Management Strategy for Open Innovation in Korean Biochip Industry

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Jeong-Woo Choi

Abstract

Due to the need to access external knowledge for new product development (NPD), open innovation has been widely used in the biochip industry. Since current resources owned by single firm do not have all the capabilities, NPD in biochip requires strong interdisciplinarity, wide diversity of technological knowledge, and integration capabilities. In the present study, management strategy for open innovation is investigated for NPD in the Korean biochip industry. Open innovation is classified in three steps: (1) switching phase about starting open innovation in the NPD initial stage; (2) implementation phase about open innovation management in the NPD middle stage; and (3) transition phase about change to close innovation in the NPD final stage. Three models for three phases are developed and then tested by carrying out surveys in the Korean biochip firms. In addition, the transition phase model is evaluated in the Korean bio-pharmaceutical firms.

The switching phase model suggests that research capability and external trust are the main variables that affect switching cost, which relates to the perception of advantage of open innovation. The implementation phase model suggests that technological novelty affects degree of openness, which, in turn, relates to technological capability and firm performance. Furthermore, institutional-, environmental-, and firm characteristics affect the depth- and breadth of open innovation activity. The transition phase model suggests that knowledge connected with product innovation has an impact on the open-close transition tendency, which relates to perception of advantage of close innovation. Based on the results for three phases of open innovation, we propose the management strategy for open innovation during NPD. Therefore, based on the results of analyses of the proposed model, we can evaluate the factors that affect open innovation activity and develop an appropriate management strategy of open innovation for NPD of biochip.

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Table of Contents

List of Figures

List of Tables

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Dedication

To My God

and

To My Family

Chapter 1. Introduction

1.1. Introduction

Innovative product development in the leading-edge technology area has been subjected to two major pressures: reducing time-to-market and increasing the disintegration of product development processes into both production and development activities to get knowledge from the outside. Therefore, innovation for product development has been conducted with networks of partners outside organization and lead users all over the world, in the process that can be called open innovation (Chesbrough 2003a). In the process of coordinating the distributed innovative product development activities, project managers should use new network technologies.

Due to the need of external knowledge for new radical product development, open innovation has been applied to the leading-edge technology in, for instance, the biotechnology and pharmaceutical areas (Nilsson 2009; Fetterhoff and Voelkel 2006). Owing to the characteristics of this area, such as the need of combination of various techniques and scarcity of resources inside a company, the application of network or external scientists is needed for the development of radical product in the nanotechnology and nanobiotechology fields (Lane and Kalil 2005; Conrad 2009). Furthermore, since biosensor and biochip are products of the nanobiotechnology field, a relevant strategy to handle application of network or external scientists as one way of open innovation is urgently required. However, the management strategy in nanobiotechnology in open innovation, especially for the biosensor and biochip industries[1] has not been thoroughly investigated yet.

To practice open innovation in the biochip industry, the following questions need to be addressed:

−*How can a company get various technologies from the outside to make biochips?*

−*What would be a most appropriate management strategy for open innovation to get*

[1] In what follows, the biosensor industry and the biochip industry will be referred to as the biochip industry, since the assembly of various biosensors on one chip has been described as biochip.

technologies from the outside world and to control the technology supply chain?

The above questions are essential for the following reasons. The construction of a biochip needs a fusion of technologies, such as the biotechnology, electronics, chemistry, and the microelectromechical system (MEMS) technology. Therefore, firms want to get the technologies for product development from external partners, as firms cannot have all technologies and because there is a need to reduce the time for the development of technology. Open innovation is one way of outsourcing of technology. A new management strategy for open innovation is needed to efficiently get the technology from outside in order to effectively innovate in the biochip industry. The strategy should be made based on the combination of viewpoints of the technology supplier (external researcher) and the technology buyer (firm).

To construct a relevant strategy to get the knowledge from the outside, appropriate technologies for major stages of innovation (e.g. initial, implementation, final) are investigated in this study. Specifically, we propose that the technology supply chain is constructed based on open networks and proprietary networks.

In the initial stage, what is important is the decision to participate in open innovation and seeking participation of the technology supplier. To investigate the decision to participate in the open innovation, the switching cost from close innovation to open innovation is considered (Son et al. 2014; Matos 2009). Therefore, in this study, we investigate the firm's willingness to participate in open innovation related to the switching cost and its perception of advantage of open innovation based on external trust and research capacity. To construct the management strategy, the switching cost theory is examined to verify the relations between the technology supplier (researcher) and the technology buyer (firm). Furthermore, we also investigate the relation between the supplier of technology, type of collaboration with other companies, reward for technology transfer, as well as coordinator of technology transfer to major and education levels. In the initial stage, the strategy of organization to adopt open innovation in the biochip industry is suggested and the relations between variables are analyzed.

In the implementation stage, the management strategy for open innovation is related with the degree of open innovation (openness) and firm performance. The technology novelty and technology complexity affect openness and, in turn, openness is related to firm performance (Tatikonda and Rosenthal 2000; Vahter et al. 2014, Vahter et al. 2016). The resultant model for

relationships among technology novelty, technology complexity, openness, and firm performance is constructed and evaluated. Furthermore, breadth and depth of innovation related with firm performance that exits as a different form of open innovation is also investigated (Laursen et al. 2006; Greco et al. 2016). The factors that affect breadth and depth, such as environmental characteristics, firm characteristics, and organization characteristics, are also investigated. In the implementation stage, the strategy of organization to adopt open innovation in the biochip industry is suggested and the relations between variables are analyzed.

