identified constraining factors, dependencies, routines, and environmental variables from the previous studies discussed in Chapter 3.

Table 17. The individual-level analytical framework

	Trust / Coordination	Motive / Incentive
Intra-organizational factors	Interpersonal relationship Risk sharing Contract / cheating cost	Profit / cost New market / market share Productivity
Extra-organizational factors	Public ownership Societal trust Innovation intermediaries	Access to external resources Ecosystem Sustainability

Source: Made by the author.

In Section 4.3, we have designed a game theoretical approach for collective level analyses. Firstly, we have introduced the basic ideas of game theory, the elements and settings of a game, and the solutions to solve a game. We then designed four normal-form networked open innovation games (Game 1.1 to 1.4) and a two-stage hybrid-form Lumpy signal open innovation game (Game 2). The normal-form game models cover different innovation types of the networked open innovation implementations that we will analyze in the case studies. The Lumpy signal game provides a model to analyze the implicit constraining factors, particularly the collective factors of trust / coordination, to maintain an open innovation network. Such factors are difficult to be observed and analyzed from the data.

To answer the collective-level research questions, we refer to the Henderson-Clark model of innovation typology which we have discussed in Section 2.5.1. Based on the Henderson-Clark model, we have discussed and simulated four different sets of configurations of potential open innovation networks, and come up with two hypotheses and one sub-hypothesis concerning the applicability of the open innovation paradigm in different innovation types (Figure 31). Furthermore, we have discussed and simulated a potential mechanism, the “Lumpiness”, for the establishment of “zero-trust” open innovation networks.

Figure 31. The collective-level analytical framework for different open innovation networks

		Technology: Existing	Technology: New
Market	Existing	**Incremental Innovation** Hypothesis 1. Open innovation is applicable	**Modular Innovation** Hypothesis 2. Open innovation is not applicable
Market	New	**Architectural Innovation** Hypothesis 1.1. Open innovation is the best practice	**Radical Innovation** Hypothesis 1. Open innovation is applicable

Source: Made by the author, based on Henderson & Clark, 1990, p. 12.

Based on the analytical frameworks above, this research adopts an ethnographic approach and conducts a series of small-N comparative case studies to identify the critical managerial and environmental factors of open innovation networks.

The empirical case studies focus on commercial companies adopting open innovation paradigm and conducting networked open innovation implementation from different industrial sectors in China. The companies are divided into three groups: the capital-intensive group, the labor-intensive group, and the knowledge-intensive group. The open innovation implementations of these companies differ from each other due to their different innovation types and different open innovation approaches. Nevertheless, our comprehensive analytical frameworks cover all their open innovation implementations, managerial approaches, and types of innovation networks.

Since we adopt an ethnographic approach in our empirical studies, we will tweak and choose the methodology that fit the case most in each particular study. While due diligence (particularly the financial due diligence) and in-depth interview are the primary methodologies used in the case studies of the empirical research, the details of the methods will be introduced in each case of the empirical research.

Chapter 5

Implementations of Open Innovation in Distributed Network

In this chapter, we analyze a series of case studies from different industrial sectors, with different open innovation implementations, and cover different categories of the open innovation research framework. In Section 5.2, the cases are analyzed with their financial data, the findings from the due-diligences and the in-depth interviews with the executive managers and core staffs. From the case studies, this chapter presents an extensive understanding of the practical managerial mechanisms of open innovation in commercial companies. Particularly, the successful open innovation cases of capital-intensive and labor-intensive firms have proven that the open innovation paradigm can be also applied to industries other than the knowledge-intensive ones. After the case studies, we identify the conditions, path dependencies, and the necessary and sufficient factors to implement open innovation in distributed network in Section 5.3. After concluding the cases, we will answer the research questions we have set in the previous chapter.

5.1 The Objectives of the Empirical Case Studies

The empirical research series focuses on the open innovation implementations in commercial companies outside the ICT industry. From the case studies, we would like to investigate the current status of open innovation adoptions in real business context, identify the driving factors and limitations of open innovation, and provide possible open innovation strategies for future business applications.

In Chapter 3, we have surveyed various pieces of previous literature that focusing on the open innovation implementations in the ICT industry, a typical industrial sector to apply the open innovation paradigm. However, digital production is much different from agriculture, manufacturing, and service productions. The digital goods such as software can be copied and reproduced at an extremely low cost. On the contrary, we cannot easily dismiss or ignore the marginal costs in industrial sectors other than the ICT. Furthermore, the ICT industry is generally considered as a knowledge-intensive production. However, we still have capital-intensive and labor-intensive ones in real business world. The wide variety of different industries makes it difficult to design a ceteris paribus empirical research.

In this chapter, we will discuss both the successful cases and the failed attempts. These cases are adopting different open innovation approaches, creating different new combinations of internal and external components, and thus covering different innovation types in the Henderson-Clark model. In these case studies, we will further discuss and analyze the driving factors and limitations of open innovation adoptions.

5.2 Case Studies: Business Implementations of Open Innovation

Although most theoretical development and empirical research are done in the ICT industry, the open innovation paradigm should not be limited to the ICT related companies and organizations. In this part, we would like to verify and extend the current research framework to more industrial sectors. Furthermore, we want to develop a common methodology for different types of firms to adopt the open innovation approaches.

In order to include as many different production types as possible, we choose the cases based on a non-randomized purposive sampling strategy from a vast variety of empirical cases. We have chosen firms from different industries with different production types (factor intensities), but have similar approaches for open innovation. Notably, we have chosen three capital-intensive firms and a labor-intensive firm – the compatibility of open innovation for these types of commercial companies is lacking in both theoretical and empirical studies.

The seven cases we have chosen are shown in Table 18. According to the production type, they can be categorized into three groups:

1) Capital-intensive group: This group is made up of three manufacturers. A) Borche Machinery Co., Ltd., which develops and produces plastic molding system. B) Ewatt Technology Co., Ltd., which develops and produces industrial drones. C) Han's Robot Co., Ltd., which develops and produces industrial robots and collaborative robots.
2) Labor-intensive group: This group contains a logistic service provider. D) Prolog Technology Co., Ltd., which provides full-managed logistic solutions and manages its own warehouses.
3) Knowledge-intensive group: There are one manufacturer and two service providers in this group. E) Xiangyuan New Material Technology Inc., which develops and produces hi-tech thermoplastic materials. F) Yuanqi Technology Co., Ltd., which develops and provides hospital management services. G) Hanbroad Business Management Group Co., Ltd., which develops and provides retail management services.

Table 18. Overview of the cases

Group	Capital-intensive			Labor-intensive	Knowledge-intensive			
Case	A	B	C	D	E	F	G	
Company name	Borche Machinery Co., Ltd.	Ewatt Technology Co., Ltd.	Han’s Robot Co., Ltd.	Prolog Technology Co., Ltd.	Xiangyuan New Material Technology Inc.	Yuanqi Technology Co., Ltd.	Hanbroad Business Management Group Co., Ltd.	
Location	Guangzhou, Guangdong	Wuhan, Hubei	Shenzhen, Guangdong	Wuhan, Hubei	Xiaogan, Hubei	Wuhan, Hubei	Beijing	
Industrial sector	Manufacturing	Manufacturing	Manufacturing	Service (Logistics)	Manufacturing	Service (Financing)	Service (Business)	
Main product	Plastic molding system	Industrial drone	Robots	Full-managed warehouse service	Thermoplastic materials	Hospital management service	Retail management service	
Open innovation approaches								
Since	2017	2016	2019	2014	2008/2014	2017	2012	2020
Main approach	Collective production	Collective R&D	Collective R&D	Collective production	Collective R&D	Collective R&D	Collective production	Collective R&D
Major implementation	Asset sharing in manufacturer network	Open cross-functional team in manufacturer network	Open agile development in manufacturer network	Asset sharing in customer network	Accessing external resource in customer network	User innovation in customer network	Asset sharing in customer network	Knowledge sharing in customer network

Source: Made by the author.

From the overview, we can see that the seven cases have both similarities and differences in their open innovation implementations:

1) Borche Machinery and Prolog Technology adopted open innovation mostly in their productions. On the contrary, Ewatt Technology, Han's Robot, Xiangyuan New Material Technology, and Yuanqi Technology's open innovation adoptions focus on their research and development workflows. Hanbroad Business Management Group is the only company that have attempted both approaches.
2) The open innovation implementations of the capital-intensive group are based on manufacturer networks. The open innovation implementations of labor-intensive and knowledge-intensive groups are based on customer networks.
3) Borche Machinery, Prolog Technology, and Hanbroad Business Management Group have attempted asset sharing strategy in the open innovation network.
4) Ewatt Technology, Han's Robot, and Yuanqi Technology are all developing their new products (services) in open networks with one or more novel innovation management methods; while the other innovation networks we found in the cases are somewhat restricted.
5) All the cases' productions as well as their research and development workflows are somehow distributed in networks. Some cases are even implementing globally distributed networks.

We will discuss the details of each company's open innovation implementation and the performances of their open innovation adoptions in the following sections.

5.2.1 Case A: Borche Machinery Co., Ltd.

Borche Machinery Co., Ltd. (henceforth, Borche Machinery) is a plastic injection molding machine (henceforth, IMM) manufacturer located in Guangzhou, Guangdong. Borche Machinery's registration information at MOFCOM (Ministry of Commerce of the People's Republic of China) is shown in Table 19.

Table 19. The commerce registration information of Borche Machinery Co., Ltd.

Company name:	Borche Machinery Co., Ltd.		
Representative:	Zhu Kangjian	Registration status:	In operation, Open
Registered capital:	CNY ¥165,000,000	Date of establishment:	2011-08-26 (Its predecessor: 2002-12-26)
Industrial sector:	Manufacturing of equipment for plastic processing[16]	Enterprise type:	Other incorporation (FDI; Unlisted)
Business scope:	Manufacturing and sales of special equipment for plastic processing. Mechanical technology development and consulting services. Data processing, storage, and transaction services. Development of data processing and storage products. Manufacturing and sales of intelligent machinery systems. Technical consulting services related to intelligent machinery systems. Manufacturing of molds. Manufacturing of industrial management systems. Manufacturing of industrial robots and robotic systems.		

Note: As of the date of the last interview (September, 2018).

Source: Made by the author, based on the information provided by the company.

[16] Industrial classification No. C-3523 as defined in Chinese standard GB/T 4754-2017.

According to the historical information, Borche Machinery was founded as a subsidiary of the state-owned rolling stock manufacturer CRRC Group in 2002. After CRRC sold all its stocks to foreign investors during 2005 and 2007, the company re-registered as a foreign direct invested (FDI) incorporation with the same English name (Borche Machinery Co., Ltd.)[17] in 2011. At the same time, Borche Machinery also modified its registered business scope and removed all the railway-related businesses. During the period of our research, Borche Machinery has no business with the Chinese railway system.

Borche Machinery was a manufacturer of plastic molds more than the special equipment vendor for plastic manufacturing when the state-owned rolling stock manufacturer CRRC founded it in 2002. After the foreign investors acquired the company from CRRC, they wanted to upgrade Borche Machinery's product line to improve its profitability. Since then, it dropped the less profitable plastic molds manufacturing business in 2011 and focused on the molding machines. It had also individually developed ("in-house innovated" in the context of this research) a two-platen IMM solution (henceforth, the new generation IMM) in 2007, and started to mass-produce and sell the new generation IMMs since 2011. Unlike the traditional molding devices, the new generation IMMs can achieve a stronger clamping force together with higher precision. The new generation IMMs can be used to produce high value-added plastic parts for aerospace crafts, automobiles, and electronic devices. The success in developing the two-

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[17] The Chinese name has been changed. Old name: *Guangzhou Bochuang **Jixie** Youxian Gongsi* [Guangzhou Borche **Machinery** Limited]; New name: *Guangzhou Bochuang **Zhineng Zhuangbei** Gufen Youxian Gongsi* [Guangzhou Borche **Intelligent Equipment** Co., Ltd.].

platen IMM enabled the company to compete with the top-tier vendors in the plastic molding equipment industry.

Manufacturers of this type (special equipment vendor) are usually capital-intensive firms. Borche Machinery is also a capital-intensive firm in many senses. Firstly, Borche Machinery's asset turnover rate keeps lower than 1 during the period of research (from the fiscal year 2017 (henceforth, FY2017) to the first half of the fiscal year 2020 (henceforth, 1H2020)). For instance, the asset turnover rate of FY2017 is 0.81. Secondly, the amount of illiquid capital assets of Borche Machinery is considerably large. The assets' structure suggests that the company requires a large number of capital input in its production. According to the financial reports of the company (Table 20), the tangible assets, the construction in progress, and the land tenures made up 91.78% of the company's fixed assets in FY2017 (86.04% in the 1st half of 2020). The illiquid capital assets combining with the inventories occupied 59.84% of the company's current and noncurrent assets in FY2017 (51.93% in 1H2020).

Table 20. Borche Machinery Co., Ltd.'s assets and liabilities

	1H2020 (in CNY¥)	**FY2017** (in CNY¥)
Current assets	**788,683,213.47**	**596,342,323.96**
Cash and cash equivalents	158,214,503.78	83,385,881.48
Notes receivables	20,241,862.64	45,992,445.06
Accounts receivables	275,436,403.21	166,704,658.02
Prepaid expenses	31,839,252.89	3,898,339.79
Other receivables	14,095,077.78	6,577,442.93
Inventories	309,185,043.67	272,758,469.91
Raw materials	125,040,394.48	143,985,760.46

Commodity stocks	184,144,649.19	128,772,709.45
Other current assets	7,287,691.78	17,025,086.77
Fixed (noncurrent) assets	**294,201,803.19**	**263,344,738.79**
Investments	1,500,000.00	
Tangible assets	208,172,869.68	112,264,693.63
Real estates	116,468,820.61	76,567,517.05
Equipment	85,666,567.96	31,160,400.20
Conveyances	1,323,723.54	2,158,367.20
Computers	3,745,264.07	1,659,329.20
Other tangible assets	968,473.50	719,079.98
Construction in progress	123,079.74	81,493,408.45
Intangible assets	66,098,205.84	48,145,238.79
Land tenures	44,825,787.42	47,926,969.62
Computer software	21,272,418.42	218,269.17
Deferred expenses	1,374,714.35	1,023,244.41
Deferred taxes	14,721,951.72	8,592,324.23
Other noncurrent assets	2,210,981.86	11,825,829.28
Liabilities	**743,844,354.44**	**511,709,175.73**
Current liabilities	657,429,650.50	460,224,103.40
Noncurrent liabilities	86,414,703.94	51,485,072.33
Shareholders' equity	**339,040,682.22**	**347,977,887.02**
Assets in total	**1,082,885,016.66**	**859,687,062.75**

Source: Da Hua Certified Public Accountants SGP, 2020.

More clearly, the production costs of Borche Machinery show that the company's business is a capital-intensive one. According to the production data (Table 21) provided by the company, the production factors land T (expenses; including the costs and depreciation of real estates, equipment, etc.) and capital K (material costs) accounted for 9.20% and 84.27% respectively in Borche Machinery's overall productions in FY2017.

On the contrary, the labor factor L (labor costs) accounted for only 6.53% in FY2017. Therefore, we can define case A (Borche Machinery) as a typical capital-intensive firm.

Table 21. The costs of Borche Machinery Co., Ltd.'s production

Cost	1H2020		FY2019		FY2018		FY2017	
	Value (thousand CNY¥)	Percent-age (%)	Value (thousand CNY¥)	Percent-age (%)	Value (thousand CNY¥)	Percent-age (%)	Value (thousand CNY¥)	Percent-age (%)
Material	196,476	81.86	417,371	82.98	393,623	84.27	365,657	84.27
Labor	15,814	6.59	35,537	7.07	30,591	6.53	28,319	6.53
Expense	27,728	11.55	50,071	9.95	48,428	9.20	39,923	9.20
Total	**240,018**	**100.00**	**502,979**	**100.00**	**472,642**	**100.00**	**433,899**	**100.00**

Source: Borche Machinery Co., Ltd., 2020, p. 349.

Table 22. The revenues of Borche Machinery Co., Ltd.'s products (services)

Revenue	1H2020		FY2019		FY2018		FY2017	
	Value (thousand CNY¥)	Percent-age	Value (thousand CNY¥)	Percent-age	Value (thousand CNY¥)	Percent-age	Value (thousand CNY¥)	Percent-age
IMMs	316,352	94.58%	722,508	97.44%	668,080	98.75%	639,238	99.09%
New-gen	82,090	24.54%	292,437	39.44%	240,570	35.56%	198,885	30.83%
Traditional	234,262	70.04%	430,071	58.00%	427,510	63.19%	440,353	68.26%
iPlasCloud	11,638	3.48%	13,591	1.83%	4,607	0.68%	-	-
Others	6,501	1.94%	5,425	0.73%	3,885	0.57%	5,878	0.91%
Total	**334,491**	**100%**	**741,524**	**100%**	**676,572**	**100%**	**645,116**	**100%**

Source: Borche Machinery Co., Ltd., 2020, p. 358.

As a capital-intensive firm, the shareholders wanted to improve the company's profitability by reducing the material costs and increasing the gross profit rates. The two-platen IMM, their traditional "in-house" innovation, is developed with these aims. The new generation IMMs have simpler structures and are using fewer parts than the traditional molding machines. It is expected that the introduction of the new generation IMM product line could lower the overall material costs. Borche Machinery also decided to sell the new generation IMMs at higher prices to achieve a higher gross profit rate.

However, the introduction of the new generation IMM production did not succeed in improving the profitability of the company. During the time of research, the majority of Borche Machinery's revenue were still from the sales of traditional three-platen IMMs that can be dated back to 2003 (see Table 22; For instance, traditional IMMs made up 68.26% of the total revenue in FY2017 and decreased a little to 58.00% in FY2019). Furthermore, the gross profit ratio of the new generation IMMs is almost the same as the traditional ones' (see Table 23; the GPRs of the new generation and the traditional IMMs are both around 30% during the research period).