In final stage, the transition of innovation type from open to close occurs and, therefore, a strategy to manage this transition is needed. The effect of technology development for transition from open innovation to close innovation is analyzed based on the stage of new development in the biochip industry. Transition point from close- to open- innovation is decided based on the stage of the commercial product opening. Repeat of transition from close- to open- innovation is performed as new product emerges in the biochip industry. This transition from close to open innovation is important in terms of devising a management strategy of new product development in biochip firms. The model for relation between the transition tendency among technology knowledge, product innovation stage, government approval stage, and close innovation is constructed based on semi-structured interview in the biochip industry and then extended to biotechnology industry. Finally, in the implementation stage, the strategy of organization to adopt open innovation in biotechnology firms is suggested and the relations between variables are analyzed.

Research methodology used in the present study mainly involves data collection through e-mail surveys and semi-structured interviews with researchers in the Korean biochip and biotechnology firms. Data analysis is performed by using quantitative statistical approaches and SPSS is used as the analytical software. Semi-structured interviews are used as a research method to investigate the issues of the switching cost, openness, and transition. The required management strategy of organization to adopt open innovation in the biochip industry is suggested and future directions of open innovation in leading-edge technology area are outlined.

1.2. Open Innovation

1.2.1. Open innovation

Nowadays, industrial innovations is becoming more open, requiring changes in how firms manage innovations (Edward 2016; Chesborough 2003a,b; Hodson 2016; Holmes 2016; von Hipper 1999, 2005). Accordingly, external sources of knowledge become more prominent, while external channels to market offer a greater promise. Based on open innovation concepts, in order to advance technologies, firms should use both internal and external paths to the market (Bender 2016; Owens 2016).

Despite the growing body of evidence that supports how effective open innovation can be, companies still resist its ideas. Many researchers have explained open innovation as inbound- and outbound- innovation (Chesborough 2006b; Chesborough and Crowthther 2006; Savage 2016; von Hipper and Krogh 2015). However, in recent years, industry leaders have had to face a new reality: the situation when really good ideas are coming from the outside. Thus, deciding to open up to external ideas is a vital step towards stimulating a greater growth and innovation in firm. However, it is not just the first step. It was found that even committed companies believe in the myths and share the misconceptions that impair their ability to connect to useful external thinking (Chesborough 2004, 2006a). The four common myths about open innovation are as follows: (1) No one understands your needs; (2) There are no new ideas; (3) Response to your needs will be too academic to be useful; (4) Intellectual property issues make access to external innovation too complex. Once company overcomes these myths, it must face the reality: the prevalence of the Not Invented Here Syndrome. This syndrome should be overcome again to achieve open innovation.

In such open innovation and uncertain circumstances, the firm needs to “play poker” (Chesborough 2004) and chess to compensate for the measurement error and manage risk such as “false negatives”. “Play poker” means that firms do not know all the information in advance and, therefore, have to decide whether to spend additional money to continue with the current project or to move to next projects, which makes new metrics for firms. New metrics could help a firm focus more upon external sources of innovation to enhance its business model. The concept of use of external sources based on new metrics in open innovation is one of the basic

principles of innovation in the new product development.

In an investigation of recent trends and tendencies in open innovation, Gassmann (2005) shows that, although a trend towards open innovation can be observed, open innovation is not an imperative for every company and every innovator. Rather, there is a need for a contingency approach regarding the management of innovation with the focus on determining which of the factors that drive higher performance should be open and which should be closed. The nuclear and military industries are typical examples of close innovation industries where non-proliferation of technology and protection remain important. Grassman (2006) reports that the more an industry's idiosyncrasies correspond to the developments and trends, such as globalization, technology intensities, technology fusion, new business model, and knowledge learning, the more appropriate the open innovation model appears to be.

To date, open innovation concepts have been regarded as relevant primarily to top 'high-technology' industries, with examples that include Lucent, 3Com, IBM, Intel, and Millennium Pharmaceuticals (Chesbrough and Crowther 2006). Chesbrough and Crowther (2006) provide the explanation of the application of open innovation to outside high technology industry and report that, specifically, it was identified that organizations in industries outside 'high technology' are also early adopters of the concept. The investigation results reported by Chesbrough and Crowther (2006) demonstrate that many open innovation concepts are already in use in a wide range of industries. The authors document practices that appear to assist organizations in adopting these concepts and conclude that open innovation is not *ipso facto* a recipe for outsourcing R&D. Rather, open innovation has utility as a paradigm for industrial innovation beyond high tech to more traditional and mature industries.

Furthermore, O'Conner (2006) suggests that radical innovation must be open innovation in large established firms. While growth and profit alternatives continue to erode many companies, the importance of radical innovation as a mechanism for organization rejuvenation is increasing (O'Conner and Ayers 2005). Some firms are building entire manufacturing systems to enable radical innovation over and over again. They are experimenting with different organizational structures that vary in terms of their relationship with R&D and in terms of how far down the commercialization path they oversee projects. To have a fully developed radical innovation capability, the firms should manage the following three sets of activities: discovery, incubation, and accelerated growth of new businesses. In addition, they should also ensure smooth transitions between these activities. In addition, there is a number of organization factors that

leverage the human side of making radical innovation happen that, if viewed systematically, could be more broadly used for a greater radical innovation success (O'Conner and McDermott 2004). Specifically, O'Conner and McDermott (2004) outline gaps and mismatches that emerged between the expectation for radical innovation to happen and the mechanisms by which people are incented to do so (O'Conner and McDermott2004).