Table 23. The gross profit ratios of Borche Machinery Co., Ltd.'s products (services)

Gross Profit Ratio (%)	**1H2020**	**FY2019**	**FY2018**	**FY2017**
IMMs (new generation)	24.90	32.90	27.89	32.75
IMMs (traditional)	28.11	30.92	31.41	32.87
iPlasCloud	57.93	60.33	41.84	-
Others	22.23	21.35	16.39	22.91
Overall	**28.24**	**32.17**	**30.14**	**32.74**

Source: Borche Machinery Co., Ltd., 2020, p. 359.

Borche Machinery Co., Ltd.'s Open Innovation Implementation

Nevertheless, Borche Machinery started to emerge as a game changer in the industry after adopting open innovation in 2017. By implementing an open business approach, the company changed its business strategy and started to provide services together with the hardware. It is switching to provide both the molding machines and a manufacturer network-based cloud platform "iPlasCloud" that enables its customers to co-produce and crowdsource the plastic goods.

Table 24. Interviews conducted for case study A (Borche Machinery Co., Ltd.)

	Post[18]	Date	Main Theme
Mr. A_1	Chairman	August, 2018	Introduction of Borche Machinery's product line and business plan.
Mr. A_2	Chief Engineer	August, 2018	Introducing the mechanism of Borche Machinery's molding cloud platform "iPlasCloud" service.
Mr. A_3	Sales Manager	September, 2018	Salespoints of Borche Machinery's devices, especially the benefits from the molding cloud platform.

Source: Made by the author.

In order to analyze Borche Machinery's open innovation strategy and the implementations, we have acquired and analyzed the financial and technical data between FY2016 to 1H2020 from the company as well as its prospectus at the Shanghai Stock

[18] The posts are as of the date of the interviews.

Exchange STAR[19] market. To understand the details, we have also interviewed the Chairman (Mr. Zhu, henceforth A_1), the Chief Engineer (Mr. Huang, henceforth A_2), and the sales manager (Mr. Liang, henceforth A_3) of the company during August 2018 and September 2018. The interviews we have conducted are listed in Table 24.

According to Chairman Mr. A_1 (personal communication, 2018), the primary purposes of Borche Machinery's open innovation approach are 1) to increase the overall gross profit rate by providing services, and 2) to make extra profits from its current IMM product line.

In 2017, after Borche Machinery had achieved a leaping growth during the previous years, the company decided to develop and provide a cloud platform service to the plastic manufacturers. The platform can be bundled to the company's two generations of molding machines, both the newly produced ones and the already sold ones.

According to the introduction of Mr. A_2 (personal communication, 2018), the "iPlasCloud" platform focuses on providing a new business model for both the company itself and its customers. With the "iPlasCloud" MES system, third-party buyers can order customized products remotely from the platform. The platform distributes tasks to the idle devices in the manufacturers' network. After the production, the respective device owner delivers the ordered products to the buyers and gets payments. As the platform operator, Borche Machinery earns the system fees from both the buyers and the manufacturers.

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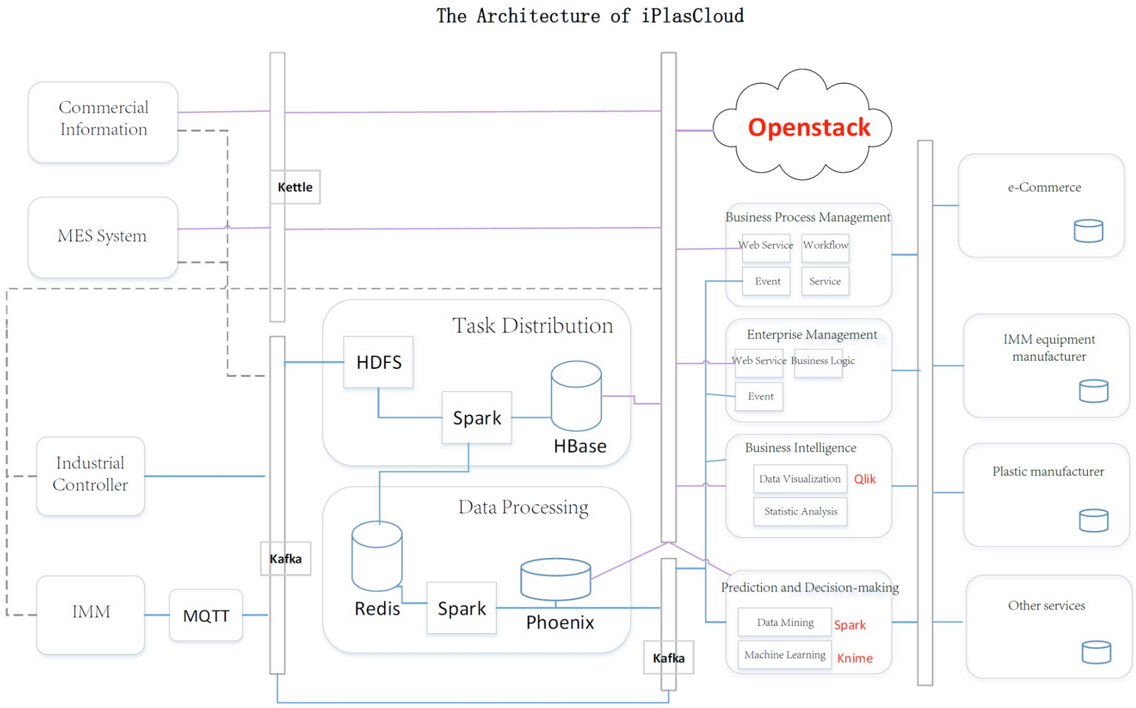
[19] STAR is the abbreviation of the Science and Technology innovation boARd of the Shanghai Stock Exchange.

Figure 32. The architecture of iPlasCloud of Borche Machinery Co., Ltd.



Source: Borche Machinery Co., Ltd., 2020, p. 109.[20]

The architecture of the "iPlasCloud" platform is shown in Figure 32. The left side components (commercial information, MES system, industrial controller, and IMM) are the software and hardware owned by the plastics manufacturer. The platform can only be bundled with Borche Machinery's IMMs. However, the platform supports many industrial standards including RS485, MODBUS, CAN, and EtherCAT. The platform and the IMMs can work together with any existing MES systems and industrial controllers under the same industrial standard that have already been deployed in the manufacturers. The task distribution and data processing are done in the cloud platform. Although Borche

20 Texts in serif font are translated by the author.

Machinery has the centralized control of the cloud platform, the platform itself is opened. The platform has interfaces (the business process management, enterprise management, business intelligence, and prediction and decision-making service modules in the middle of Figure 32) that are opened to all its customers (plastic manufacturers) and the customers' customers (wholesalers and consumers of plastic goods) – which are shown in the right side of the figure (e-Commerce platform, IMM equipment manufacturer (Borche Machinery), plastic manufacturers, and other consumers). Therefore, "iPlasCloud" can be treated as an open incremental innovation: the "iPlasCloud" is based on the existing molding technology, applied in the existing plastic market, but provided openly to all the parties in the market.

In this sense, the "iPlasCloud" is an "inter-organizational" open innovation because it links the discrete peers in the network. By improving the information flows of the market, the supply chain should be more efficient and stable. In an industrial network, the assets are not always equally distributed. According to the introduction of Mr. A_3 (personal communication, 2018), most molding machines are located in Eastern China in the Chinese plastic manufacturing industry. Customers from the other regions often find it difficult to find a proper manufacturer that can deliver specific goods in time. Furthermore, the needs of a particular product are also changing rapidly every day. The manufacturers' devices are often run at a very low utilization rate, which is both a waste of assets and increase the failure rates.

The open innovation of "iPlasCloud" platform provides a new management method for both ends of the supply chain. By distributing tasks to different manufacturers automatically, all the manufacturers can achieve higher utilization rates of devices. At the same time, the customer can get its order delivered faster. For the company itself, by deploying such a platform, it is now providing a higher profit rate, longer-term service product instead of selling the devices and getting revenue only for once during the devices' life cycle. Therefore, the introduction of the manufacturer network-based platform suggests a win-win-win scenario for the equipment manufacturer (the company), the plastic manufacturers (the company's customers), and the plastic buyers (the customers' customers).

According to Mr. A_3 (personal communication, 2018), the plastic manufacturers (the company's customers) have been very satisfied with the "iPlasCloud" platform. The manufacturers joined the network because it can improve the utilization rates of their devices, increase the asset turnover ratios, and limit the risks of machine idling as well as the failures of product delivery. Currently, there are more than 300 firms and 7,000 IMMs registered in the "iPlasCloud" platform (Borche Machinery Co., Ltd., 2020, p. 110).

Borche Machinery Co., Ltd.'s Open Innovation Results

As an open industrial network service, the "iPlasCloud" platform has been widely accepted. The open innovation attempt itself is very successful. However, due to the trade war between the United States and China, the depression of the plastics manufacturing industry as well as the molding equipment industry, and the influence of the COVID-19 pandemic, Borche Machinery did not achieve as great growth as it expected after the introduction of open innovation in its business (Borche Machinery Co., Ltd., 2020, pp. 5-8). From the data provided by the company, the annual growth rate after FY2018 dropped largely from FY2017's 37.58% and 32.95% (Table 25).

Although the profitability did not improve as much as the company had expected, we still evaluate Borche Machinery's open innovation implementation as generally successful. We appreciate Borche Machinery's open innovation strategy because the company is performing better than its competitors in the same industrial sector with the help of its open innovation implementations.

Table 25. Financial performance of Borche Machinery Co., Ltd. during the research period

	1H2020	**FY2019**	**FY2018**	**FY2017**
Revenue (thousand CNY¥)	382,813	763,977	694,173	660,847
Annual growth rate	-	10.06%	5.04%	37.58%
Net profit (thousand CNY¥)	30,175	72,462	61,822	56,872
Annual growth rate	-	17.21%	8.70%	50.40%
Gross profit ratio	29.54%	32.07%	30.04%	32.95%
Net profit ratio	7.88%	9.48%	8.91%	8.61%

Source: WUYIGE Certified Public Accountants LLP, 2018; Da Hua Certified Public Accountants SGP, 2020.

The plastic molding equipment industry suffers from fierce global competition. Almost all companies in this industrial sector have their business performances declined during the period of this research. For instance, Krauss Maffei, the largest plastic molding equipment vendor in the world, fell into red in FY2019 (revenue -6.44%; net profit -183.07%) and kept the deficit in FY2020 (revenue -7.18%; net profit -45.18%) (Krauss Maffei Co., Ltd., 2021, p. 8). Haitian International, the leading plastic molding equipment vendor in China with more than 50 years of history, also suffered declining in its revenue (-9.60%) and net profit (-8.64%) during FY2018 and FY2019 (Haitian International Holding Limited, 2020, p. 5). Despite the depression of the plastic molding equipment industry, Borche Machinery kept growing during our research period (Table 25). From the perspective of financial performance, Borche Machinery outran its competitors.

However, we still need to investigate whether the open innovation implementation is the reason for Borche Machinery's business success. First of all, the open innovation attempt itself has succeeded. According to the company (Borche Machinery Co., Ltd., 2020), the "iPlasCloud" service ranked top 3 in its revenues (Table 22). The "iPlasCloud" service has also achieved much higher (about two times) gross profit ratio than the selling of IMMs (Table 23). The open innovation attempt "iPlasCloud" platform is not a nominal concept but a real business in Borche Machinery's business plan.

Borche Machinery is not the only company that adopted the open innovation methodology in the industry. Haitian International Holdings Ltd. (henceforth, Haitian International), Borche Machinery's biggest rival, is also providing a similar manufacturer network-based asset sharing platform named "Haitian Industry 4.0" since the second half of 2019. Guangdong Yizumi Precision Machinery Co., Ltd. (henceforth, Yizumi), another Chinese IMM manufacturer, has an open "Synergistic Collaboration" platform for collective R&D in both the molding equipment development and the applications of plastic molding devices. While focusing more on the collective research and development workflow, Yizumi's platform is also an open innovation implementation that connects the IMM equipment manufacturer and the plastic manufacturers together. According to the annual reports of the companies in the plastic molding equipment industry (Table 26), the companies that adopted open innovation approaches have achieved higher net profit rates than those without open innovation implementations. We address the succeed of open innovation to the production type: the special equipment manufacturing industry is highly capital-intensive. The manufacturing costs and the R&D costs are relatively high in the companies of this industry. By adopting the collective R&D approaches, Yizumi was able to keep its development costs lower than the industry's average. Similarly, Borche Machinery can also make use of the data acquired from the open platform to iteratively improve its own IMM products. The lower R&D costs have contributed to the net profits of the open innovation companies.[21]

Table 26. Comparison of the plastic molding equipment manufacturers

Company	Revenue in FY2019 (thousand CNY¥) / Annual growth rate	Net profit in FY2019 (thousand CNY¥) / Annual growth rate	Implementation of open innovation
Borche Machinery	**763,977 / 10.06%**	**63,569 / 18.66%**	**Yes**
Haitian International	9,809,716 / -9.60%	1,750,651 / -8.64%	Yes
Yizumi	2,113,851 / 4.91%	196,263 / 9.01%	Yes
Chen Hsong	1,347,098 / -1.92%	89,229 / -13.23%	No
Krauss Maffei	10,576,101 / -6.44%	-158,420 / -183.07%	No

Source: Borche Machinery Co., Ltd., 2020, pp. 174-175.

Besides the innovation, we need to consider the scales of the companies in our analyses. Borche Machinery is a relatively small and entrepreneurial company in the industry. Comparing to the international giants Krauss Maffei (Germany), Engel (Austria), Fanuc (Japan), and Haitian International (China), Borche Machinery has an annual

[21] Although Haitian International also has a manufacturer network-based platform "Haitian Industry 4.0", the platform is launched much later than Borche Machinery's "iPlasCloud". The data pool of Haitian's platform should be much smaller than Borche Machinery's. Therefore, the open innovation has not yet contributed to the business performance of Haitian International.

revenue of less than 10% of any of them. When an industry is facing depression due to external reasons (the trade war between U.S. and China, for instance), the larger companies often perform better. During the interviews, Borche Machinery's staff have also mentioned that the larger companies can deal with the business cycle better (A_3, personal communication, 2018). However, that is also why Borche Machinery wanted to innovate to give an impetus to the "creative destruction". In 2007, when Borche Machinery had a very healthy income from the traditional three-platen IMMs and molds productions, it decided to invest and develop an innovative new generation IMM and drop the molds manufacturing business. In 2017, when Borche Machinery enjoyed rapid growth in both the revenue and the net profit, it decided to switch to become a service provider. According to Mr. A_1 (personal communication, 2018), Borche Machinery's business strategy is to invest during its peak in the business cycle (2007 and 2017), and to use the innovations (the two-platen IMM and the "iPlasCloud" platform) to survive the potential recession of the industry (2008 and 2018).

The creative destruction generates waves in the business cycles, but an entrepreneur should be able to invest and create some "new combination" before the recession. What Borche Machinery has done is exactly what Joseph Alois Schumpeter has suggested on dealing with the business cycles (Schumpeter, 1939, pp. 148-149).

Conclusion of Borche Machinery Co., Ltd.'s Open Innovation Approaches

In Table 27, we locate Borche Machinery's open innovation approach as an asset sharing platform that sharing the inbound and outbound knowledge flows to better utilize the existing assets.

Table 27. Borche Machinery Co., Ltd.'s open innovation approaches and results

Factors	Inbound knowledge	Outbound knowledge	Inbound resource	Outbound resource
Develop new business model (organizational innovation)	◎ Asset sharing	◎ Asset sharing		
Enter new market (market innovation)				
Improve productivity (process innovation)	(◎) (For customers)	(◎) (For customers)		
Create and capture new values (product innovation)				
Reduce costs (input and organizational innovations)	◎ Asset sharing	◎ Asset sharing		

Legend:
◎ – Succeeded in the particular innovation type with the open innovation attempts;
○ – The particular open innovation process is still in progress, but seems fruitful;
× – Failed in the particular innovation type with the open innovation attempts.

Source: Made by the author.

Borche Machinery's open innovation is an **incremental innovation** for the company itself in the Henderson-Clark model: The open platform is still based on the company's previous IMM products and previous customers in the plastic manufacturing industry. With the asset sharing platform, Borche Machinery manages and intermediates information for its customers, and improves the productivity and the utilization rate of the customers' assets. This is a new business model for both the company and its consumers. The customers are willing to join the open innovation because it can lower the risks of their equipment investments. Moreover, Borche Machinery becomes an innovation intermediary between its customers and its customers' customers. The open network helps to balance the capacities of the manufacturers, and increases the industry's sustainability. Furthermore, Borche Machinery can also apply the data and information it acquired from its end-users and the end-users' customers to iteratively improve its own products and reduce the R&D costs.

5.2.2 Case B: Ewatt Technology Co., Ltd.

Ewatt Technology Co., Ltd. (henceforth, Ewatt Technology) was a drone manufacturer located in Wuhan, Hubei. Ewatt Technology produces customized industrial drones, particularly for the State Grid Corporation of China. The company's registration information at MOFCOM[22] is shown in Table 28.

At the beginning of this section, we want to stress on that Ewatt Technology is a failed case of open innovation implementation. Ewatt Technology was a very successful vendor in a niche market – the industrial drones for smart grid. However, the company suffered from huge losses in both cash flows and human resources after it implemented the open innovation approaches in the hope of expanding its business to other market sectors. Currently, Ewatt Technology is a paper company with no active business operation, and has no sufficient assets for its proposed business scopes. Therefore, there is no auditor's report or other trustworthy data sources for the company after 2017.

[22] MOFCOM is the abbreviation of the Ministry of Commerce of China.

Table 28. The commerce registration information of Ewatt Technology Co., Ltd.