In addition, Christensen et al. (2004, 2005) report how the open innovation concept can be analyzed from industrial dynamic perspectives. In these studies, the main proposition is that the specific models using which different companies manage open innovation with regard to an emerging technology reflect their differential positions within the innovation system in question, as well as the nature and stage of maturity of technological regime and the particular value position pursed by companies. This proposition was analyzed through an in-depth study of the current transformation of sound amplification from linear solid state technology to switched or digital technology within the consumer electronics system of innovation (Christensen et al. 2004, 2005). The results of this analysis suggest that there is a complex interplay between technology entrepreneurs and incumbents and that sometimes open innovation has to be conducted under the conditions of high transaction costs.

Furthermore, Krischbaum (2005) reports an example of application of open innovation to company and suggests the optimal strategy of open innovation. By combining internal and external competencies and knowledge, both in R&D and marketing, the multinational life sciences and performance materials company Dutch State Mines (DSM) is opening up its innovation process. DSM recognizes that successful, profitable innovation depends upon team work and appropriate entrepreneurial culture. The presence of a business group dedicated to business development and venturing testifies to the increased importance of speeding up innovation at DSM, using both internal and external leads at all stages of new business development. During this process, different management styles are required, ranging from a scientific approach in early stages, through an entrepreneurial attitude in the early phase of commercialization, to a more risk-adverse mindset once the business has matured.

Taken together, the results of the above studies suggest that management strategy should be needed for activity of open innovation.

1.2.2. Open source

Goldman and Gabriel (2005) explain the open source approach, alternatively referred to as "innovation happens everywhere", as s different way of doing business. There exists a large open-source community with established practices and cultures. Companies and other parties willing to start or join an existing open-source project need to understand the ground rules and established practices of this larger community, as there are the term open source sets expectations that need to be either met or explained. There are many definitions of what constitutes an open source. The basic idea is very simple: for open source software as an example, by opening the source code for a piece of software available to all, the programmers can modify it to better suit their needs and redistribute the improved versions to other users. By working together, a community of both users and developers can improve the functionality and quality of the software. Therefore, an open source requires that anyone can get and modify the source code and that they can freely redistribute any derived works created from it. Thus, the open-source community has been worked as the resource of the technology supplier in the open source computer.

The "hybrid open source project" concept was first proposed by Goldman and Gabriel (2005). When companies start open-source projects, it is typical for those projects to be part of a company's initiative for strategic purposes and aims. Since many companies use a more traditional or conventional development process, such companies starting open-source projects are likely to want to engage the open-source community with some of their traditional tools and in-house experts. When this happens, it can be called as "hybrid open-source project". For example, while GE started its Visualization Toolkit open-source project, they wanted to establish a strong cultural value around testing and quality. Based on some ideas from Extreme Programming, they instituted a distributed, automatic testing system that kicks in every night on the changes submitted project that day.

The open-source project has been applied as the concept of open innovation with a company's initiative and use of external resources in biotechnology areas. A.R.A. Jefferson, an American-born molecular biologist, seeks to increase innovation in the life sciences by applying software's open-source model to biotechnology (Broothaerts et al. 2005). His goal is to change the global patent system and how people use intellectual property, as well as to break

the grip of the big multinationals on the tool of innovation. Currently, open source movement in biotechnology has been done by CAMBIA, an international, independent non-profit research institute (www.cambia.org). CAMBIA has been creating new enabling tools to foster innovation and spirit of collaboration in the life sciences. CAMBIA's BIOS Initiative™ (Biological Innovation for Open Society) is exploring new R&D paradigms, practices, and policies that would address neglected priorities of disadvantaged communities.

CAMBIA's[2] activities are as follows: (1) Open innovation depends on transparency in the patent system. CAMBIA's Patent Lens™ provides tools to make the world of patents and patent landscapes more transparent, to help focus paths leading to freedom to cooperate. These tools include one of world's largest free-full text searchable life sciences patent databases, now expanding to include all technology classifications, as well as a variety of technology landscapes and intellectual property tutorials. (2) BiOS (Biological Open Source) Licenses have resonance with the licensing strategies that have evolved around free and open source software, but are uniquely crafted for the characteristic complexities, constraints, and business practices of modern life sciences. The BiOS Compliant Licenses are also designed to stimulate new opportunities, galvanize new groups of innovators, and achieve new efficiencies by encouraging a distinction between tools of innovation and the products and services. Biological Open Source Compliant Licenses create a dynamic protected technology commons where a material or invention can be improved by the ideas of many; however, access is maintained for all who agree to the terms without exclusive capture by anyone. CAMBIA has seeded this movement with its own technologies and other technology owners may also provide licenses to their technologies using this framework.

Furthermore, BioForge,[3] an online collaborative research platform for biological innovation, has been launched and developed in partnership with CollabNet Inc.[4]. In tradition of open source software, BioForge makes it possible for scientists to work together to craft new, deliverable technologies within a protected commons.

Therefore, the open-source community in biotechnology should be the resource of technology supply in open innovation of the biotechnology field, which can be further applied to construct the technology supply diagram for the biochip field in the present study.

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[2] For further detail, see www.cambia.org
[3] For further detail, see http://www.bioforge.net
[4] For further detail, see http://www.collab.net

1.3. Technology Development

Currently, firms urgently need to reduce time-to-market in new product development (NPD) and, therefore, to get enough technology for commercial product-to-market inside the firm imports using knowledge from external partners. Thus, increasing NPD should be carried out with partners and lead users outside organizations, and then be distributed all over the world, transforming thus into distributed new product development (DNPD). The project managers should use new network technologies in the process of coordinating the DNPD activities.

Since the innovation type is affected by the stage of new product development, the new product development in the biochip industry is related to the construction of management strategy of open innovation. The recombinant innovation, democratization and 'connect and develop' have been proposed as the way of open innovation in new product development as explained in the followings.

1.3.1. Recombinant innovation

Rather than cashing entirely new ideas, successful firms to achieve innovations focus on recombining old ideas in new ways by working with social networks during breakthrough innovation (Hargadon 2003a, 2004). Instead of insulating their innovation efforts from operating divisions, customers, and suppliers, these firms extensively rely on these partners. An intelligent recombination of existing technologies and innovations has driven the breakthrough in technologies. By spanning multiple, otherwise disconnected industries and markets, successful firms become the first to see how the existing technology in one market could be effectively used to create breakthrough innovations in another market.

The technology brokering for recombinant innovation requires to bridge distant communities and to build new communities around those innovative recombination, which involves tapping the networks of innovation (Hargadon 2000). Bridging the otherwise disconnected communities in a firm's external networks causes bringing the firm's technical expertise to new

markets and industries. Devoting more resources to building new networks around a potential innovation can prove to be equally beneficial. Rather than nurturing individual geniuses, successful firms develop strong social networks both within and outside their groups (Hargadon 2004). This kind of social network base innovation should be the key principle of distributed new innovative product development in open innovation.

However, pursuing the strategy of technology brokering does not mean throwing out the old R&D organization altogether (Hargadon 2003b). Aside from trying to invent the future, traditional R&D provide two critical competencies. First, these labs foster the expertise needed to evaluate existing technologies developed and used elsewhere. Second, the labs are best equipped to provide process innovations that fit within the organization's particular constraints. To pursue a strategy of technology brokering means recognizing that a key role of corporate R&D is bridging the many different existing industries and markets and building the necessary combinations of technologies and people to enable potential breakthroughs. However, making this happen means moving the organization and the culture of R&D away from the leading edge pursuit of inventions.

1.3.2. Democratization

R&D has long been a costly and inexact process. Presently, some companies are trying a radically new approach by providing their customers with the tools to create, design, and develop their own products (von Hippel 1999; Thomke and Von Hippel 2002). For example, in their study of this democratization, Thomke and Von Hippel (2002) show that the customer, especially a lead user, has been emerged as innovators for a new way to create value. While trapping in top customer innovation can certainly generate tremendous value, capturing this value is hardly a simple or straightforward process. The companies should not only must develop the appropriate toolkit, but also revamp their business models and their management mind-sets. Now, with customers taking over more of the design task, companies should more closely focus on providing the best custom manufacturing. Said differently, as the location where value is both created and captured changes, the companies must reconfigure their business models accordingly. In addition, innovation development, production, distribution, and consumption networks can be built-up horizontally by and for users (Von Hippel 2005).

Furthermore, as suggested by Von Hoppel and Krogh (2006), free revealing of product and process designs is a defining characteristic of open innovation. Specifically, free revealing is the feature that facilitates collaborative design where all can participate, as in the well-known case of open source software projects. However, empirical research shows that free revealing of product and service designs is practiced far beyond the software industry. Therefore, a central tenant of open innovation is free revealing of the detailed workings of novel products and services, so that others may use them, learn from them, and perhaps improve them as well. Innovators frequently do freely reveal proprietary information and knowledge regarding both information-based products and physical products they have developed. On top of that, free revealing can make good economic sense for innovators and the society on the whole. Free revealing can be understood in terms of 'private-collective' model of innovation incentives. This model occupies a fertile middle ground between the traditional private and the collective action model of innovation incentives. This model explains conditions under which an innovation created by private funding may be offered freely to all. When these conditions are met, the society appears to have the best of both worlds: new knowledge is created by private funding and then the result is freely offered to all.

1.3.3. Connect and develop

Another process using open-source innovation strategy is "connect and develop" developed by Procter and Gamble Co. (P&G) (Dodgson et al. 2006; Huston and Sakkab 2006). "Connect and develop" is not a different type of innovation, but is rather an example of specific implementation choice of open innovation. As reported by Huston and Sakkab (2006), P&G created a technology brief that defined the problems needed to be solved and circulated it throughout the global networks of individuals and institutions to discover if anyone in the world had a ready-made solution. In 2000, realizing that P&G could not meet its growth objectives by increasingly spending more on R&D for less and less payoff, the reinvention of company's innovation business model started. At that time, most of P&G's best innovations had come from connecting ideas across internal businesses and, in this context, the external connection could provide highly profitable innovations. Betting that these connections were the key to future growth, P&G set the goal to acquire 50% of innovations from outside the company. As

outside source of innovation was studied, it was estimated that, for every P&G researcher, there were 200 scientists and engineering experts elsewhere in the world who were just as good, which amounted to a total of ca. 1.5 million people whose talents they could potentially use. The massive operational change and culture change have been implemented for tapping into the creative thinking of inventors and other external parties. This kind of innovation model was called as “connect and develop”. The model works and, today, over 35% of new products in the market have elements originating from outside P&G. Through “connect and develop” coupled with improvements in other aspects of invention related to production costs, design, marketing, R&D productivity has increased by nearly 60%.