Company name:	Ewatt Technology Co., Ltd.		
Representative:	Zhao Guocheng	Registration status:	Existing (In operation, Open, Registered)
Registered capital:	CNY ¥58,155,000	Date of establishment:	2010-05-13
Stock exchange and symbol (code):	(NEEQ[23]: 834809.NQ before termination)	Date of Initial Public Offering:	2015-12-14 (Terminated on 2018-06-04)
Industrial sector:	Wholesale of other machinery and electronic products[24]	Enterprise type:	Private incorporation (Unlisted; Controlled by natural persons)
Business scope:	Development, manufacturing, sales, and testing and maintenance services of UAV (unmanned aerial vehicle) systems (including multi-rotor drones, fixed-wing drones, and unmanned helicopters). Training services of UAV pilots. Data storage services. UAV flight control system services. Sales and technical services of smart grid management systems.		

Note: As of the date of the last interview (July, 2021).

Source: Made by the author, based on the information provided by the company.

Before its failure, Ewatt Technology was an industrial drone manufacturer. Ewatt Technology had been developing and producing customized unmanned aerial vehicle (henceforth, UAV) systems since 2012. Ewatt Technology had enjoyed great successes in the niche market of smart grid. Ewatt Technology's unmanned helicopter-based electricity

[23] NEEQ is the abbreviation of the Chinese over-the-counter stock exchange system "National Equities Exchange and Quotations".

[24] Industrial classification No. I-5179 as defined in Chinese standard GB/T 4754-2017.

monitoring system was the de-facto standard of the Chinese market (Ewatt Technology Co., Ltd., 2016a, p. 2). In 2016, Ewatt Technology was the largest bid winner among the seven industrial drone suppliers of the state-owned electric utility corporation State Grid Corporation of China (State Grid Corporation of China, 2016).

Table 29. Ewatt Technology Co., Ltd.'s assets and liabilities

	FY2015 (in thousand CNY¥)	**FY2014** (in thousand CNY¥)
Current assets	**207,701**	**110,861**
Cash and cash equivalents	66,330	9,858
Notes receivables	1,165	500
Accounts receivables	123,598	63,479
Prepaid expenses	3,107	3,488
Other receivables	6,363	3,711
Inventories	7,138	29,825
Fixed (noncurrent) assets	**21,860**	**16,137**
Tangible assets	8,074	2,912
Construction in progress	531	
Intangible assets	12,604	12,863
Land tenures	12,604	12,863
Deferred taxes	651	362
Liabilities	**77,383**	**70,256**
Current liabilities	77,383	70,256
Shareholders' equity	**152,178**	**56,742**
Assets in total	**229,561**	**126,998**

Source: Ewatt Technology Co., Ltd., 2016a.

According to Ewatt Technology's financial data (Table 29), we category Ewatt

Technology as a capital-intensive firm. Ewatt Technology ran its own drone factories and UAV flight control centers, such heavy assets occupied a large amount of capital of the company. Although the weight of fixed assets was not very high (9.52% in the fiscal year 2015 (henceforth, FY2015) and 12.71% in the fiscal year 2014 (henceforth, FY2014)), the current assets were occupied mainly by receivables and inventories (66.57% in FY2015 and 87.96% in FY2014). Therefore, the assets of Ewatt Technology were not so liquid as the balance sheets hinted. In Table 30, although the other financial data in FY2015 were telling a different story, the Return on Equity (ROE) of the company was as low as what a capital-intensive firm should be. Furthermore, the Debt Asset Ratio in FY2014 also suggested the company was a capital-intensive firm.[25]

Table 30. The financial analyses of Ewatt Technology Co., Ltd. in FY2015 and FY2014

	FY2015	**FY2014**
Debt Asset Ratio	33.71%	55.32%
Current Ratio	2.68	1.58
Quick Ratio	2.59	1.15
Gross Profit Ratio (overall)	36.40%	30.95%
Net Profit Ratio (overall)	11.12%	12.11%
Return on Equity	**14.36%**	**27.12%**
Receivables Turnover Ratio	5.01	6.28
Inventory Turnover Ratio	7.29	5.31

Source: Made by the author, based on the data provided by the company.

[25] Ewatt Technology had a large amount of financing from the stock market in FY2015. This is the reason why the cash and cash equivalents increased and the Debt Asset Ratio dropped largely in 2015.

According to the income statements (Table 31), the company was on a roll in its business from 2013 to 2015. In 2012 and 2013, the company focused on the customized UAV systems for smart grids. The customized products had given the company a stable revenue, but with a low gross profit ratio (around 25%). Since 2014, the company started to apply its UAV technology in other market sectors. During 2014 and 2015, Ewatt Technology entered emergency rescue, aerial photography, aero pesticide spraying, and aerial surveying markets. The industrial drones sold in these four markets had achieved a higher GPR (around 40%) than the business with State Grid.

Table 31. The revenues and gross profit ratios of Ewatt Technology Co., Ltd.'s products

	FY2015			**FY2014**			**FY2013**		
	Revenue (thousand CNY¥)	Perce-ntage (%)	Gross Profit Ratio (%)	Revenue (thousand CNY¥)	Perce-ntage (%)	Gross Profit Ratio (%)	Revenue (thousand CNY¥)	Perce-ntage (%)	Gross Profit Ratio (%)
Industrial drones	131,910	62.30	41.39	82,643	60.52	34.94	24,092	31.18	33.58
Customized products for State Grid	79,833	37.70	28.16	53,912	39.48	24.84	53,165	68.82	26.27
Total / Overall	**211,743**	**100**	**36.40**	**136,555**	**100**	**30.95**	**645,116**	**100**	**28.55**

Source: Ewatt Technology Co., Ltd., 2016a;

Beijing Xinghua Certified Public Accountants SGP, 2015.

Nevertheless, the executive board of Ewatt Technology wanted to expand its products to even more profitable markets: for instance, the consumer drone market (Ewatt

Technology Co., Ltd., 2016b, pp. 60-61). The board believed that the company had similar or better core competencies with the other UAV manufacturers (Ewatt Technology Co., Ltd., 2016a, pp. 130-131). According to Ewatt Technology's business plan at that time, the company is aiming the consumer market: As long as the growth of the company was not as satisfactory as the drone manufacturers (such as DJI) in the consumer market, the company should enter the same market to enjoy the similar rapid growth. Since Ewatt Technology was a start-up company that did not have the sufficient capability to promote its products to the new markets, the company started to implement open innovation in its expansion (Ewatt Technology Co., Ltd., 2016a, pp. 136-137).

The Implementations and Failure of Ewatt Technology Co., Ltd.'s Open Innovation Approach

In 2016, Ewatt Technology started implementing an open innovation approach to collectively develop new products with its subsidiaries in Italy, Switzerland, and the United States, its customers, and its external suppliers. From 2016 to 2018, Ewatt Technology had more than 10 collaborative R&D teams that assigned to the development of multi-rotor drones, fixed-wing drones, and unmanned helicopters in 16 different markets.

To manage the numerous teams with members in various locations, Ewatt Technology adopted the cross-functional team (CFT) methodology to make full use of different parties in the collaboration. Ewatt Technology also adopted knowledge management methods such as the agile development methodology in order to accelerate its development in the markets that the company was unfamiliar with.

Table 32. Interviews conducted for case study B (Ewatt Technology Co., Ltd.)

	Post[26]	Date	Main Theme
Mr. B_1	CEO	August, 2016	The organizing and management of the cross-functional teams.
Mr. B_2	Production manager	August, 2016	The adoption of agile development methods in the cross-functional teams.
Mr. B_3	Directorate secretary	March, 2017	The financial status after adopting open innovation.
Mr. B_4	Managing director	July, 2021	The current situation and the reasons of failure.

Source: Made by the author.

In order to investigate the failure of Ewatt Technology's open innovation implementations, we have interviewed the company's CEO (Mr. Zhao, henceforth B_1) in August 2016; a production manager (Mr. Luo, henceforth B_2) in August 2016; a directorate secretary (Mr. Bie, henceforth B_3) in March 2017; and one of the managing directors (Mr. Liu, henceforth B_4) in July 2021. The interviews we have conducted are listed in Table 32.

It is worth mentioning that since Ewatt Technology is currently a paper company, there is no sufficient financial and technical data after FY2017. Furthermore, it was very difficult to find anyone from the company after 2018 because 1) most of them have already left the company; 2) the managerial board members are not willing to accept our interview requests[27].

[26] The posts are as of the date of the interviews.

[27] Because they are involved in the litigations with the shareholders and the creditors.

At the beginning of the implementation of open cross-functional team, it had produced some positive results mainly due to the large number of R&D teams and their broad scopes. In 2016, Ewatt Technology applied for a total of 89 invention patents – more than 22 times the company had applied during 2013 and 2015. The business performance was also satisfying. The overall GPR of Ewatt Technology had increased to 45.67% in FY2016 after the company entered the consumer markets.

Since the initial results of the open innovation were fairy promising, the company believed that it had already built comprehensive profitability from the high-margin consumer markets through the R&D investments (B_1, personal communication, 2016). However, the operating costs of Ewatt Technology were increasing rapidly at the same time. The company addressed the reason of high operating costs as the increasing of sales expenses in the new markets and R&D expenses of the many R&D teams – which should benefit the revenue in the coming fiscal years. In fact, Ewatt Technology was very optimistic during the first year of its open innovation implementation, believing that the expansion in its sales team and the R&D investments would lay a good foundation for the rapid growth in the coming future (B_4, personal communication, 2021).

As we have mentioned, Ewatt Technology was a capital-intensive manufacturer that required a large amount of capital input in its production. However, after the vast investments in so many different collaborative R&Ds, the temporal debt-asset ratio of the company had exceeded 90% in 2017 (B_3, personal communication, 2017), which is very unhealthy even for a knowledge-intensive firm. Mr. B_3 had already found it difficult to operate the company with an exhausted cash flow, and was trying to introduce new investors to invest the company.

Unfortunately, the emergency financing did never work out. As the result, the situation of Ewatt Technology got even worse in 2018. The company had run out of cash flow during the 1H2018 (see Table 33, the cash and cash equivalents dropped by 90.8%), and had to apply for terminating from the stock market in 2018[28]. The company was somehow kept its operations in 2018, but then collapsed without warning.

Table 33. Ewatt Technology Co., Ltd.'s assets and liabilities after FY2017 (unaudited)

	1H2018 (in thousand CNY¥)	**FY2017** (in thousand CNY¥)
Current assets	**254,188**	**110,861**
Cash and cash equivalents	13,602	148,572
Notes receivables	130	11,507
Accounts receivables	159,253	127,656
Prepaid expenses	8,414	12,015
Other receivables	20,032	7,965
Inventories	52,757	18,761
Fixed (noncurrent) assets	**185,558**	**63,942**
Tangible assets	15,126	9,216
Construction in progress	67,087	14,589
Intangible assets	16,491	14,661
Deferred taxes	915	915
Liabilities	82,044	83,356
Shareholders' equity	357,701	189,330
Assets in total	**439,745**	**272,686**

Source: Made by the author, based on the financial data provided by the company.

[28] After delisting from the stock market, there is no duty for B to publish an annual auditor's report. Therefore, it can conceal its bad financial situation from the investors.

According to the interviews with Ewatt Technology's managing director Mr. B_4 (personal communication, 2021), the company's failure was mainly due to the bad practices of the internal innovation process management. The cross-functional team with staff from different departments seems to be a good sphere for internal and external knowledge exchange. However, in practice, the company's cross-functional teams were full of conflicts and chaos.

In fact, as many previous research papers (Boehm, 2002; Conboy & Morgan, 2011; Remneland-Wikhamn, et al., 2011; etc.) suggest, the knowledge management mechanisms, such as the agile development and the cross-functional team that Ewatt Technology applied in its R&D workflows, are not compatible with the open innovation paradigm. Open innovation focuses on increasing internal and external contacts to promote new combinations. In contrast, the knowledge management mechanism focuses on an iterative and incremental development logic that only accelerates the internal knowledge transfer. The iterative agile development is usually too fast for external staff from different working cultural backgrounds to fit in.

Mr. B_2 (personal communication, 2016) had already noticed and mentioned the mismatching of the cross-functional team management methods and the knowledge management methods during our interview in 2016. Although Mr. B_2 was generally optimistic and believed the problem will be solved at that time, the communication issues became more and more significant as the R&D projects went on. Eventually in 2017, the foreign experts, who are the core inventors of a wide range of the company's patents, left Ewatt Technology's Italy and U.S. subsidiaries after failing to cooperate with the other peers in the cross-functional teams. After the core developers' withdrawal from the cross-functional teams, the R&D projects could no longer produce any meaningful results.

Moreover, Ewatt Technology's open innovation approach is too ambitious and too broad for a start-up company to implement. Mr. B_4 has mentioned another drone company named Skycam Technology Co., Ltd. (henceforth, Skycam) in the interview (B_4, personal communication, 2021). Founded in 2004, Skycam was also a drone manufacturer focusing on a niche market: the anti-drug patrol drones. After dominated the niche market like Ewatt Technology, Skycam still followed the in-house innovation methodology and expanded to the nearby market sectors one by one. As the result, Skycam achieved a steady growth and became the first listed company in the Beijing stock exchange market in 2021.

Conclusion of Ewatt Technology Co., Ltd.'s Open Innovation Approach

As shown in Table 34, the cross-functional team that is made up of internal and external peers was the open innovation approach of Ewatt Technology. The company aimed to develop some new technologies to enter a red ocean – the consumer drone market which is not familiar for them, therefore we can define Ewatt Technology's open innovation approach as a **modular innovation** in the Henderson-Clark model.

However, Ewatt Technology's open innovation attempts failed due to the inappropriate managerial mechanism of open innovation. Open cross-functional team with agile development was proved to be a bad practice for a commercial company to adopt the open innovation paradigm. Furthermore, Ewatt Technology had invested too much in the R&D activities to keep a healthy financial balance. If Ewatt Technology was challenging the new technologies and new markets one by one, the story might be different.

Table 34. Ewatt Technology Co., Ltd.'s open innovation approaches and results

Factors	Inbound knowledge	Outbound knowledge	Inbound resource	Outbound resource
Develop new business model (organizational innovation)				
Enter new market (market innovation)				
Improve productivity (process innovation)				
Create and capture new values (product innovation)	× Open CFT	× Open CFT	× Open CFT	× Open CFT
Reduce costs (input and organizational innovations)				

Legend:

◎ – Succeeded in the particular innovation type with the open innovation attempts;

○ – The particular open innovation process is still in progress, but seems fruitful;

× – Failed in the particular innovation type with the open innovation attempts.

Source: Made by the author.

Nevertheless, this case was one of the earliest cases in China that a commercial company introduced the open innovation approach in a global distributed network. The entrepreneurs and managers were not familiar with the concepts and the best practices of open innovation. While Ewatt Technology had failed in its open innovation attempts, there are successful cases after its failure – for instance, the next case.

5.2.3 Case C: Shenzhen Han's Robot Co., Inc.

Shenzhen Han's Robot Co., Inc. (henceforth, Han's Robot) is the youngest start-up company among the cases in this research. The headquarter of Han's Robot is located in Shenzhen, Guangdong. The company has a German subsidiary in Metzingen, Germany which focuses on R&D; two sales departments in Tianjin and Singapore; and a factory in construction in Foshan, Guangdong. Han's Robot's registration information at MOFCOM[29] is shown in Table 35.

Table 35. The commerce registration information of Shenzhen Han's Robot Co., Inc.

Company name:	Shenzhen Han's Robot Co., Inc.		
Representative:	Wang Guangneng	Registration status:	Existing (In operation, Open, Registered)
Registered capital:	CNY ¥81,802,721	Date of establishment:	2017-09-07
Industrial sector:	Other general equipment manufacturing[30]	Enterprise type:	Limited Liability Company
Business scope:	Development, manufacturing, sales, and technical services of robots. Development, system integrations, sales, and technique services of machinery system, electrical system, and automation equipment as well as their related software. Development and technique services of medical equipment. Import and export business.		

Note: As of the date of the last interview (August, 2021).

Source: Made by the author, based on the information provided by the company.

[29] MOFCOM is the abbreviation of the Ministry of Commerce of China.

[30] Industrial classification No. I-5179 in the Chinese standard GB/T 4754-2017.

Han's Robot is a robotic manufacturer incubated by a listed company named Han's Laser (stock code: 002008.SZ). Han's Laser group funded a R&D institute in its industrial park. The institute allows the group's employees to do research and development on projects that are not in Han's Laser's business scope but somehow related to its business. The prospective projects will be invested and incubated by Han's Laser group's corporate incubator, and can either be acquired by the group or become an independent company. Han's Laser group allows the founders of the projects to acquire its shares of the independent company at a reasonable price. While Han's Laser's incubator is also a very promising open innovation approach suggested by many scholars ("Corporate Incubator" in Latouche, 2019; "Corporate Venture Capital" in Takei, Saeki, & Nagae, 2019; etc.), this research will focus on Han's Robot's open innovation strategy.

Since it is incubated by Han's Laser's incubator, Han's Robot used to be a 100%-owned subsidiary of Han's Laser group when it was established. During February 2018 and May 2021, the project leaders Mr. Wang and Mr. Zhang acquired most (about 72%) of the shares from Han's Laser group at a relatively low price (around CNY ¥3 per share in average). Han's Laser group plans to further reduce its shares in Han's Robot to make the company an independent company that can apply initial public offering itself eventually.

Although we categorized Han's Robot as a capital-intensive manufacturer, it is rather asset-light in the robotic manufacturing industry at present. In Table 36, we compare Han's Robot with two listed companies in the same industrial sector: Siasun Robotics & Automation Co., Ltd., the largest industrial robot manufacturer in China; KUKA Aktiengesellschaft, one of the top robotic vendors in the world. Due to the COVID-19 pandemic and the depression in all sectors of manufacturing, all the three companies were in the red last year[31].