As specified by Huston and Sakkab (2006), the connect-and-develop strategy requires that a senior executive has day-to-day accountability for the company’s vision, operations, and performance. At P&G, the vice president for innovation and knowledge has this responsibility. Connect-and-develop leaders from each of the business units at P&G have dotted-line reporting relationships with VIP. The managers of virtual R&D networks (such as NineSigma and P&G’s virtual supplier network), as well as the technology entrepreneur and hub network, connect and develop legal resources and directly report on training resources. The VIP oversees the development of networks and new programs, managers the corporate budget, and monitors the productivity of networks and activities. This includes tracking the performance of talent markets, like NineSigma and InnoCentives (virtual open innovation web-site), as well as measuring connect and developing productivity by region evaluations, e.g. the costs and output (as measured by products in the market) of foreign hubs. Productivity measurements for the entire program are reported annually.

Following the success of P&G, several other forward-looking companies like IBM and Eli Lilly started to experiment with the new concept of open innovation, leveraging one another’s competition assets – products, intellectual property, and people (Husto and Sakkab 2006). By now, the open innovation method of “connect and develop” has been widely spread worldwide due to its benefits for companies and their need of innovation (Dodgson et al. 2006).

The main philosophy of the “connect and develop” method will be applied to construct the strategy for open innovation proposed in the present study.

1.4. Biotechnology

1.4.1. Alliance characteristics of biotechnology industry

Alliance is a way of collaboration that is the main activity of open innovation. In the biotechnology industry, strategic alliance including mergers and acquisitions (M&A) is essential for the survival and evolution of companies. Although strategic alliances are generally analyzed as planned and rational developments with clearly measurable outcomes, de Rond (2003) provides an important new explanation of how strategic alliances develop in the biotechnology industry. Since alliances in the biotechnology industry have become an important way of competing in our globalizing world to increase firms' performance, their number has dramatically increased in recent years.

In this respect, Williams (2005) argues that consolidation is a necessary activity for biotechnology companies and corporate development in biotechnology. The author considers consolidation as an important mean for biotechnology companies to acquire strong positions to enter into partnering negotiations in the spirit of combining their core competencies with those of partners with complementary skills (especially in sales), rather than to act as financially starved supplicants (Williams 2005).

The numbers conspire to make finding a partner increasingly difficult. In 2004, there were 4,500 biotechnology companies and only 15 large pharmaceutical companies, i.e. potential partners with near global reach. Therefore, a biotechnology company faces a strong competition and the partnership between a big pharmaceutical company and a biotechnology company is necessary for their mutual development.

Previous data monitor analysis undertaken by Pavlou and Belsey (2005) has identified two key company categories currently shaping the biotechnology industry, namely, the leading biotherapeutics players and the emerging biotherapeutics players. The mergers and acquisitions (M&A)/licensing agreements and current-in-house-technology development by R&D are critical factors for the evolution of the leading and emerging biotherapeutics business model. Through consolidation, the emerging companies become to be fully integrated and gain sustainable profitability. Intrabiotechnology companies or biotechnology company-to-

pharmaceutics company deals and commercially attractive technology acquisition activities should help to win the race of innovation and sustainable growth (Pavlou and Belsey 2005). Therefore, the alliance including M&A and technology development due to alliance are key factors enhancing the organization evolution in the biotechnology industry..

In sum, as suggested by the results overviewed above, the alliances between intrabiotechnology companies or biotechnology company-to-pharmaceutical companies are among the major factors to be considered for the development of the biotechnology industry.

1.4.2. Innovation management in biotechnology

Innovation is the fuel of the biotechnology industry; accordingly, biotech innovations arise from many fields, including biology, physics, computation, and engineering. However, all these fields share the common goal of the development of products or processes designed to improve our health, environment, or agriculture resources (Lőffler 2005). Clearly, not all innovations lead to the creation of good products, and not all good products build profitable companies. Innovations are particularly difficult to access because of the problems inherent in estimating all possible applications, market size, and time to market. Although quantitative assessments (such as net present values, risk-adjusted present values, and options) provide us with concrete numbers, they also yield an incomplete picture of the potential value of a technology. Using quantitative assessment alone may result in overlooking the most intriguing and revolutionizing biotechnologies. A more accurate assessment is possible when quantitative factors are also considered, such as inventive potential (i.e. whether the technology is revolutionary or evolutionary), applicability (i.e. whether the technology has a clear commercial application), and market environments (i.e. whether the public, regulatory, and policy environments are ready to deal with the innovation). Upon integration of qualitative and quantitative measurements, a quadrant emerges where, depending on their relative qualitative versus quantitative scores, different technologies can be compared and categorized as “winners”, “promising”, ”dogs”, and “low-hanging fruit” (Lőffler 2005).

Since the nanobiotechnology to be investigated in this study is a revolutionary emerging technology, the proposed analysis (qualitative versus quantitative score) will be performed for nanobiotechnology.

As explained by Shohet (2004), biotechnology companies are under intense scrutiny and unremitting pressure from shareholders and inventors to overt their costly R&D inputs into value-creating outputs. However, the techniques and tools to influence and manage R&D productivity are often weakly developed and are rarely fully deployed in many early-stage and mid-cap biotech businesses. There are many reasons for this trend, not least of which is that biotech companies often have a strong-science-led heritage and ethos, where the anarchic elements of research are encouraged. In big pharmaceutical companies, diagnostics, and medical technology companies, the disciplined tools for research management and product development are not at first seen as necessary and are frequently overlooked as the company grows. In fact, as will be argued in the present study, there is a considerable opportunity for biotech managers to strengthen R&D performance productivity through deploying more robust management tools that would enhance strategic, organizational and operational processes. This will lead to a better allocation and use of resources, as well as ensure that the right products are developed in the right way and at the right time. In relation to R&D, there are many ways for the senior managers of biotech companies to achieve a better practice, even if the best practice in biotech has yet to be well defined and validated. As the business grows, robust systems for R&D management become essential, not just to help allocate resources, but also to organize the company and to minimize risks and properly exploit the product opportunities. Managing these opportunities using a better R&D practice will help to ensure the sustainability of the business and deliver the growth and success required by shareholders and investors.

In the present study, the open innovation in R&D of the biochip industry will be proposed to be managed based on the concepts outlined above.

1.4.3. Open innovation in biotechnology

In the increasingly competitive landscape, there is a growing demand for companies to be innovative. However, the concept of innovation in a product innovation is confused by the development of technology to make product. If innovation is defined as the commercialization of an enabling technology that provides the customer with a new capability, then there are two key requisites for innovation: customer insight to identify unmet need, on the one hand, and technology awareness to identify the respective enabling technology, on the other hand. Drivers

for innovation can be thought of as any force that links customer need uniquely with an enabling technology solution; this region of overlap is described as the innovation space. As shown by a report Fetterhoff and Voelkel (2006), Roche Diagnostics manages the challenges of sourcing external technologies by leveraging these drivers through comprehensive technology evaluation.

Although most companies understand the need for external innovation, only few capture the full value of partnership with external technology providers. Value can be progressively built throughout the process of managing external innovation. This external innovation value chain can be thought of as consisting of the following five key stages: (1) Seeking opportunities; (2) Evaluating the market potential and inventiveness of a given opportunity; (3) Recruiting potential partners by building a convincing argument; (4) Capturing value through commercialization; and finally (5) Extending the innovation offering. Each stage offers a unique opportunity for value creation, but presents different challenges requiring unique skills and responsibilities. At Roche Diagnostics, for the start stage of external innovation, seeking and evaluating were mainly considered.

At Roche Diagnostics, a process built upon six axes for technology assessment has been established (Fetterhoff and Voelkel 2006). These six axes, resembling a hexagonal ring, are as follows: (1) Customer utility; (2) Competition, or uniqueness of the opportunity; (3) Commerce, or market size; (4) Capital, or cost of opportunity; (5) Copyright, an intellectual property; and (6) Company fit, or strategy. Moreover, the space created by the corresponding axes defines perspectives from which the market potential for a given technology can be assessed. This six axis chart and the space created within it define multiple perspectives that offer a comprehensive approach to the assessment of the market potential for a given opportunity. If a given technology opportunity is positively evaluated, then recruitment, value capture, and extending processes have been done for external innovation. Roche Diagnostics manages external innovation by creating a vision of future based on customer insight and provides a comprehensive assessment of enabling technologies through multiple perspectives. Implementing the process outlined in the above within Roche Diagnostics has led to a successful value creation through multiple technology partnership and technology acquisition.

In the present study, the technology assessment skill proposed above will be applied to evaluate the market potential and inventiveness of a given opportunity in open innovation in the field of nanobiotechnology.

Another relevant company of open innovation in biosciences is InnoCentive[5]. InnoCentive was created to foster innovation and efficiency in the area of R&D for major companies around the globe. The company was launched in 2001 as a start-up business venture incubated through a division of Elli Lily and Company. InnoCentive is an unbiased knowledge broker between major global companies and the worldwide scientific community, enabling them to collaborate and solve difficult problems. Global companies post their tough R&D problems on the confidential InnoCentive website[6] for more than 22,000 leading scientists and researchers in 125 countries to solve these problems for financial reward (Demir 2003).

Solution-seeking companies, called Seekers, post their scientific problems on the InnoCentive website for the global community of registered scientists, called solvers, to access and have the opportunity to submit solutions. After a careful review by InnoCentive and the seeker's company, awards are issued by InnoCentive only for the best solution that met the seeker's requirement. Award amounts range from US$5,000 to $100,000. In exchange, intellectual property rights are transferred from the solving scientist to the anonymous solution-seeking company. In addition to network of scientists that make up global Solver base, InnoCentive has a core team of top scientists and business executives in Andover, Massachusetts, and Indianapolis, Indiana. To date, InnoCentive is working with leading global companies such as BASF, DOW Chemical, P&G, Syngentra, and others, enabling them to confidentially post their tough R&D problems on the InnoCentive website. In addition, InnoCentive collaborates with a number of academic and research-based institutes around the globe. Initially, InnoCentive began with a focus on chemistry challenges (organic, inorganic, bio-organic, medicinal, biological, structural, etc.), but, in the past year, it has been expanded into other scientific disciplines including biology (microbiology, genetics, proteomics, genomics, pharmacology, bioengineering), biochemistry, and material science.

Therefore, InnoCentive has introduced open innovation in biotechnology, such as in the bioscience and bioengineering areas, which can be applied for open innovation of nanobiotechnology to be investigated in this study.

Furthermore, as concerns the pharmaceutical industry, Nilsson (2006) has reported open innovation in the pharmaceutical industry as follows. Since the pharmaceutical industry is both

[5] For further detail, see www.innocentive.com
[6] For further detail, see www.innocentive.com

one of the most research-intensive industries and a big industry in terms of revenue, it is important to acquire a deeper understanding of the trends in localization of R&D facilities. The open innovation strategy, where companies' R&D crosses over corporate and national borders, becomes popular in the pharmaceutical industry. A challenge in pursuing open innovation strategy is the coordination of R&D sites. In localized R&D sites, it is important to optimize the use of technologies, systems, and processes so that to ensure the collaboration across the organization.