Table 36. Comparison of the financial performances of companies in the robotic manufacturing industry in the fiscal year 2020

(FY2020)	Han's Robot[32]	Siasun Robotics	KUKA AG
Current assets	¥[redacted]4,862,606.41	¥7,032,020,525.50	€1,819,800,000.00
Inventories	¥[redacted],952,846.86	¥3,379,219,008.95	€307,900,000.00
Fixed (noncurrent) assets	¥[redacted],657,933.62	¥3,744,945,039.33	€1,296,700,000.00
Tangible assets	¥[redacted],396,408.05	¥1,584,348,522.30	€353,100,000.00
Intangible assets	¥[redacted],578.88	¥562,841,490.80	€533,300,000.00
Revenues	¥[redacted],632,355.76	¥2,659,636,080.48	€2,573,500,000.00
Operating Costs	¥[redacted],538,933.38	¥2,148,018,278.94	€2,069,400,000.00
Debt Asset Ratio	(Less than 20%)	55.72%	61.38%
Current Ratio	(Between 4 and 8)	1.49	1.42
Quick Ratio	(Between 3 and 6)	0.72	1.18
Gross Profit Ratio (overall)	[redacted].33%	19.25%	19.59%
Net Profit Ratio (overall)	-[redacted].43%	-14.88%	-3.68%

Note: ¥ is the symbol of Chinese Yuan; € is the symbol of Euro.

Source: Made by the author. Based on the data provided by Han's Robot; Siasun Robotics & Automation Co., Ltd., 2021; and KUKA Aktiengesellschaft, 2021.

From the financial comparison (Table 36) of the robotics companies in the fiscal year 2020 (henceforth, FY2020), it is obvious to address Siasun and KUKA as capital-

[31] Therefore, the Returns on Equity of the three companies are negative.

[32] According to the non-disclosure agreement, some of the numbers are redacted.

intensive firms: they have large amounts of fixed assets; the Debt Asset Ratios are high. On the contrary, Han's Robot's financial data suggests it to be an asset-light knowledge-intensive company. However, this is because of the open innovation approaches between the company and its former controlling shareholder Han's Laser group. Han's Robot does not own the factory and equipment for its manufacturing. Instead, Han's Robot rents them from Han's Laser's industrial park. Nevertheless, after the company's independence, Han's Robot will construct its own factory and purchase its own devices in 2022. Therefore, Han's Robot will become a capital-intensive firm like the other companies in this industry.

The collaborative robots are Han's Robot's main products. As shown in Table 37, the collaborative robots have occupied more than 80% of the company's sales in the first half of the fiscal year 2021 (henceforth, 1H2021). Han's Robot has the ability to develop and produce five of the six core components of the collaborative robot independently: the servo motor, the servo drive, the controller, the encoder, and the force/torque sensor. Han's Robot is not able to produce the last component – harmonic drive – of the collaborative robot itself. However, there is another group company named Han's Motion from the Han's Laser group that can provide the necessary harmonic drive for Han's Robot to develop and manufacture its collaborative robots.

Table 37. The sales data of Han's Robot Co., Inc. in 1H2021[33]

Customer	Product	Orders in hand (thousand CNY¥)
W[redacted] (A European wholesaler)	**Collaborative robots**	[redacted],280
Q[redacted] (A robotic system integrator)	**Collaborative robots**	[redacted],000
H[redacted] (A motor manufacturer)	Servo drives (parts)	[redacted],910
G[redacted] (A robotic system integrator)	**Collaborative robots**	[redacted],400
M[redacted] (A clinical device manufacturer)	Cartesian robots	[redacted],800
H[redacted] (An air conditioner manufacturer)	**Collaborative robots**	[redacted],000
H[redacted] (A Korean manufacturer)	**Collaborative robots**	[redacted],990
Q[redacted] (An airport)	**Collaborative robots**	[redacted],470
Others	**Collaborative robots**	[redacted],150
Total		**1[redacted],000**

Source: Made by the author, based on the data provided by Han's Robot.

Han's Robot Co., Inc.'s Open Innovation Implementation and Results

Born with open innovation genes, Han's Robot has implemented a lot of practices following the open innovation paradigm. In this research, we will mainly discuss Han's Robot's open innovation implementation in globally distributed R&D, which is very similar to Ewatt Technology (case B)'s failed approach.

To analyze the open innovation implementation of Han's Robot, we have acquired and analyzed financial data in FY2019, FY2020, and 1H2021 from the company. We have also interviewed the co-founder and the CEO of Han's Robot (Mr. Wang, henceforth C_1),

[33] According to the non-disclosure agreement, some of the names and numbers are redacted.

the co-founder and the CTO of Han's Robot (Mr. Zhang, henceforth C_2), the CEO of Han's Robot's German subsidiary (Mr. Reger, henceforth C_3), the sales manager of Han's Robot (Mr. Zhao, henceforth C_4), and one of Han's Robot's customers (Mr. Wu from a sanitary manufacturer; henceforth C_5). The interviews we have conducted are listed in Table 38.

Table 38. Interviews conducted for case study C (Shenzhen Han's Robot Co., Ltd.)

	Post[34]	**Date**	**Main Theme**
Mr. C_1	CEO	July, 2021 August, 2021	The company's open innovation business strategy.
Mr. C_2	CTO	August, 2021	The reasons to stop in-house R&D and cooperate with external providers instead.
Mr. C_3	CEO of the German subsidiary	August, 2021	Open innovation made it possible to adopt agile development in hardware manufacturing.
Mr. C_4	Sales manager	August, 2021	Leave and open up some less profitable markets to avoid fierce competition in Han's Robot's main market.
Mr. C_5	(Customer)	August, 2021	The good compatibility is the reason to choose Han's Robot's product.

Source: Made by the author.

As of the date of the last interview (August, 2021), Han's Robot has more than 280 employees. They are working in the Shenzhen headquarter (around 200), the Northern China subsidiary in Tianjin (around 10), and the German subsidiary in

[34] The posts are as of the date of the interviews.

Metzingen (around 60) and Hamburg (less than 10). While all the mass-production is done in Shenzhen headquarter[35], the in-house R&D workflows are distributed among the four locations. As for the core competencies of the company, the servo motor, servo drive, and controller are developed by the Shenzhen R&D team. The robot mechanical structure, the encoder and the force/torque sensor are developed in the two German locations.

Furthermore, the five core competencies of Han's Robot are fairly heterogeneous. In order to develop all of them, the company has a wide range of different R&D workflows including the mechanical design, the microelectronics design, the cybernetics design, the sensor technology, the automation technology, and the artificial intelligence technology. There are more than 150 engineers from 19 different countries currently working for Han's Robot's R&D projects. They have different cultural, academic, and working backgrounds. They are familiar with different R&D approaches and tools. It is almost impossible to organize them together with the traditional knowledge management methodology. Therefore, the first challenge for Han's Robot's R&D strategy is to organize the distributed peers in a discretely distributed innovation network.

Although the situation Han's Robot faces is quite similar to Ewatt Technology (case B), Han's Robot has managed to develop an open innovation implementation to manage the culturally, technologically, and geographically distributed innovation network. According to Mr. C_1 (personal communication, 2021a) and Mr. C_3 (personal communication, 2021), the open innovation methods adopted by the company have enabled the R&D teams to cooperate better. Similar to Ewatt Technology (case B), Han's

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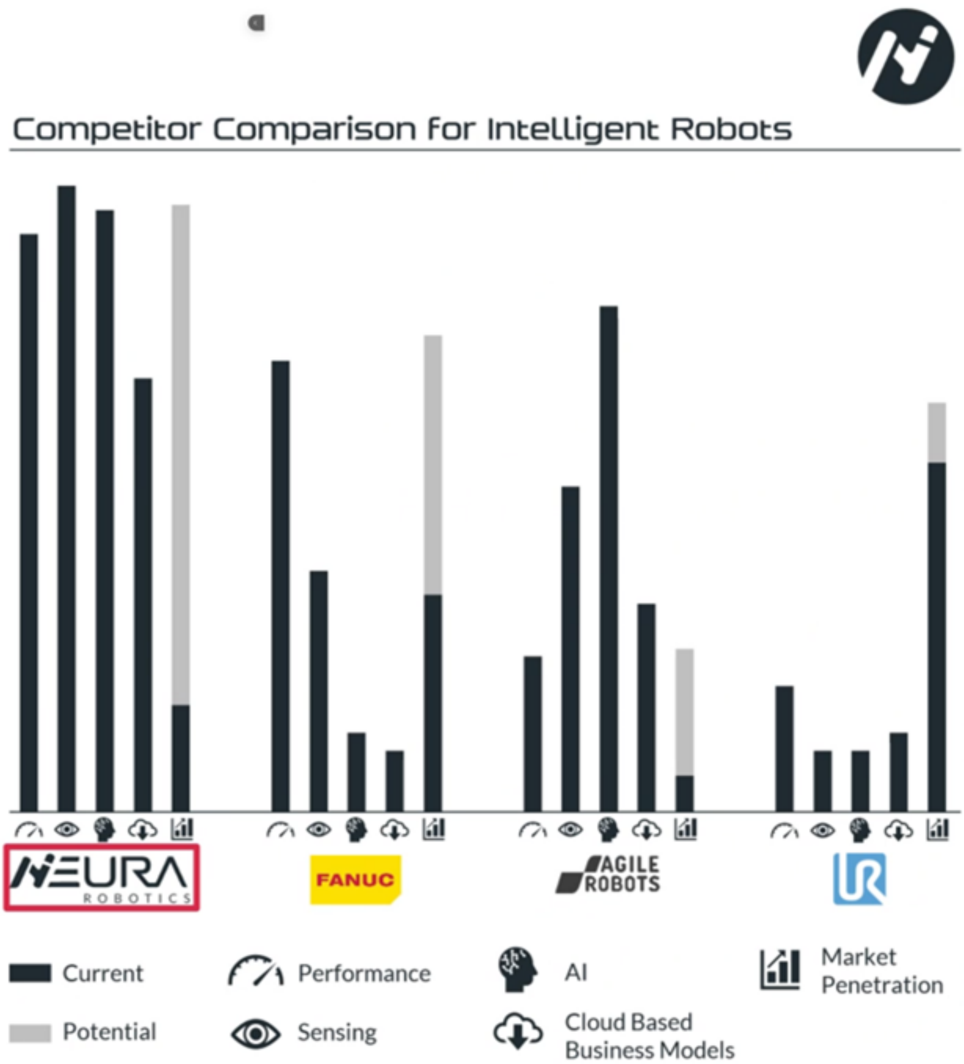
[35] Currently, the manufacturing of core components and the final assembling of robots are all done in Han's Laser's factory in Shenzhen. The company plans to move them to its own factories in Foshan, 2022.

Robot also adopts the agile development methodology in its R&D workflows. However, Han's Robot has modified the original agile development practice suggested by Nonaka & Takeuchi (1995). Instead of a cross-functional team like what Ewatt Technology (case B) has implemented, Han's Robot divided the R&D projects into small scrums. The division of scrums is designed and decided by a group of executives from both the R&D department and the sales & product center. Each scrum has only a few engineers with similar backgrounds assigned in the same location. Scrums are required to work closely with both the internal and external nodes including the other scrums, the external suppliers, the technical salesmen, and end-users of Han's Robot's products. But the performance of each scrum is evaluated only with their own achievements. Therefore, each scrum has the freedom to work with the members' familiar development methods, development tools, and even the working times (C_2, personal communication, 2021). The open agile development methodology relaxes the heterogeneous requirements of traditional knowledge management-based agile development procedures. In fact, the open agile development practices can even make full use of the plurality of the nodes in the network (C_3, personal communication, 2021).

The open agile development methodology adopted by Han's Robot has significantly accelerated its development. The start-up company with less than four years' history has developed the world's best collaborative robots (Figure 33) – better than the competitors including the giants Fanuc, Yaskawa, ABB, and KUKA. Thanks to the open innovation implementations, the German subsidiary of Han's Robot has successfully developed the seven-axis robotic arm (with the top speed and precision in the robotic industry), the high-quality force/torque sensor (with ten times precision than the second in the robotic industry), and the world's first grating encoder that can work with different harmonic drives, in only two years.

Figure 33. The comparison of specs between Han's Robot Co., Inc.'s product (in red box) and its competitors



Source: Data provided by Mr. C_3.

The managers of Han's Robot (Mr. C_1, Mr. C_2, and Mr. C_3) have particularly stressed on the importance of interpersonal communication in organizing open innovation with the globally distributed agile teams. According to the managers, the German teams and the Chinese teams were visiting each other at least once a month before the COVID-19 pandemic. Due to the quarantine regulations and the restrictions on international flights, they cannot meet as frequently as it was in 2019. Although they are keeping in contact through internet conferences and centralized knowledge-bases, they have still found the lack of face-to-face communication to be influential. In fact, the insufficient amount of interpersonal communication has led to some problems in the mass-production processes of their new generation robots, which will be introduced later.

Han's Robot's open innovation business strategy also encourages the use of external resources. Both Mr. C_1 (personal communication, 2021b) and Mr. C_2 (personal communication, 2021) have mentioned that they have tried to develop their own harmonic drive, the last core component of the collaborative robot. However, they eventually decided to abandon the in-house development and purchase from the external suppliers instead. Mr. C_1 has pointed out that the in-house development cannot reduce the costs – instead, purchasing from the external suppliers is usually the cheaper and safer solution.

The executives of Han's Robot (Mr. C_1, Mr. C_2, and Mr. C_4) have also claimed that the capability of developing is more important than in-house development itself. With the capability of developing collaborative robots' core components, the R&D team has a better understanding of the robot architecture which gives them more creativity in imagination new types of robots. Nevertheless, such "capability" can be acquired from the external knowledge. While Han's Robot abandoned to develop its own harmonic drive, the company is still employing researchers on harmonic drive and sending them to the external suppliers to take part in their collective R&D projects.

Thanks to its open mind in allowing external resources, the production model of Han's Robot is also very open and flexible. As we have introduced, the company is producing its own servo motors, servo drives, controllers, grating encodes, and sensors for its collaborative robot products. However, the company is also open to purchasing components from the external suppliers in case the external resources fit the customers' needs better. For instance, in order to deliver a rapid order in January 2021, the company purchased a large volume of parts from external suppliers because the order exceeded its own production capacity (C_1, personal communication, 2021a). Under the open innovation paradigm, Han's Robot's products are designed to have the ability to replace most of its parts. The excellent compatibility of Han's Robot's products helps the company to adopt flexible production planning.

The customers love Han's Robot's products because of the extraordinary compatibility with other industrial devices. According to the introduction of its customer Mr. C_5 (personal communication, 2021), Han's Robot is the only provider that has supports for all the different industrial interfaces used in C_5's factory. Therefore, C_5's factory did not have to replace its existing equipment when introducing the collaborative robots from Han's Robot.

Not only in R&D and mass-production, Han's Robot also adopts an open business model in its sales strategy. Unlike many other collaborative robot manufacturers that prefer the direct sales business model to cut the middlemen and enjoy a higher margin, Han's Robot is willing to coexist and cooperate with the system integrators (C_4, personal communication, 2021).

From the interviews, we can evaluate Han's Robot's open innovation implementation as highly successful. In the meanwhile, some recent mass-production issues might suggest the limitation of the company's open agile development implementation.

Although Han's Robot has released its latest seven-axis collaborative robot product last year, it is still not able to mass-produce the new generation robots. The German engineers have the know-how of manufacturing seven-axis robots, but they are not able to come and instruct the mass-production in Shenzhen due to the travel restrictions during the COVID-19 pandemic. The Chinese engineers have tried test-production for months through remote communications with the German teams, but still cannot succeed in some special manufacturing processes.

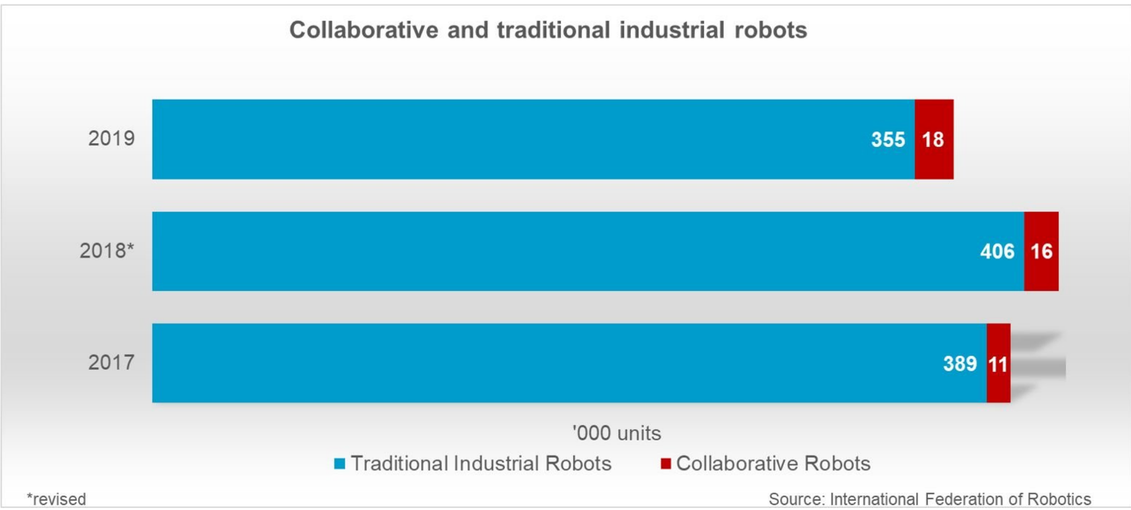
The production crisis of the company suggests that while open agile development is an excellent approach in R&D and product innovation (creating and capturing the new values), the lack of in-depth communication (due to the COVID-19, though) may limit its ability in process innovation (improving the productivity). Furthermore, the mass-production might be a potential weak point of the open agile development approach, and might also hinder the chances for other manufacturers to adopt a similar open innovation approach.

Conclusion of Han's Robot Co., Inc.'s Open Innovation Approach

Han's Robot adopts a revised open agile development methodology as its open innovation approach. Han's Robot's agile development procedures are different from the traditional knowledge management theory has suggested. The minimum scrums involved in virtual teams (Lipnack & Stamps, 1997) avoid the limitations of cross functional team practices (which led to the failure of Ewatt Technology). However, while the open agile development has achieved great success in R&D workflows, it failed in the mass-production at the time of the interviews. Therefore, we locate Han's Robot's open innovation approach as an open agile development approach that actively and purposively makes use of the inbound and outbound flows of knowledge and resources.