Leading research-based pharmaceutical and biotechnology companies in the United States spend on an overwhelming percentage of R&D dollars in the U.S. At the same time, the number of R&D laboratories that these companies locate outside the U.S. is growing, alongside with their overall spending on R&D. The increased complexity of the science used to develop today's medicine drives more pharmaceutical companies to establish laboratories close to research hotbeds around the world.

While acknowledging the need for an open innovation strategy and sharing the belief that this strategy will grow increasingly prevalent within the pharmaceutical industry, involved actors also point out that costs and coordination difficulties create constrains in implementing the strategy. Moreover, the time necessary to get a new laboratory up and running is considerable. Therefore, there are reasons to expect the process of establishing R&D facilities in new places to move slowly and to depend on the financial situation of the companies.

Cookie (2009) reported that micro-economic geography related to knowledge capabilities of firms, and their network in open innovation of biotechnology industry as follows. R&D outsourcing and open innovation economic geography for biotechnology have been investigated and collaborative relations between firms or between firms and clusters are focused in research. In UK's biotechnology sector, there is considerable asymmetry in the location of research-driven clustering. Innovation attracts distant networks of cooperation in UK's biotechnology sector, which well matches the characteristic feature of biotechnology where R&D is related to collaboration between external partner firm and inside laboratory.

In the present study, the results on open innovation in the biotechnology industry overviewed above will be applied to construct the strategy of open innovation in the biochip industry.

1.4.4. Innovation management in nanobiotechnology

At present, since the nanobiotechnology-based products are in the developing stage at laboratories and commercial products have not been made, few reports are available about the management of innovation and case study of open innovation in nanobiotechnology.

According to Adhikari (2005) the convergence of technology with biology at the nano level is called nanobiotechnology. Nanobiotehnology has immense implications for medicine. However, while it works well in laboratory conditions, the transition of therapeutic concepts from mice to men is not easy to make. Four key areas of nanobiotechnology are therapeutics, drug delivery, tissue reconstruction, and imaging and diagnostics. Although the benefits of nanobiotechnology are huge, there are certainly many hurdles ahead to lead nanobiotechnology-based new products to become approved therapies.

In the present study, a strategy of innovation in nanobiotechnology so that make commercial products will be proposed.

According to Thomas and Acuna-Narvaez (2006), nanotechnology offers a promise to revolutionize the life sciences, because it equips biologists with tools and materials that can interact directly with the studied biomolecules. Both biotechnology and nanotechnology have matured to the point where their convergence offers opportunities for novel solutions to the unmet needs in biology. Although nanotechnology has always held a great promise as a platform for biotechnology applications, this convergence has taken longer than anticipated. Nevertheless, the pace of this convergence is now accelerating. Although there are a number of factors that have probably catalyzed this convergence, the primary ones relate to the increasing maturity of biotechnology and nanotechnology, greater opportunities for public funding and collaborations, and increasing interest and funding from the private sector, which is helping to convert technological advances into commercial applications.

In this study, in order to design the strategy of innovation of nanobiotechnology, the key factors to catalyze the convergence of biotechnology and nanotechnology will be considered.

Furthermore, in their report on the application and commercialization strategies in nanobiotechnology, Amurthur et al. (2005) distinguish between two forces that are driving applications in nanobiotechnology: the sheer force of the scientific advances that provide

revolutionary enabling technologies, on the one hand, and the tremendous need to surmount specific medical and pharmaceutical hurdles, on the other hand. In general, these applications can be divided into three main categories: detection, diagnosis, and therapeutics. The commercialization of nanobiotechnology is characterized by three distinguishing factors: (1) boundaries between research and commercialization are blurred; (2) transformation agents need to be highly technical; and (3) conversion agents need to devise multiple strategies. Advances in enabling technologies have accelerated the onset and development of nanobiotechnology. Compelling scientific and business drivers will accelerate the pace of innovation in this field and create significant commercialization opportunities. It is widely assumed that university and research labs are playing a decisive role in closing the gap between research and commercialization frontiers for nanobiotechnology applications.

Therefore, in the present study, the commercialization strategies will be be combined with open innovation strategy of nanobiotechnology.

Furthermore, as reported by Conrad (2006), the National Cancer Institute (NCI) recognizes the needs of physicians and basic research scientists to collaborate and, therefore, has established a new “team science” model for cancer research by aligning funding mechanisms, organization culture, and strategic investments to accelerate interdisciplinary research. This team-oriented model lies at the core of new programs that form the Alliance for Nanotechnology in Cancer. The model includes teams of experts who can not only view the many elements of the cancer progress, but can also integrate that knowledge and design in an innovative and targeted strategy of drugs, biologics, and even devices that can be used in all phases of the cancer process in an integrated fashion.

In the present study, the concepts for open innovation in the nanobiotechnology industry outlined above will be applied to construct the strategy of open innovation of the biochip industry.

1.4.5. Development of the biochip technology

The biochip technology has been developed from biosensor array to DNA chip or protein chip. Recently, cell chip is being developed, which will be followed by the development of

organ chip. Microarray technology such as MEMS (microelecromechanical system), has been applied to the fabrication of all kinds of biochip.