Han's Robot is a typical case of **radical innovation** in the Henderson-Clark model: the new technology (collaborative robots) and the new market (collaborative robot market). The collaborative robot was invented in 1996 and not commercialized until 2008. According to the annual report of international federation of robotics (2020), the market share of collaborative robot is still as small as 18,000 units or 4.8% of the global industrial robot market in 2019 (Figure 34). In China, the collaborative robot market is about 8,000 units or ¥1.2 billion CNY per year (Yano Research Institute, 2021). Both the technology and the market are new enough to define Han's Robot's business attempt as a radical innovation.

Figure 34. The market scales of collaborative robots and industrial robots



Source: International Federation of Robotics, 2020.

The factors involved in Han's Robot's open innovation implementation as well as the results are shown in Table 39. Through the use of inbound knowledge, outbound knowledge, inbound resources, and outbound resources, Han's Robot has successfully developed advanced robotic components and collaborative robots in the initial stage of R&D. However, the mass production of the R&D achievement in the latter stage was not as good as the product innovation in Han's Robot's open innovation implementation.

Table 39. Han's Robot Co., Inc.'s open innovation approaches and results

Factors	Inbound knowledge	Outbound knowledge	Inbound resource	Outbound resource
Develop new business model (organizational innovation)				
Enter new market (market innovation)				
Improve productivity (process innovation)	× Open agile development	× Open agile development	× Open agile development	× Open agile development
Create and capture new values (product innovation)	◎ Open agile development	◎ Open agile development	◎ Open agile development	◎ Open agile development
Reduce costs (input and organizational innovations)				

Legend:

◎ – Succeeded in the particular innovation type with the open innovation attempts;

○ – The particular open innovation process is still in progress, but seems fruitful;

× – Failed in the particular innovation type with the open innovation attempts.

Source: Made by the author.

Although we evaluate Han's Robot's attempts in process innovation as failed, things might be different if we do not have the COVID-19 pandemic. Regardless, Han's Robot's successful attempts in product innovation have broken the superstition on the combination of agile development with open innovation. Nevertheless, Han's Robot proves that an asset-heavy manufacturer can adopt the open innovation paradigm.

5.2.4 Case D: Hubei Prolog Technology Co., Ltd.

Hubei Prolog Technology Co., Ltd.[36] (henceforth, Prolog Technology) is a logistics solution provider located in Wuhan, Hubei[37]. Prolog Technology designs, constructs, and runs the fully-managed warehouses for its customers. As of the date of the last interview, Prolog Technology has 16 subsidiaries in 12 provinces of China. Most of its subsidiaries own and operate the warehouses of the company. Prolog Technology's registration information at MOFCOM[38] is shown in Table 40.

Prolog Technology has registered a wide range of business scopes because the company has changed its business model and switched its business strategies several times. Prolog Technology was a software developer when it was established in 2012. Before the fiscal year 2014 (henceforth, FY2014), the software products and the software integration services accounted for more than 95% of the company's revenues (for instance, the software development related revenue was CNY ¥19,473,800 in FY2014, took up 95.7% in the company's total revenue of CNY ¥20,357,400).

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[36] The company has been migrated to Hubei Province and renamed to the current name "Hubei Prolog Technology Co., Ltd." on December 24, 2018.

[37] The company was registered in Beijing when we conducted the interviews. But the headquarter of the company had already been migrated to Wuhan, Hubei at that time.

[38] MOFCOM is the abbreviation of the Ministry of Commerce of China.

Table 40. The commerce registration information of Prolog Technology Co., Ltd.

Company name:	Beijing Prolog Technology Co., Ltd.		
Representative:	Zhou Zhigang	Registration status:	Existing (In operation, Open, Registered)
Registered capital:	CNY ¥59,560,000	Date of establishment:	2012-01-16
Stock exchange and symbol (code):	(NEEQ[39]: 870279.NQ before termination)[40]	Date of Initial Public Offering:	2017-01-12 (Terminated on 2018-06-16)
Industrial sector:	Other technology promotion services[41]	Enterprise type:	Other incorporation (Unlisted)
Business scope:	Technology promotion services. Software development services (development of basic software systems and applications; excluding medical software). Management services for cultural and industrial parks. Convention and exhibition services. Data processing, storage, and application services. Consulting services of business and trade management. Sales and installation of computer software and related equipment, electronic equipment, and mechanical equipment. Warehousing services (excluding hazardous chemical warehouses). Packaging services (excluding gas packaging). Market research services. Import and export business. General cargo transportations.		

Note: As of the date of the last interview (September, 2018).

Source: Made by the author, based on the information provided by the company.

[39] NEEQ is the abbreviation of the Chinese over-the-counter stock exchange system "National Equities Exchange and Quotations".

[40] The company terminated from NEEQ as a part of its migration.

[41] Industrial classification No. M-7590 as defined in Chinese standard GB/T 4754-2017.

In 2014, the company started to adopt an open innovation approach by launching the sharing warehouse service named "Intplog Cloud Warehouse". In the first half of the fiscal year 2017, the "Intplog Cloud Warehouse" and its related services became the main business of the company and achieved a revenue of CNY ¥64,734,000 (occupied 97.5% of the total revenue CNY ¥76,653,300 in 1H2017).

The "Intplog Cloud Warehouse" is a fully-managed logistic solution. Through the supply chain analysis, the warehouse designing, the supply chain and logistics software development, the automation system integration, the warehouse operation and other services, Prolog Technology provides its customers with fully-managed all-in-one logistics and supply chain management services.

As a warehouse service provider, Prolog Technology is a typical labor-intensive firm. At the time of the interviews, nearly half of its long-term employees (Table 41) and almost all its part-time employees were in the warehouse operation department.

Table 41. The personnel composition of Prolog Technology Co., Ltd. in 2018

Department	**Number (percentage) of long-term employees**
Warehouse operation	177 (48.0%)
Software R&D	71 (19.2%)
Technical sales	65 (17.6%)
Hardware R&D	20 (5.4%)
Sales	18 (4.9%)
HR and training	8 (2.2%)
Accounting	6 (1.6%)
Business management	4 (1.1%)

Source: Made by the author, based on the data provided by the company.

However, as Prolog Technology owned more than 130,000 square kilometers' warehouses in big cities including Beijing, Shanghai, Guangzhou, Wuhan, and Chengdu, the company also had a relatively high portion of fixed assets at the time of the interviews. In the financial data of FY2017, the value of its warehouses (CNY ¥142,328,519.72) accounted for 80.3% of its total tangible assets (while the intangible assets accounted for only 0.3%), and its gross profit rate was also relatively low (13.69%). Nevertheless, the company still enjoyed a relatively low dept asset ratio (26.12%) in FY2017. According to the financial analyses, we define Prolog Technology as a labor-intensive company, since its main service (the full-managed logistic service) is a typical labor-intensive business.

As we will introduced later, the basic idea of sharing warehouse is the dynamic (re)allocation of the heavy assets to make better use of the fixed properties. The dynamic reallocation of assets requires as much market information as possible. This is why Prolog Technology adopts an open innovation approach in running its sharing warehouse: to make use of inbound and outbound information flows.

Prolog Technology Co., Ltd.'s Open Innovation Implementation and Results

To analyze the open innovation implementation of Prolog Technology, we have acquired and analyzed the financial data and the operation data in FY2016 and FY2017. We have also acquired some technical data of "Intplog Cloud Warehouse" from the company. In addition, we have conducted several in-depth interviews with the CEO (Dr. Zhou, henceforth D_1), the chief automation engineer (Mr. Lu, henceforth D_2), the head of software department (Mr. Ma, henceforth D_3), and a technical salesman (Mr. Meng, henceforth D_4). The interviews we have conducted are listed in Table 42.

Table 42. Interviews conducted for case study D (Hubei Prolog Technology Co., Ltd.)

	Post[42]	Date	Main Theme
Dr. D_1	CEO	August, 2018	The business model of sharing warehouse.
Mr. D_2	Chief automation engineer	September, 2018	The improvement of utilization rates and productivity. The root of the company's open innovation (open source) strategy.
Mr. D_3	Head of software department	September, 2018	The comparison between the traditional architectures of logistic management solution and Prolog Technology's flexible software design.
Mr. D_4	Technical salesman	August, 2018	The reasons of user acceptance: costs and benefits.

Source: Made by the author.

According to the introduction by Dr. D_1 (personal communication, 2018), the concept of sharing warehouse is based on a finding of his research on logistic management. Different suppliers usually have different utilization cycles of the warehouse. When a supplier faces a shortage in warehouse space, there is always another one (in a different industry, sequence, etc.) that has its warehouse idle. A warehouse is not only a large amount of fixed property but also requires a large number of logistic staff to operate. By sharing a warehouse between parties with different utilization cycles, the turnover rates of both the capital assets K and the labor resources L can be improved, and thus the productivity of the warehouse can be enhanced (see Table 43).

[42] The posts are as of the date of the interviews.

Table 43. The comparison between sharing warehouse ("Intplog Cloud Warehouse") and dedicated warehouses

	Intplog Cloud Warehouse		**Traditional Warehouses**	
	Low workload (10,000 shipment/day)	High workload (100,000 shipment/day)	Low workload (10,000 shipment/day)	High workload (100,000 shipment/day)
Required labor input L (average person/day)				
Pickers	11	118	26	274
QC staff	13	108	23	216
Packaging staff	25	236	33	444
Total	**49**	**462**	**82**	**934**
Labor cost per day	¥12,857.60	¥107,184.00	¥21,516.80	¥216,688.00
Labor productivity				
Shipments per person	204.08	216.45	121.95	107.07
Labor cost per shipment	¥1.29	¥1.07	¥2.15	¥2.17
Fixed costs per shipment	¥0.38[43]	¥0.38[36]	[44]	[37]
Average cost per shipment	**¥1.67**	**¥1.45**	**¥2.15**	**¥2.17**

Note: ¥ is the symbol of Chinese Yuan.

Source: Data provided by Prolog Technology Co., Ltd., 2018.

[43] The system fees to use the Intplog Cloud Warehouse (pay-per-use); which are usually counted as the operation costs in the financial data.

[44] The main fixed costs of a traditional warehouse are the real estates and the equipment, which are usually counted as tangible assets in the financial reports.

By improving the turnover rate, Prolog Technology has achieved the top warehouse utilization rate in the logistics industry (D_4, personal communication, 2018). The high turnover rate also means the low marginal cost. The innovative assets-sharing warehouse system also enables the company to set an aggressive price (the labor fees and the system fees in Table 43) that is even lower than the average cost of the logistic industry. According to Mr. D_4, the company's warehouse service is the cheapest solution in the Chinese market.

Furthermore, the assets-sharing open innovation strategy also changed the production function of the warehouse business. Traditionally, the warehouse generates diminishing marginal productivity. As shown in Table 43, for a traditional warehouse operation, the marginal cost in a high workload situation is higher than when the workload is low. In the meanwhile, the sharing warehouse is able to achieve the economies of scale. By sharing the illiquid assets and labor resources, the sharing warehouse system is more flexible and scalable than the traditional warehouses. Therefore, the sharing warehouse performs better in a complex and rapid-changing business network – for instance, the e-commerce.

However, such asset allocating strategy requires the understanding of each customer's profile and utilization cycle. Therefore, Prolog Technology has committed to a business model that only provides the fully-managed warehouse solution (D_1, personal communication, 2018). Traditionally, the logistic solution providers provide the logistic management software systems; the customers design and construct the warehouses; and the logistic service providers run the customers' warehouses with the third-party systems (D_3, personal communication, 2018). On the contrary, Prolog Technology offers an all-in-one solution. As an innovative pioneer in the logistic industry, Prolog Technology designs and builds both the software and hardware of its own warehouse systems, and operates all its warehouses directly. Therefore, the company can make use of the existing user data in its profiling of the future customers (D_2, personal communication, 2018).

Although Prolog Technology is an asset-heavy and labor-intensive logistics company at present, it was an asset-light software company until 2014. The know-how of open innovation acquired at that time has helped the company in implementing and operating its open innovation practices in the new businesses (D_2, personal communication, 2018).

Conclusion of Prolog Technology Co., Ltd.'s Open Innovation Approach

Prolog Technology's open innovation approach is the public ownership through its sharing warehouse service. The public ownership makes it possible to share the fixed assets among clients with different utilization cycles, and thus increase the utilization rate of the heavy assets warehouses. Therefore, as an open innovation implementation, the public ownership can reduce the costs of owning assets, and the assets sharing platform itself creates a new business model to provide small business owners with a better and more customized logistic solution.

In Table 44, we locate Prolog Technology's open innovation implementation as a public ownership approach in reducing costs (by improving the turnover rates) and developing a new business model. According to its business strategy, Prolog Technology only provides the fully-managed logistics solution and does not make use of the outbound knowledge.

Table 44. Prolog Technology Co., Ltd.'s open innovation approaches and results

Factors	Inbound knowledge	Outbound knowledge	Inbound resource	Outbound resource
Develop new business model (organizational innovation)			◎ Public ownership	◎ Public ownership
Enter new market (market innovation)				
Improve productivity (process innovation)				
Create and capture new values (product innovation)				
Reduce costs (input and organizational innovations)	◎ Public ownership		◎ Public ownership	◎ Public ownership

Legend:

◎ – Succeeded in the particular innovation type with the open innovation attempts;

○ – The particular open innovation process is still in progress, but seems fruitful;

× – Failed in the particular innovation type with the open innovation attempts.

Source: Made by the author.

We define Prolog Technology's open innovation type as an **architectural innovation** in the Henderson-Clark model: Prolog Technology does not develop or exploit any new technology in creating the new business model. However, with the innovative sharing warehouse service, the company can attract customers who are not able to afford the customized private warehouse. Particularly, small and middle-sized enterprises have joined the market after the launch of Prolog Technology's affordable customized logistic service "Intplog Cloud Warehouse". Therefore, Prolog Technology is using its existing technology (developed and delivered during 2012 to 2014) in a new SME-oriented market.

Furthermore, the innovative sharing warehouse system also sets up a new production function that overcomes the diseconomies of scale in the traditional warehouse market, which is a typical innovation process (Schumpeter, 1939, p. 84). In fact, assets reallocating (Demsetz, 1967) is a new institutional economics approach we have mentioned in the discussion of the property rights theory (see Section 2.4.1). In this case, Prolog Technology has successfully improved the assets allocation in a collective manner through the open innovation.

5.2.5 Case E: Hubei Xiangyuan New Material Technology Inc.

Hubei Xiangyuan New Material Technology Inc. (henceforth, Xiangyuan New Material) is a hi-tech thermoplastic materials manufacturer. Xiangyuan New Material is the only case located in a rural area (Xiaogan, Hubei) in the series of case studies. By introducing the open innovation approach in its R&D processes, Xiangyuan New Material is able to produce the most advanced thermoplastic materials and compete with its rivals in the global thermoplastic market.

Xiangyuan New Material's registration information at MOFCOM[45] is shown in Table 45.

[45] MOFCOM is the abbreviation of the Ministry of Commerce of China.

Table 45. The commerce registration information of Xiangyuan New Material Technology Inc.

Company name:	Hubei Xiangyuan New Material Technology Inc.		
Representative:	Wei Zhixiang	Registration status:	Existing (In operation, Open, Registered)
Registered capital:	CNY ¥71,898,056	Date of establishment:	2003-04-29
Stock exchange and symbol (code):	ChiNext[46]: 300980.SZ	Date of Initial Public Offering:	2021-04-21
Industrial sector:	Plastic parts and other plastic products manufacturing[47]	Enterprise type:	Private incorporation (Listed)
Business scope:	Research, development, production, processing, and sales of polymer, rubber, plastic, ceramics, and fiber materials with the application of electron accelerator (radiation involved). Research, development, production, processing, and sales of radiation materials (radiation involved). Research, development, production, processing, and sales of nanomaterials, graphene, superconductors, biological, and foaming materials (radiation involved). Research and development of degradable polymer and plastic materials (radiation involved). Research, development, trade, and consulting services of new materials. Import and export of technology.		

Note: As of the date of Initial Public Offering (April, 2021).

Source: Made by the author, based on the information provided by the company.

[46] ChiNext is the second-board subsidiary of the Shenzhen Stock Exchange.

[47] Industrial classification No. C-2929 as defined in Chinese standard GB/T 4754-2017.

As one of the few listed hi-tech companies from less developed regions, Xiangyuan New Material has a fairly unique history. In 2003. Mr. Wei Zhixiang and Ms. Wei Qiong, the founders of the company, acquired a state-owned noodle factory and founded the company as a noodle manufacturer named "Hubei Xiangyuan Wheat & Noodles Inc." In the next year, the company changed its business scope to non-woven fabric manufacturing and had been renamed as "Hubei Xiangyuan Non-woven Fabric Technology Inc." respectively. In 2007, the company started to produce polymer and plastic materials (particularly, the agricultural plastic film) other than the non-woven fabric. In 2008, the company had its name changed to the current name "Hubei Xiangyuan New Material Technology Inc."

The founders of the company do not have any technology background at all. The co-chairman Mr. Wei Zhixiang was a shopkeeper of the state-owned noodle factory. The co-chairwoman Ms. Wei Qiong, the younger sister of Mr. Wei, was an accountant. Due to the rural location of the company, there was absolutely no chance for Xiangyuan New Material to recruit researchers and technicians in the fields of chemical and biological new materials. Before the first master's degree holder joined the company in 2014, the executive board members, production managers, and workers were all undergraduates or lower without any research or engineering experience (see Table 46). Definitely, Xiangyuan New Material did not have the sufficient capability in its business scope of thermoplastic material manufacturing.

Table 46. The educational background of employees in Xiangyuan New Material Technology Inc.

Academic background	Number of employees		
	2015	2017	2021
Master and Doctoral	3	6	12
Bachelor	10	34	65
Three-year college	30	49	90
High school or lower	187	295	427
Business management	230	384	594

Source: Made by the author, based on the data provided by the company.

Nevertheless, Xiangyuan New Material has succeeded in the development and manufacturing of the IXPE (irradiation cross-linked polyethylene) and IXPP (irradiation cross-linked polypropylene) thermoplastic materials by introducing the open innovation paradigm. After a series of collective R&D and external R&D processes, Xiangyuan New Material became the first Chinese company that can produce 0.06mm-thick IXPE foaming materials (the thinnest foaming material in the world) in 2015, and the only Chinese company that can produce IXPP materials in 2017 (ChinaLin Securities Co., Ltd., 2021, pp. 1-1-143~1-1-144). As one of the top thermoplastic manufacturers in China, Xiangyuan New Material has built its international competitiveness and become able to compete with Sekisui Chemical (the only company that can provide 0.06mm-thick IXPE foaming materials before 2015), Toray Industries (world's only IXPP provider before 2017), and other multinational giants in the global market. The products of Xiangyuan New Material have been exported to developed countries, including the United States, Japan, and Korea.

Xiangyuan New Material Technology Inc.'s Open Innovation Implementation and Results

Table 47. Interviews conducted for case study E (Xiangyuan New Material Technology Inc.)

	Post[48]	Date	Main Theme
Ms. E_1	Co-chairwoman	August, 2017	The strategy of collective R&D. The importance in recruiting external resources for the company.
Dr. E_2	(External researcher)	March, 2018	The reason to accept collaborative R&D request. The difficulties in co-development.

Source: Made by the author.

Since Xiangyuan New Material is a small company in a rural area without any sufficient knowledge or resource, we want to know the path dependencies and key factors that Xiangyuan New Material has applied to construct and maintain its open innovation networks. Particularly, we would like to understand 1) How Xiangyuan New Material was able to reach its required know-whos from the use of the innovation intermediary; 2) How Xiangyuan New Material was able to perform long-term cooperation with the external researchers and institutions. In order to solve these problems, we have acquired

[48] The posts are as of the date of the interviews.

and analyzed the operating data of its R&D processes between 2015 and 2017. We have also interviewed the co-chairwoman of the company (Ms. Wei, henceforth E_1) and the external researcher (Dr. Shan, henceforth E_2). The interviews we have conducted are listed in Table 47.

As a company with very limited human and capital resources, Xiangyuan New Material was forced to adopt the open innovation approaches since the in-house "closed" innovation was impossible for it. According to Ms. E_1 (personal communication, 2017), the company had been actively chasing the ideas and knowledge inflows from its customer network since the early days when it was named "Hubei Xiangyuan Wheat & Noodles Inc." In 2003, the company recognized the needs of non-woven films from its agricultural suppliers, and switched to that business as soon as possible. During the manufacturing of agricultural films, the company noticed that the radiation process is critical in the plastic manufacturing. In 2007, the company decided to acquire the technology of radiation and enter the IXPE market. While Xiangyuan New Material started from the manufacturing of 3mm-thick IXPE foaming materials by purchasing existing plastic manufacturing solutions in 2008, the company started to look for chances of collective R&D at the same time.

At the beginning, Xiangyuan New Material was attempting the traditional university-industry collaborations (Motohashi, 2005). The company had contacted several near-by universities. However, the company's reputation was too low to attract any researchers from the universities.

In order to cut into the innovation network of its new business scope, Xiangyuan New Material tried to discover and make use of innovation intermediaries in its customer network. The products of Xiangyuan New Material, such as the IXPE foaming materials, are intermediate goods in other productions. The customers of the intermediate goods usually have more than one supplier from the same industrial sectors. By addressing and utilizing the external ties in its customer network, Xiangyuan New Material was able to break the network barriers and reach external researchers including Dr. E_2.

According to Dr. E_2 (personal communication, 2018), Xiangyuan New Material is a good partner in joint R&D practices. Although the executives of Xiangyuan New Material do not have the sufficient technology background, they have open minds in collaborative research. Unlink many corporates request short-term business results from the collective R&D projects, Xiangyuan New Material is permissive with the long-term research themes involving forward-looking scientific and technical issues. Xiangyuan New Material also allows the external researchers to participate the joint-research in their spare time without leaving their current positions. Furthermore, the intellectual property generated from the collaborations can be shared with both parties. Although Xiangyuan New Material did not have the sufficient resources for Dr. E_2's research, Dr. E_2 found Xiangyuan New Material trustworthy and was willing to share his research results with the company. The collective research projects between Xiangyuan New Material and the external researchers have created 28 patents for the company.

After Xiangyuan New Material had built its reputation from open innovation practices, the traditional collective innovation methods eventually became available for the latter R&D stages of the company in 2014. During 2014 and 2017, Xiangyuan New Material has started four joint-research projects with universities and institutes, including Huazhong University of Science and Technology, Hubei University, Hubei University of Technology, and Hubei Research and Design Institute of Chemical Industry.

Interestingly, unlink the other cases where the managers know more or less about the open innovation paradigm and innovation management methods, Xiangyuan New Material's executives does not have much knowledge on the innovation and innovation process management. We have never heard a word related to the open innovation paradigm during the conversations with Ms. E_1 and the staff of Xiangyuan New Material.

Conclusion of Xiangyuan New Material Technology Inc.'s Open Innovation Approach

Among the cases we have studied in this chapter, Xiangyuan New Material has the most "typical" open innovation approach. Just like what Henry Chesbrough suggested in his original definition, Xiangyuan New Material used "purposive inflows" of knowledge and resources to "accelerate internal innovation", and expanded "the markets for external use of innovation" (Chesbrough, 2006a, p. 17).

Furthermore, Xiangyuan New Material's successfully exploitation of external resources through the open innovation network has proven the "lumpiness" hypothesis. Although the incentives of Xiangyuan New Material's joint R&D are fairly small, the company minimized the costs for participation. "When costs of participation are low enough, any motivation may be sufficient to lead to a contribution" (Feldstein, 2007). Since the lumpiness of a joint research project is always positive, external researchers are willing to take part in the low-cost open innovation practices with Xiangyuan New Material.

The results of Xiangyuan New Material's open innovation approaches are concluded in Table 48. We can easily locate Xiangyuan New Material's open innovation as the discovery and exploitation of external knowledge and resources from an innovation intermediary in its reputational network (Sakai, 2017). As the result of the successful product innovation, Xiangyuan New Material is also able to enter a new market through the reputational network. By adopting the open innovation approach, the reputation of Xiangyuan New Material can be built from both its own customer network and the external researchers' networks.

Table 48. Xiangyuan New Material Technology Inc.'s open innovation approaches and results

Factors	Inbound knowledge	Outbound knowledge	Inbound resource	Outbound resource
Develop new business model (organizational innovation)				
Enter new market (market innovation)		◎ Reputational network		
Improve productivity (process innovation)				
Create and capture new values (product innovation)	◎ Innovation intermediary		◎ Innovation intermediary	
Reduce costs (input and organizational innovations)				

Legend:
◎ – Succeeded in the particular innovation type with the open innovation attempts;
○ – The particular open innovation process is still in progress, but seems fruitful;
× – Failed in the particular innovation type with the open innovation attempts.

Source: Made by the author.

Xiangyuan New Material develops the new products IXPE and IXPP to enters the new market. Therefore, the innovation approach of Xiangyuan New Material can be categorized as a **radical innovation** in the Henderson-Clark model. According to the open innovation results shown in Table 48, Xiangyuan New Material is another successful case in radical innovation in addition to Han's Robot (case C).

As a unique case of open innovation implementation in a rural area, Xiangyuan New Material has provided several implications for the business applications of the open innovation paradigm in the similar conditions:

1) Open innovation is a potential solution for the companies in the less developed and least developed countries and regions. As an agricultural plastic manufacturer in a rural region, Xiangyuan New Material was not able to attract high level human resources. However, by allowing the external research Dr. E_2 to co-develop without quitting his current employment, Xiangyuan New Material successfully got Dr. E_2's help.
2) Consensus and commons are very important in recruiting the external resources, particularly when the incentives for an outside-in flow are insufficient. While Xiangyuan New Material had very limited R&D resources for Dr. E_2's research on IXPE, the company and Dr. E_2 had reached a consensus that attracted Dr. E_2 to join the open innovation network.
3) Reputation is very important in the initializing stage of an innovation network, particularly through the traditional collective innovation management methods. Siefkes suggests the reputation of a peer "tends to be important both as driving forces and as factor for judging others" in the network (2007, p. 15). In Xiangyuan New Material's case, it made use of both its customer network

and Dr. E_2's resources to generate the necessary reputation.

5.2.6 Case F: Wuhan Yuanqi Technology Co., Ltd.

Wuhan Yuanqi Technology Co., Ltd. (henceforth, Yuanqi Technology) is a hospital management service provider located in Wuhan, Hubei. Yuanqi Technology's registration information at MOFCOM[49] is shown in Table 49.

Table 49. The commerce registration information of Yuanqi Technology Co., Ltd.

Company name:	Wuhan Yuanqi Technology Co., Ltd.		
Representative:	Qian Haiyuan	Registration status:	Existing (In operation, Open, Registered)
Registered capital:	CNY ¥18,002,880	Date of establishment:	2007-03-15
Stock exchange and symbol (code):	NEEQ[50]: 836949.NQ	Date of Initial Public Offering:	2016-04-26
Industrial sector:	Information system integration services[51]	Enterprise type:	Private incorporation (Listed)
Business scope:	Consulting services related to computer technology, networking, electronic computers, and electronic information services. Consulting services related to telecommunication engineering and network engineering. Development and sales of computer software and hardware.		

Note: As of the date of the last interview (August, 2018).

Source: Made by the author, based on the information provided by the company.

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[49] MOFCOM is the abbreviation of the Ministry of Commerce of China.

[50] NEEQ is the abbreviation of the Chinese over-the-counter stock exchange system "National Equities Exchange and Quotations".

[51] Industrial classification No. I-6531 as defined in Chinese standard GB/T 4754-2017.

Yuanqi Technology is registered as a system integrator that provide financing services to the hospitals. According to the auditor's report (see Table 50), the company's gross profit rate was 56.40%, the net profit rate was 22.42%, the debt asset ratio was 44.63%, and the fixed asset occupied only 0.53% in total in the fiscal year 2017 (henceforth, FY2017). The financial data suggested that Yuanqi Technology is a typical asset-light knowledge-intensive firm.

Table 50. The financial analyses of Yuanqi Technology Co., Ltd. from FY2016 to 1H2018

	1H2018	**FY2017**	**FY2016**
Debt Asset Ratio	39.35%	44.63%	39.85%
Current Ratio	2.28	2.20	2.46
Gross Profit Ratio (overall)	45.82%	56.40%	56.10%
Net Profit Ratio (overall)	-48.80%	22.42%	17.41%
Receivables Turnover Ratio	1.29	1.81	3.49
Inventory Turnover Ratio	18.13	21.72	6.28

Source: Made by the author, based on the financial data provided by the company.

The main service of Yuanqi Technology is a hospital management platform named "Yuanqi smart hospital: An integrated solution for financial services" during the period of research. The company was attempting agile development in an open innovation approach in the development of the Yuanqi smart hospital platform since the second half of the fiscal year 2016 (henceforth, 2H2016): The software part of the platform was developing in a user-driven open innovation approach together with the end-users (hospitals) and other general financing service providers (including AliPay, Tencent TenPay, and UnionPay). The hardware part of the platform was purchased by the end-users themselves. Yuanqi Technology adjusted its software to integrate the existing hardware systems of the hospitals into the Yuanqi smart hospital system.

After adopting the user-driven open innovation approach in its development, Yuanqi Technology became more similar to the software companies we have surveyed in the literature review. As the previous research suggested, the open innovation implementation benefited Yuanqi Technology's productivity. The inventory turnover ratio increased rapidly from 6.28 in FY2016 to 21.72 in FY2017 (see Table 50), which means that the company had improved the productivity remarkably in the deployment of its platform.

During the research period, the sales performance was quite satisfying. The Yuanqi smart hospital platform was widely accepted by hospitals in China. As of the date of the last interview, there were more than 200 hospitals from 18 provinces using Yuanqi Technology's hospital management platform. As a result, the sales in the first half of the fiscal year 2018 (henceforth, 1H2018) was CNY ¥19,353,957.66, increased by 93.27% comparing to 1H2017 (CNY ¥10,014,122.39). Although the receivable turnover ratio was decreasing since FY2016, the liquid assets (excluding the financing) were increasing considerably. From the sales data, Yuanqi Technology was enjoying rapid growth during the period of research.

However, the costs of Yuanqi Technology's business did also increase "lethally"[52] after the implementation of open innovation. The amount of operating costs of the company was CNY ¥10,485,046.57 in 1H2018, increased by 389.11% comparing to 1H2017 (CNY ¥2,143,711.99). Furthermore, the operating costs in 1H2018 were

[52] The exact word used by the CFO of the company in the interview.

640.62% of the amount in 1H2016 (CNY ¥1,636,705.80) when the company had not yet introduced the open innovation methods in its business operation. As a result, the gross profit rate dropped from 78.59% in 1H2017 to 45.82% in 1H2018. The net profit ratio was even worse, making a negative number of -48.80% in 1H2018 (it was positive in FY2017) as shown in Table 50. The net loss in 1H2018 was an astonishing number of CNY ¥9,444,996.72, in other words, 10.27% of the company's total assets or 52.46% of the company's registered capital. Although the other financial data[53] (including the debt asset ratio, current ratio, and quick ratio) was not as bad as the huge loss, it seems that Yuanqi Technology's growth was not healthy and sustainable.

Although Yuanqi Technology is a listed company on the NEEQ, the founder's family is keeping a controlling share in the company. At the time of the interviews, Mr. Qian Haiyuan, the founder and the CEO of the company, controlled 61.22% of the shares; Ms. Wu Qiong, Mr. Qian's wife and the CFO of the company, controlled 13.91% of the shares. The more than 75% actual controlling shareholding ratio of the company suggested 1) The corporate governance of Yuanqi Technology was top-down and still in an entrepreneurial stage; 2) The scale of the shareholders' network of Yuanqi Technology is limited. We will introduce how these factors affected Yuanqi Technology's open innovation implementation in the following analyses.

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[53] Note: The successful financing in 1H2018 had provided an extra amount of liquid assets to the company's account.

Yuanqi Technology Co., Ltd.'s Open Innovation Implementation and Results

Table 51. Interviews conducted for case study F (Yuanqi Technology Co., Ltd.)

	Post[54]	Date	Main Theme
Mr. F_1	CEO	August, 2018	The reasons why hospital management system/platform needs to be open.
Ms. F_2	CFO	August, 2018	The financial status before and after the launch of the platform service.
Mr. F_3	Developer	August, 2018	Difficulties in the open agile development.
Mr. F_4	Sales manager	August, 2018	Feedbacks from the customers after the adoption of user-driven open innovation in the development and deployment.

Source: Made by the author.

In order to analyze Yuanqi Technology's user-driven open innovation implementation, we have acquired and analyzed financial data from FY2016 to 1H2018 of the company. In addition, we have conducted two interviews with the company's executives, including the CEO (Mr. Qian, henceforth F_1) and the CFO (Ms. Wu, henceforth F_2), to investigate the background of introducing the open innovation, the managerial approaches to organize the open innovation processes, and the effects of the open innovation implementation. We have also interviewed a developer (henceforth F_3) and a salesman (henceforth F_4)[55] to understand the reasons for the rapid increases in both

54 The posts are as of the date of the interviews.

55 F_3 and F_4 did not disclose their names to us.

the sales and the operating costs after the adoption of the open innovation paradigm. The interviews we have conducted are listed in Table 51.

According to the introduction of Mr. F_1 (personal communication, 2018), the traditional hospital information systems (HIS) are no longer suitable for modern hospital management. Firstly, the internal management of a hospital is becoming more and more complex. There are so many different clinics, laboratories, and pharmacies in a typical Chinese hospital. Different departments have different billing periods, cost incurring mechanisms, and management routines. Furthermore, different departments usually have their own information systems (for instance, the clinical information systems (CIS), the laboratory information systems (LIS), the picture archiving and communication systems (PACS), and the electronic medical record systems (EMR)). Hospital staff would have to learn multiple systems. Both the learning costs and the operating costs of the multiple systems cannot be ignored. Secondly, the external management of a hospital is also complicated. A hospital management system should be able to connect to different parties including the government, the third-party payment provider, and the patients' portable devices. Furthermore, a user-friendly hospital financing system requires a visualized user interface for all these different parties as well as the managers, doctors, and nurses of the hospital. It is obvious that a closed system cannot fulfill the wide variety of needs in different departments: The traditional HIS is such a dedicated system that it cannot or it is difficult to connect with the other systems.

To solve this issue of complexity, Yuanqi Technology designed an open development framework named "PowerNT" to develop the Yuanqi smart hospital platform. PowerNT is designed to have as much compatibility as possible: 1) PowerNT provides a unified user interface with multiple application interfaces that are implicit to the users. After connecting all the existing systems, the Yuanqi smart hospital platform beomes the only system that a staff or a patient needed to learn. 2) PowerNT has high modularity. A programmer can develop a new module without reading the source codes of other modules. A hospital can also construct its own management system with its own choice of modules. 3) PowerNT is a language-free development framework. Programmers with different skills can use their favorite programming languages in the development of the Yuanqi smart hospital platform. It is also easier to interconnect the existing systems that were written in different languages. The open framework PowerNT provided the necessary "commons" and consensus for the peer production model (Raasch, Herstatt, & Balka, 2009) as well as the user innovation model (Von Hippel, 2001).

According to Mr. F_1 (personal communication, 2018), Yuanqi smart hospital was designed as a network connector to promote new combinations between the hospitals, the patients, and the external parties.

Compared to the traditional hospital information systems, the salesman Mr. F_4 (personal communication, 2018) found it much easier to sell the open hospital management platform. By connecting and reusing the existing systems of the hospital, the launching cost of the Yuanqi smart hospital was much lower than the traditional systems. Furthermore, as a cloud-based Service-as-a-Service platform, the Yuanqi smart hospital could be deployed in a hospital without completing all the system integrations. This also made it easier to promote the Yuanqi smart hospital platform to the hospitals.

However, Mr. F_3 (personal communication, 2018) claimed that the "DevOps" (developing during operations) style was difficult for the developers. Despite the fact that software development can be easily done remotely, the integration of different hospital systems often requires working at that hospital. During the first half of 2018, Yuanqi Technology had received too many new orders from different provinces, the internal developers of the company could not communicate with every customer outside the Hubei Province. As a result, the development was very challenging and lots of codes were wasted. The sticky information issue (Von Hippel, 1994) of the innovation process cannot be overcome with the user-driven open innovation approach.

According to Mr. F_3 (personal communication, 2018), there was also a sustainability issue in Yuanqi Technology's user-driven open innovation implementation. Although the PowerNT framework allows inflows of source codes from the customer and the third parties to accelerate the development, the maintenance of the heterogeneous codebase is very complicated. Since the PowerNT framework allows modules to be written in different programming languages, the internal developers without the knowledge and skills of the target language can neither add new functions nor fix the bugs of an external module. If an external developer of a special module quitted the network, the module becomes unmaintainable and has to be abandoned when the application interfaces of the platform get updated.

Conclusion of Yuanqi Technology Co., Ltd.'s Open Innovation Approach

According to the analyses, we can recognize that Yuanqi Technology was adopting the user-driven open innovation model (Wise & Høgenhaven, 2008) as its open innovation implementation. By adopting the user-driven open innovation model in the agile development of its platform service, Yuanqi Technology would like to 1) purposively interact and communicate with its users, understand the changing demands in the dynamic market, and rapidly fulfill the customers' needs with the company's core competences; 2) purposively access external resources to flexibly satisfy the intensive market demands beyond the company's own capability.

The open innovation approaches of Yuanqi Technology are actively applying the existing technologies (integrating and reusing the existing systems) in a new market (the cloud-based unified hospital management system). Therefore, Yuanqi Technology's open innovation implementation is an **architectural innovation** in the Henderson-Clark model.

Table 52. Yuanqi Technology Co., Ltd.'s open innovation approaches and results

<table>
<tr><th>Factors</th><th>Inbound knowledge</th><th>Outbound knowledge</th><th>Inbound resource</th><th>Outbound resource</th></tr>
<tr><td>Develop new business model (organizational innovation)</td><td rowspan="4">◎ User innovation</td><td rowspan="4">◎ User innovation</td><td rowspan="4">◎ User innovation</td><td rowspan="4">◎ User innovation</td></tr>
<tr><td>Enter new market (market innovation)</td></tr>
<tr><td>Improve productivity (process innovation)</td></tr>
<tr><td>Create and capture new values (product innovation)</td></tr>
<tr><td>Reduce costs (input and organizational innovations)</td><td></td><td></td><td>× User innovation</td><td>× User innovation</td></tr>
</table>

Legend:
◎ – Succeeded in the particular innovation type with the open innovation attempts;
○ – The particular open innovation process is still in progress, but seems fruitful;
× – Failed in the particular innovation type with the open innovation attempts.

Source: Made by the author.

As shown in Table 52, Yuanqi Technology had succeeded in improving productivity by exploiting knowledge and resources from both outside-in and inside-out. However, Yuanqi Technology failed to reduce its development cost with the user-driven open innovation implementation. Instead, the operating cost of the company was inflating quickly after the implementation of open innovation. The cost reduction issue might even abandon the business of Yuanqi Technology's innovation.

After introducing the user-driven open innovation approach, Yuanqi Technology is almost a software company. According to many pieces of previous research (for instance, Huang, 2016), the internal productivity of software development should benefit from the introduction of open innovation approaches. The modularized open development framework "PowerNT" is also a state-of-the-art software development practice suggested by the previous research (for instance, Raasch, Herstatt, & Balka, 2009).

However, as a service provider, the cost function of Yuanqi Technology seemed to be different from the software companies. Although most pieces of open innovation research on the software industry (for instance, Henkel, 2007) have suggested that the development costs can be reduced by introducing an open innovation approach, Yuanqi Technology has suffered from the failure of cost reduction.

From Yuanqi Technology's open innovation implementation and the network configurations, this research has raised three hypotheses to explain its failure in cost reduction:

1) The compatibility issue of agile development in open innovation practices: As discussed in Section 5.2.2, previous research (Conboy & Morgan, 2011; Remneland-Wikhamn, et al., 2011; etc.) has suggested that the agile development methods should not be applied in open innovation practices.

Regardless, Yuanqi Technology was running a "DevOps" with the user-driven open innovation. The mismatching of innovation process managerial mechanisms might result in the high operating costs.

2) Unmatched network scales: The open innovation network created by Yuanqi Technology was unbalanced. The internal network (the entrepreneurial company Yuanqi Technology) was too small, while the external networks (hospitals, patients, and third parties) were too large. Although the open innovation theory (Chesbrough, 2006a; etc.) does not require any certain network settings for the adopters, the "lead user" in a user innovation network should have an appropriate network centrality according to the user innovation theory (Von Hippel, 1976; Von Hippel, 2005; etc.). As the "lead user" in the user-driven open innovation network, Yuanqi Technology's network centrality might not be appropriate to promote the innovation effectively.
3) Insufficient managerial capability: Yuanqi Technology was controlled and managed by the founder's family in a top-down style. However, the user innovation is a bottom-up process. The company might not have the sufficient managerial capability to organize a user-driven open innovation network.

Unfortunately, we do not have the chance to design a participatory experiment to verify our hypotheses in this research.

Nevertheless, Yuanqi Technology has benefited a huge amount in its sales and productivities (the pace of deployment and development) after its adoption of the open innovation paradigm. Therefore, we evaluate Yuanqi Technology's open innovation implementation as partially succeeded. Yuanqi Technology's user-driven open innovation approaches were able to provide productivity incentives to the company, but failed in controlling the operating costs.

5.2.7 Case G: Hanbroad Business Management Group Co., Ltd.

Hanbroad Business Management Group Co., Ltd. (henceforth, Hanbroad Business Management) is a retail management service provider located in Beijing. Hanbroad Business Management's registration information at MOFCOM[56] is shown in Table 53.

Hanbroad Business Management is the only case that has implemented two different open innovation approaches during the period of research. The previous open innovation strategy adopted by Hanbroad Business Management had been successful during 2012 and 2018. However, the rapid changing retail market as well as the new normal after the COVID-19 pandemic forced the company to switch to another implementation in 2020.

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[56] MOFCOM is the abbreviation of the Ministry of Commerce of China.

Table 53. The commerce registration information of Hanbroad Business Management Group Co., Ltd.

Company name:	Hanbroad Business Management Group Co., Ltd.		
Representative:	Wang Wei	Registration status:	Existing (In operation, Open, Registered)
Registered capital:	CNY ¥225,500,000	Date of establishment:	2007-03-15
Stock exchange and symbol (code):	(NEEQ[57]: 831576.NQ before termination)	Date of Initial Public Offering:	2015-01-05 (Terminated on 2020-02-06)
Industrial sector:	Other general business management services[58]	Enterprise type:	Private incorporation (Unlisted)
Business scope:	Business management. Market research and survey. Business and corporate consulting and planning services. Rental and management services of commercial real estates. Public relations services and advertising agency. Retail services.		

Note: As of the date of the last interview (August, 2021).

Source: Made by the author, based on the information provided by the company.

In its first open innovation implementation, Hanbroad Business Management developed and offered a fully-managed shopping mall management service. In the first half of the fiscal year 2019 (henceforth, 1H2019), the company was managing 190

[57] NEEQ is the abbreviation of the Chinese over-the-counter stock exchange system "National Equities Exchange and Quotations".

[58] Industrial classification No. L-7229 as defined in Chinese standard GB/T 4754-2017.

shopping malls in China. To better manage the heavy assets of commercial properties as well as the human resources, Hanbroad Business Management had developed a data-mining system to predict the customer behavior, and adjust the operational resources among its shopping malls based on the big data.

From the financial data, we can define Hanbroad Business Management as an asset-light knowledge-intensive company. During the fiscal year 2017 (henceforth, FY2017) and the first half of the fiscal year 2019 (henceforth, 1H2019), the weight of the fixed assets was between 1% to 4%, and the staff number was about 450. Considering the fact that Hanbroad Business Management was managing 190 shopping malls, the capital and the human resources of the company were extremely small. The business of the company relied on the sharing of knowledge in its open innovation network.

Table 54. The financial analyses of Hanbroad Business Management Group Co., Ltd. from FY2017 to 1H2019

	1H2019	**FY2018**	**FY2017**
Debt Asset Ratio	15.82%	16.57%	13.73%
Current Ratio	3.49	3.33	3.96
Revenue (CNY)	¥124,121,421	¥251,914,816	¥191,312,381
Gross Profit Ratio (overall)	32.02%	38.94%	46.60%
Net Profit Ratio (overall)	6.94%	11.40%	13.75%
Receivables Turnover Ratio	2.68	6.57	5.31
Inventory Turnover Ratio	161.93	138.68	150.24

Source: Made by the author, based on the financial data provided by the company.

The business model of the first open innovation implementation has once succeeded. However, the profitability of this service is declining during the period of research due to the change of the customer behaviors in the Chinese retail market. In Table 54, we can see that both the gross profit ratio and the net profit ratio are decreasing and reaching the lowest-end in the industrial sector of service.

However, the company still enjoyed a very good financial condition in 1H2019 while the profitability was declining. Both the debt asset ratio and the current ratio were kept at a healthy level, and were still among the best in the business management service industry. The excellent financial management performance made the company possible to rechallenge with a different approach.

Hanbroad Business Management Group Co., Ltd.'s Open Innovation Implementation and Results

Since Hanbroad Business Management has implemented open innovation in two different approaches, we would like to adopt a self-controlled research methodology in comparing the two different implementations. Particularly, we would like to recognize the critical factors that led to the opposite results in the open innovation implementations.

In order to analyze Hanbroad Business Management's two implementations of the open innovation paradigm, we have conducted in-depth interviews with the two core executives of each implementation. Mr. Zhu (henceforth, G_1) was the previous CEO who had designed the first open innovation implementation of the company. Mr. Wang (henceforth, G_2) has been the current CEO since 2020. After his appointment as the new CEO, Mr. Wang directed and managed the revised open innovation implementation of Hanbroad Business Management. The interviews we have conducted are listed in Table

55.

Table 55. Interviews conducted for case study G (Hanbroad Business Management Group Co., Ltd.)

	Post[59]	Date	Main Theme
Mr. G_1	CEO	August, 2017	The (first) open innovation strategy in the commercial property management service market.
Mr. G_2	CEO	August, 2021	The revision of the existing open innovation strategy.

Source: Made by the author.

Mr. G_1 (personal communication, 2017) was a real estate agency dealing with the commercial properties before he started the business of Hanbroad Business Management. During his days as a real estate agency, he collected the data of the commercial properties. By analyzing the environmental variables with the changes in the retail consumption behaviors, he developed a mechanism for retail business management. As a managerial mechanism highly relying on big data, he would like to manage as many shopping malls as possible to collect as much data as possible in the dynamic retail market. Therefore, he had also designed an open business model that sharing the knowledge and assets in the manufacturers (in this case, the property owners)' network.

The first open innovation implementation of Hanbroad Business Management is very similar to Borche Machinery and Prolog Technology. All the three implementations

[59] The posts are as of the date of the interviews.

are sharing the assets (capital, knowledge, and human resources) in the networks. However, the network configurations in their business implementations are different. Borche Machinery works as a *network collector* in the manufacturer network, and connects the demand-side information with the idle capacity in the supply side. The new resource combination in Borche Machinery's network is limited. Prolog Technology's open innovation implementation focuses on the asset reallocation and the resource flows. The network of Prolog Technology is restricted and does not allow the outflow of knowledge. The network of Hanbroad Business Management's open innovation strategy is between the previous two cases. Hanbroad Business Management allows the information inflows and outflows as well as the resource inflows and outflows. However, the new combinations need Hanbroad Business Management's data mechanism to become innovative and valuable. Therefore, Hanbroad Business Management is the *network broker* of its open innovation network.

After experiencing the decline of the existing open innovation implementation, Mr. G_2 (personal communication, 2021) decided to revise the company's business model after his appointment as the CEO in 2020. To make things worse, the COVID-19 pandemic has blown the offline retail market in the same year. The company had even requested delisting from the stock market due to the worries on its business model relying on the shopping malls.

After examining the assets owned by the company, Mr. G_2 found that Hanbroad Business Management has acquired a cloud computing company (Guangdong Winshang Data Service Co., Ltd., henceforth Winshang) but has not yet made full use of it. Due to the good compatibility between data mining and cloud computing, Mr. G_2 decided to combine the existing mechanism with the services of the acquired company. Under the instruction of Mr. G_2, Winshang started to develop and provide retail management Service-as-a-Service (SaaS). Generally speaking, the revised implementation is exploiting the similar business network and applying a similar open innovation mechanism compared to the original one. The only difference is the innovation type in the Henderson-Clark model. The revised one is applying the existing technology to a new market, while the original one was developing a new technology and applying it to an existing market.

Conclusion of Hanbroad Business Management Group Co., Ltd.'s Open Innovation Approaches

The analytical results of Hanbroad Business Management's two open innovation implementations are concluded in Table 56. We locate the first implementation as a knowledge sharing approach in reducing costs (by keeping extremely high turnover rates) and developing a new business model. And the revised implementation is also located as a knowledge sharing approach, but aiming at improving the productivity and developing a new business model.

In the Henderson-Clark model, Hanbroad Business Management's first implementation is a **modular innovation** approach. The company developed a data mining technology and a business model based on the new technology to reduce the operating costs, and applying the new technology as well as the new business model to the existing commercial property management market that the manager at that time had already achieved enough reputation. On the contrary, the second implementation of Hanbroad Business Management is an **architectural innovation** approach in the

Henderson-Clark model. The company acquired a cloud computing company (Winshang), applied the existing know-hows to the acquired products, created a new business model as well as a new market: SaaS-based retail management.

Table 56. Hanbroad Business Management Group Co., Ltd.'s open innovation approaches and results

Factors	Inbound knowledge	Outbound knowledge	Inbound resource	Outbound resource
Develop new business model (organizational innovation)	○ Knowledge sharing	○ Knowledge sharing	× Knowledge sharing	× Knowledge sharing
Enter new market (market innovation)				
Improve productivity (process innovation)	○ Knowledge sharing	○ Knowledge sharing		
Create and capture new values (product innovation)				
Reduce costs (input and organizational innovations)			× Knowledge sharing	× Knowledge sharing

Legend:

◎ – Succeeded in the particular innovation type with the open innovation attempts;

○ – The particular open innovation process is still in progress, but seems fruitful;

× – Failed in the particular innovation type with the open innovation attempts.

Source: Made by the author.

Since the company has decided to switch the business strategy itself, we should assume the first implementation as a failed one (×). The second open innovation attempt of Hanbroad Business Management was implemented at the end of 2020. Until the disclosure of the annual report of FY2021, we cannot recognize whether the second attempt has been successful or not. Therefore, we treat the second implementation as an open innovation process in progress (○).

Nevertheless, according to the communication with the company, the second open innovation attempt should be successful. Although the financial data is still under auditor's examinations, the unaudited raw data of FY2021 is quite satisfying. As a result, the executive board of Hanbroad Business Management is aiming to get the company listed again at the main board of the Hong Kong Stock Exchange in two years. With the faith in Hanbroad Business Management's current business strategy, a lead underwriter for the initial public offering has already been assigned to the company.

5.3 Conclusion: Business Implications of Open Innovation

In the series of comparative case studies, we have recognized a failed case (case B), three partially succeeded case (case C, case F, and case G), and three successful cases (case A, case D, and case E) in China. The analytical results of the seven cases' open innovation implementations are shown in Table 57.

In the following sections, we will compare and discuss the open innovation implementations from their sources of trust and motives, their innovation types in the Henderson-Clark model, their network configurations, and their managerial mechanisms. With the conclusion of our comparative case studies, we will answer the research questions set in the previous chapter.

Table 57. Comparison of the open innovation implementations in the case studies

Group	**Capital-intensive**			**Labor-intensive**	**Knowledge-intensive**			
Case	**A**	**B**	**C**	**D**	**E**	**F**	**G**	
Company abbr.	Borche Machinery	Ewatt Technology	Han's Robot	Prolog Technology	Xiangyuan New Material	Yuanqi Technology	Hanbroad Business Management Group	
Main approach	Collective production	Collective R&D	Collective R&D	Collective production	Collective R&D	Collective R&D	Collective production	
Open innovation implementation	Asset sharing in manufacturer network	Open cross-functional team in manufacturer network	Open agile development in manufacturer network	Asset sharing in customer network	Accessing external resource in customer network	User innovation in customer network	Knowledge sharing in manufacturer network	
Innovation type	Incremental innovation	Modular innovation	Radical innovation	Architecture innovation	Radical innovation	Incremental innovation	Modular innovation	Architecture innovation
Major sources of coordination	Public ownership; Risk sharing	Risk sharing	Interpersonal relationship	Public ownership; Risk sharing	Innovation intermediary; Reputation	Societal trust; Public ownership	Public ownership; Risk sharing	
Major incentives	Business model & productivity	New market	New values	New market & costs	New market & new values	Productivity	Business model & costs	Business model & productivity
Result	**Succeeded**	**Failed**	**Partially succeeded**	**Succeeded**	**Succeeded**	**Partially succeeded**	**Failed**	**In progress**

Source: Made by the author.

5.3.1 Applicability of Open Innovation in Different Innovation Networks

In the comparative case studies presented in this chapter, we have found that the open innovation is an applicable paradigm for commercial implementations in different industrial sectors, different markets, and different networks.

In the capital-intensive group, we have analyzed the open innovation implementations of three manufacturers. All the cases in this group are adopting open innovation in manufacturers' network.

Borche Machinery has succeeded in its open innovation attempts. By launching a manufacturers' network and act as the collector in the innovation network, Borche Machinery has built two win-win relationships: the win-win relationship between the plastic manufacturers and the customers of the plastic goods, and the win-win relationship between Borche Machinery and the plastic manufacturers. By adopting the open innovation strategy, Borche Machinery enabled itself to survive the business cycles of the industry and recessions in the dynamic market with its incremental innovation.

Ewatt Technology has failed in its open innovation implementation. The open cross-functional team mechanism, which was the major open innovation approach of Ewatt Technology, was not suitable for the modular innovation that the company would like to achieve. Furthermore, the globally distributed cross-functional teams might require a further network-oriented managerial mechanism.

Han's Robot succeeded in the initial stage of R&D with its open agile development approach. Similar to Ewatt Technology, Han's Robot's R&D processes are also extensively distributed in the manufacturers' network,

The only case in the labor-intensive group, Prolog Technology, has succeeded in its open innovation implementation in the logistic service industrial sector. Prolog Technology has designed an asset sharing network for collective logistics in an architecture innovation attempt.

In the knowledge-intensive group, we have analyzed the open innovation implementations of a manufacturer and two service providers. Since the knowledge-intensive firms have a rather extensive previous research, the open innovation approaches in this group is more similar to the existing mechanisms.

Xiangyuan New Material succeeded in recruiting external knowledge and resources by employing innovation intermediaries from its customers' network. After the company built its own reputation, the more innovation process managerial mechanisms becomes available to the company in the reputational network.

By adopting a user-driven open innovation approach in the customers' network, Yuanqi Technology had succeeded in improving productivity by exploiting knowledge and resources from both outside-in and inside-out. However, Yuanqi Technology failed to reduce its development cost in the incremental innovation processes.

Hanbroad Business Management has implemented two similar open innovation approaches by sharing the knowledge in the manufacturers' network. However, the company applied these approaches in different innovation network. The first implementation is a modular innovation attempt. Although it succeeded at the beginning, the profitability of the open modular innovation implementation is declining. The revised implementation is aiming to achieve an architectural innovation. The early data shows that the architectural innovation attempt should succeed.

To answer the research question 2.1, 2.2, and the hypotheses 1 and 2, we are using the analytical framework based on the Henderson-Clark model. As shown in Table 58, we have found a successful case in implementing the architectural innovation, a successful case and a partially succeeded case of the incremental innovation, a successful case and a partially succeeded case of the radical innovation, and two failed cases of the modular innovation.

Table 58. The innovation types of cases in the Henderson-Clark model

		Technology: Existing	Technology: New
Market	Existing	*Incremental Innovation* **A, F**	*Modular Innovation* **B, G**
	New	*Architectural Innovation* **D, G**	*Radical Innovation* **C, E**

Legend:
Cell in grey: The cases of this innovation type have achieved some business successes with their open innovation implementations.
Cell with a cross: All the cases of this innovation type have failed in their open innovation attempts.

Source: Made by the author.

Based on the Henderson-Clark model, we suggest to apply the open innovation approaches in cases of the incremental innovation, the radical innovation, and particularly the architectural innovation. On the contrary, the open innovation methodology should be avoided when aiming to achieve a modular innovation.

Although the previous research has suggested that the proven open innovation managerial mechanisms are only suitable for the ICT industry, we have recognized three successful cases of open innovation adoptions from the capital-intensive manufacturing industrial sector (Borche Machinery), the labor-intensive service industrial sector (Prolog Technology), and the knowledge-intensive manufacturing industrial sector (Xiangyuan New Material). The productions of the three successful cases are much different from the digital production in the ICT industry.

5.3.2 Commercial Implementations of Open Innovation Paradigm

Nevertheless, we would first address our findings from the case studies to answer the research question 1.1 and 1.2: the sources of trust and motives.

As shown in Table 59, we have discussed the following sources of trust and coordination in the comparative case studies: the interpersonal relationship, the risk sharing and asset sharing, the public ownership (assets reallocation), the societal trust and the reputation network, the innovation intermediary. However, we did not recognize any coordination mechanism based on the public contract or cheating costs.

And we have also discussed the possible motives and incentives for implementing an open innovation approach: increasing of the profits or reduction of the costs, the chance of entering a new market or increasing the market share, the gain in productivity, the access to external resources, the maintenance of an ecosystem or a current supply chain.

Table 59. Factors recognized in empirical research

	Trust / Coordination	Motive / Incentive
Individual factor	Interpersonal relationship **Necessary** (in Case B, Case C, Case E) Risk sharing **Sufficient** (in Case A, Case D, Case G)	Profit / cost **Sufficient** (in Case A, Case D) New market / market share **Sufficient** (in Case D) Productivity **Sufficient** (in Case A)
Collective factor	Public ownership **Sufficient** (in Case A, Case D) Societal trust (reputation) **Sufficient** (in Case E, Case F) Innovation intermediaries **Sufficient** (in Case A, Case E)	Access to external resources **Sufficient** (in Case C, Case E) Ecosystem **Sufficient** (in Case A, Case F, Case G) Sustainability **Sufficient** (in Case A, Case D)

Source: Made by the author.

Furthermore, we have recognized the following factors from the Schumpeterian innovation theory in our case studies. As shown in Table 60, all the types of the Schumpeterian innovation can be achieved through the inside-out, outside-in, or coupled new combinations formed from the open innovation approaches.

Table 60. Open innovation approaches found in the case studies.

Factors	Inbound knowledge	Outbound knowledge	Inbound resource	Outbound resource
Develop new business model (organizational innovation)	A, G	A, G	D, G	D, G
Enter new market (market innovation)	B	B, E		
Improve productivity (process innovation)	C, F, G	C, F, G	C, F	C, F
Create and capture new values (product innovation)	B, C, E	B, C	B, C, E	B, C
Reduce costs (input and organizational innovations)	D		D, F, G	D, F, G

Legend:

Case in black color: Case succeeded in this type of innovation through the factors from the open innovation.

Case in red color: Case failed in this type of innovation through the factors from the open innovation.

Source: Made by the author.

Chapter 6

Conclusion and Discussion

6.1 Summary of the Research

This research focuses on the implementations of open innovation in the business networks of a globalized economy. This research provides a comprehensive understanding of the open innovation process management in the business context. This research also proposes the determining factors, constraining factors, and managerial mechanisms of open innovation in various innovation types and network configurations.

Open innovation is a paradigm that promotes innovation from purposive utilizing and combining the internal and external ideas, knowledge, and resources. Open innovation is a distributed extension of the Schumpeterian innovation theory in order to fit the globalized networked economy. Open innovation helps manage the product innovation, the process innovation, the market innovation, the input innovation, and the managerial innovation by allowing inbound and outbound innovation processes across the boundary of an innovation organization.

Open innovation has become more and more influential in the emergence of a globalized economy. Both the digital production and the physical manufacturing are becoming more and more diverse and complicated. Companies and individuals have to collaborate agilely and flexibly to survive the rapid-changing networked era. However, the study of open innovation is in its preliminary stage. Although open innovation has already been widely accepted as a helpful solution to manage the collective productions, the current theoretical and empirical frameworks in economics and management science are still unable to understand the mechanism of open innovation. Notably, we need to find an applicable managerial mechanism for the distributed open innovation in the business networks.

Particularly there are three “new normals” in the post-networked society. Firstly, the dynamic and plural economic landscape of the globalized society requires flexible and responsive productions. The comprehensive interconnections in the networked world generate an evolving globalized economy. Today’s productions, particularly the digital productions in the global network, have to be highly agile and interoperative. Secondly, the complexities of science, technology, and business force innovation processes to be collective and distributed. To satisfy the intensive demands and requirements in a globalized business context, firms have to make full use of the global supply chain, control all the resources and information flows. A “closed” corporate or a “dedicated” individual is no longer able to survive in the globalized era. However, a typical competition in the global network should not be a zero-sum game. Instead, an innovation network can form a win-win relationship between the participants.

To understand the open innovation from the historical, academic, theoretical, and empirical perspectives, and to survive the globalized new economy with the open innovation, we have set two objectives of this research: 1) to understand the conditions and restraining factors of adopting open innovation; 2) to understand the dependencies and routines for implementing open innovation.

Under the objectives, this dissertation is composed of four parts: Part 1) Chapter 1 and Chapter 2, the introduction and the background of open innovation. Part 2) Chapter 3, the literature review on the previous theoretical implications and empirical studies of the open innovation implementations. Part 3) Chapter 4 and Chapter 5, the original analyses of various empirical implementations of open innovation in different industrial sectors. After the three parts, part 4) Chapter 6 concludes this research and discusses the impact and implications of the open innovation paradigm in the globalized business context.

In the first part, we have discussed the emergence of open innovation in the globalized business context. We started from the comparison between the physical, discrete, “real” economy and the digital, networked, “augmented” economy in Chapter 1. After the digital revolution, the new era of the human economy has some different properties than the traditional productions: the marginal cost of digital production can be as low as zero, but the fixed cost of advanced manufacturing can sometimes be extremely high. Innovation causes the response from the system (Schumpeter, 1939, p. 172), and innovation is the answer to response to the systematic changes. With the discussions on a bundle of “strange” open business strategies in both the digital production and the advanced manufacturing, we have pointed out that the open business strategy is an updated innovation paradigm to survive in the globalized society. Therefore, we need to understand the mechanism of “open” innovation in the globalized networked economy.

Since open innovation is an updated paradigm based on the traditional innovation theory, we have then introduced the Schumpeterian innovation theory and the existing innovation management theories in Chapter 2. We have introduced the history of the Schumpeterian innovation theory as well as the theoretical development before the conceptualization of Schumpeterian innovation. We have then discussed the evolution from the “closed” in-house innovation approach to the open innovation paradigm. In the following sections of Chapter 2, we have investigated the new institutional economics, the open source movement in the software industry, and other distributed innovation methodologies that related to the development of open innovation paradigm. We have introduced several innovation management theories from different academic and practical backgrounds with a cross-disciplinary view.

In the next part, we have analyzed the existing literature on open innovation. In Chapter 3, we have first distinguished the various definitions of open innovation. After comparing the different typologies of open innovation, we have discussed the implementations, the benefits, and the challenges of open innovation in the networked production environment. We have also surveyed the beneficial and constraining factors, practical experiences, empirical implementations, and managerial implications of open innovation found by the previous research. After reviewing the previous theoretical research and the empirical studies, we have concluded the current research status of open innovation and addressed the remaining problems of the previous research at the end of Chapter 3.

The next part is the original research of this dissertation. We have first introduced the methodology and research design of the three groups in Chapter 4. We have defined the term "open innovation" as "the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation" (Chesbrough, 2006a, p. 17) at the beginning of Chapter 4. From the definition and the remaining problems of the existing literature, we then set the research questions based on the objectives of this research: 1) To understand the intra-organizational and extra-organizational mechanism of peer participation in distributed open innovation networks in the individual level of analysis; 2) To understand the organizational and inter-organizational mechanism of the distributed open innovation network in the collective level of analysis. We have further set two sub-questions for each research question: 1.1) What drives peers to participate in open innovation collaborations? (i.e., What are the sources of motive?) 1.2) How can peers trust each other in open innovation collaborations? (i.e., What are the sources of trust?) 2.1) How factors of network settings affect the establishment of an open innovation network? And 2.2) How to solve the coordination games in different types of open innovation networks? To answer these two questions and four sub-research questions, we have introduced the analytical frameworks, the research methodology and the research design in the latter part of Chapter 4. After combining the theories, analytical tools, and methodologies from the Austrian school of economics, the new institutional school, and the management sciences, this research presents a comprehensive analytical framework with four axes: the open innovation processes, the innovation types, the organizational factors, and the network configurations. This framework can assign the most findings of the existing literature. This research then applies the game theory to provide a theoretical background of the analytical framework. As the game theoretical models suggest, the analytical framework of this research is able to analyze the business implementations of open innovation.

In the empirical research part, this dissertation comparatively analyzes seven commercial companies representing different types of productions and implementing different open innovation approaches. By comparing the successful cases with the failed cases, this research has identified the conditions, path dependencies, and the necessary and sufficient factors to implement open innovation in different innovation types and different production networks. The empirical case studies have proven that open innovation is an effective solution to deal with cooperation and coordination issues in the distributed business network. Particularly, the empirical research has suggested that the capital-intensive and the labor-intensive firms, being ignored by the previous research, can also benefit from open innovation implementations if organized and managed properly.

6.2 Key Insights

6.2.1 Trust and Coordination in the Open Innovation Management

In the comparative case studies conducted in Chapter 5, we have found that the successfully open innovation implementations have one or more sufficient sources of trust. On the contrary, the lack of trust and coordination would increase the risks of open innovation adoption by a large amount.

There are also many pieces of previous research (Gómez, Olaso, & Zabala-Iturriagagoitia, 2016; Brockman, Khurana, & Zhong, 2018; Takei, Saeki, & Nagae, 2019; etc.) addressing the trust as a critical factor of open innovation implementation. Therefore, we would like to discuss the sufficient sources of trust and coordination sources we have found in our comparative case studies as well as the previous research.

Building interpersonal and interorganizational trusts through appropriate communication design

The different results from a similar open innovation approach of Case B and Case C have suggested that an appropriate communication design might be the key to build the interpersonal and interorganizational trusts.

In the previous research, Takei, Saeki, & Nagae has also suggested "close and dense communication" (2019, p. 33) can contribute to a trust relationship. Similarly, Yonekura & Shimizu also addressed communication as the key for user innovation approaches (2015, pp. 283-287).

Exploiting trust by actively using innovation intermediary

The previous researchers have found that innovation intermediary helps reach external resources in innovation network (Yonekura & Shimizu, 2015, pp. 120-131); innovation intermediary helps build trust between unknown peers from different innovation networks (Gómez, Olaso, & Zabala-Iturriagagoitia, 2016); and innovation intermediary helps contracting (Takei, Saeki, & Nagae, 2019, pp. 35-36).

We can also recognize the importance of innovation intermediary in exploiting trust in an unfamiliar network. In our case studies, Case E has made use of the innovation intermediary, and Case A has worked as the innovation intermediary in the innovation network it constructed.

Trust is important in open innovation practices. However, assuming mistrust is also important in successful open innovation implementations. If Case B could be less optimistic in setting a vast-spread cross-functional team, it might have succeeded with its open innovation implementation.

6.2.2 Adopting the Appropriate Open Innovation Managerial Mechanism

In our case studies, we have found that the open innovation implementations in China share a lot of similarities with their Japanese fellows found in Yonekura & Shimizu (2015) and those cases in other countries we have discussed in Chapter 3. In the implementations of the successful cases, managers have already been applying the proven managerial mechanisms and the best managerial practices suggested by Takei, Saeki, &

Nagae (2019), Levine & Prietula (2013), Chesbrough, Vanhaverbeke, & West (2014), and many other related scholars. The failed cases, however, have proven some of the insights from Conboy & Morgan (2011) and Remneland-Wikhamn, et al. (2011), on the contrary. An appropriate and suitable managerial mechanism should be the key to a successful business implementation of open innovation.

Nevertheless, it is difficult to choose a proper managerial mechanism for the open innovation implementation in the initialization stage of an innovation network. The following suggestions are shared by this research and many previous researchers.

Setting a clear and rational goal

Takei, Saeki, & Nagae (2019, p. 36) and Yonekura & Shimizu (2015, p. 49) have both suggested that setting a clear and reasonable goal is a good practice in open innovation implementation. In our case studies, B had set a goal too big for it to achieve, and led to its collapse.

Loosening control without losing control

In the case studies in Japanese pharmaceutical industry, Yonekura & Shimizu (2015, pp. 248-253) has pointed out that an appropriate level of controlling is difficult but important in the open innovation implementation.

In our case studies, the relationship between C and the Han's Laser group is a very healthy practice in open innovation. While not discussed in this research, corporate incubator suggested by Latouche (2019) is a promising way for adjusting the control of the open innovation network, especially for the corporate venture capital funds.

Promoting "Open Innovation", avoiding "Open *and* Innovation"

It is a common mistake in different open innovation implementations that the promoter does "open" but still "innovate" itself rather than in the open innovation network (Yonekura & Shimizu, 2015, p. 47). As the result, such "open and innovation" cannot make (full) use of the inflows and outflows, and thus has much worse performance than the real "open innovation".

6.3 Limitations and Remaining Problems

This research still has its limitations and left some remaining problems for the future research.

We have summarized a number of sufficient and necessary factors of the open innovation implementation from the business cases. However, our research methodology is based on a series of small-N comparative case studies. It was impossible for us to identify the different priorities or importance of the factors with our research methodology. Since the priority of factor is significant in business implementation of the open innovation paradigm, we suggest the future research to design a quantitative research method in solving this remaining problem.

Besides, this research does not discuss the psychological effects and factors of open innovation. For instance, can we abandon the endowment effect after adopting open innovation? If we cannot treat the internal and external resources without biases, it would damage both the coordination and the motives of the open innovation implementation. Future research may also analyze the psychological factors as the potential path dependencies or factors of the open innovation implementations. Furthermore, future research can take the social welfares and altruism as the constraining or incentive factors.

We have discussed the network configuration, and suggest the entrepreneur to choose a suitable open innovation strategy to fit the current innovation network setting. However, entrepreneurs can also use open innovation to change or reset the network configuration. Future research may focus more on how the network settings can be changed by the open innovation implementations, and how the open innovation processes can benefit from the reconstructions and destructions of the existing networks.

Although we have denied the applicability of open innovation in modular innovation, the proofs of this research are not comprehensive. There might be an open innovation approach that is suitable for modular innovation and niche innovation situations. Future research may refer to the alternative managerial mechanisms including the original user innovation theory (Von Hippel, 2005) to design a practical open innovation implementation for modular innovation.

In addition, this research focuses only on the cross-organizational open innovation implementations. Fortunately, there are already some pieces of research on the intra-organizational (in-house) innovation in the global distributed network. For instance, the dynamic capability theory possessed by Helfat & Winter (2011) is a possible mechanism for managing in-house innovation in the globalized networked business environment. There are also some case studies in Japan (Iwao, 2018; Wang, 2017; etc.) that should be beneficial to the research on this type of innovation management.

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