A DNA chip is a technology used in molecular biology and biosensor fields that consists of an arrayed series of thousands of micro/nanoscopic spots of single stranded DNA oligonucleotides, known as probes (Lenoir and Giannella 2006). The probes are complementary gene sequence of desired targets, which can be hybridized to cDNA or cRNA of the analysis target. Depending on the high specificity of complementary DNA strands, an array of several targets can be used to detect multiple targets at the same time. Therefore, micro/nanoarrays have dramatically accelerated many types of investigation in the DNA chip field. DNA chips can be used to measure changes in expression levels, detect single nucleotide polymorphisms (SNPs), as well as genotype or re-sequence mutant genomes (Ramsey 1988). They also differ in sensitivity, selectivity, and cost effectiveness as compared to traditional detection techniques.

A protein chip provides a multiplex approach to identify protein-protein interactions, transcription factor protein-activation, and the targets of biologically active small molecules (Zhu and Snyder 2003). Sometimes it is referred to as a protein microarray. The protein chip is a piece of glass on which different molecules of protein or specific antibody binding for specific binding DNA sequences (as capture probes for the proteins) have been affixed at separate locations in an ordered manner, thus forming a microscopic array. The most common protein chip is the antibody microarray where antibodies are spotted onto the protein chip and are used as capture molecules to detect proteins from cell lysate solutions. Also, protein chip has not been used instead of protein microarray (Seong and Choi 2003). The protein chip was was originally used by electronics to describe small solid blocks containing various electrical circuits. Along the same lines, protein chip denotes an integrated circuit which electrical and logical functions performed by protein molecules when appropriately manipulated. However, we now call all solid membranes (glass slide, wafers, and polymers) biochips when biomolecules, such as DNA, proteins, lipid, carbohydrates, or conjugates between them are attached by covalent or noncovalent bonding. In addition, mechanical fluidic devices for the analysis of biomolecules in terms of quantity and quality are also called biochips or Lab-on the chip (LOC). Since the term ‘protein chip’ has also been used to denote biochips attached with proteins for biosensors, the terminology gets confusing. In addition, some of the chips show different patterns of protein arrays that are not observed in the fields of DNA chips.

Cell chip is a progressive type of biochip that can analyze the data of cell itself (Yea et.al. 2007). This is an integrated technology that combines surface modifications to allow *in vitro* cell culture within the micro-chip and subsequent conversion of the physiological phenomena of these cells to a readable signal (El-Ali et al. 2006). This technology can be used to detect materials and measure microbial phenomena that cannot be detected by conventional biosensors used for the analysis of DNA and proteins, as well as an *in vitro* analysis not available in normal environment due to multiple cues that vary in time and space, including gradients of cytokines and secreted proteins from neighboring cells. Over the last several years, the interest in biochemical experiments and analysis of living cells has increased for studying effects of drug and external stimuli on cell behavior. To meet the needs for proper cell analyzing tools, various analytical techniques, such as resistance-, enzyme-, or fluorescence-based methods, have been developed to detect cellular signals in a simpler way with a high sensitivity. Label-free electrical techniques have also been tried for detecting changes of action potentials or electrochemical properties of target cells. Recently, extracellular action potential of cardiac myocytes and neuron cells derived from stem cells was successfully measured using a micro electrode array, which is not available with the optical or fluorescence based technique. Furthermore, the MEMS technology was also integrated to cell chip for further cell treatment or cell separation process, which can be included in the 'lab-on-a-chip' or 'micro-total-analysis-system(μTAS)' field. These various kinds of cell chips that can integrate many different techniques for different purpose can be usefully applied to cellular research.

The microfabrication technology has been applied to construct DNA chip, protein chip, and cell chip (Šášik et al. 2004). The first widely used technology was the spotted cDNA microarray, which consists of numerous probes of PCR-amplified cDNA fragments deposited in a matrix pattern of spots. A microarray is a structure that consists of sequential dots and plays an integral role in gene expression profiling. The substrate material is plastic, glass, or a silicon chip. A microarray can be made using various methods. The simple way is to merely drop the DNA onto glass slides using pins. More sophisticated methods use photolithography, electrochemical approaches, and inkjet printing. While the array technology was in use as early as in the 1980s, it did not come into prominence until the mid-1990s, when biotechnology really began to take off. Today, microarrays are widespread in genomic research and have a diverse range of applications in biology and medicine (Hoheisel 2006). This technique allows a researcher to simultaneously perform a sequence of tests on all of the samples, which dramatically speeds up research, as traditional biological experimentation works on samples one at a time.

Therefore, considering that the innovation type can be changed based on the stage of new product development, in the present study, the history of development of new products in the biochip industry will be considered to construct the strategy of open innovation in the biochip industry.

1.5. Research Questions and Objectives of the Present Study

The two basic research questions addressed in this study are as follows:

- *How can a company get various technologies from outside to make biochip?*
- *What is an appropriate management strategy for open innovation to get technologies from outside by co-managing technology supply?*

Although there are some investigations on management strategy for open innovation in the biotechnology industry, the management of technology for open innovation in the biochip industry has not been properly addressed yet. In this study, the management of technology in biochip is investigated for each step of new product development (NPD) in open innovation, such as the switching phase in the initial stage of NPD, the implementation phase in the middle stage of NPD, and the transition stage of the last stage of NPD. The switching phase refers to the period when a firm wants to change from close innovation to open innovation; here, the switching cost refers to the cost of the change from close to open innovation. Furthermore, the implementation phase refers to open innovation that is actively being done; likewise, the degree of open innovation refers to the level of openness to external partners. The transition phase refers to the period of time when a firm wants to stop open innovation and start to close innovation, while the transition of innovation type refers to the change from open innovation to close innovation.

Each step is investigated using the model based on the switching cost, the model based on the degree of open innovation, and the model based on the transition of innovation type, respectively.

1.5.1. Research questions in the switching phase

In the initial stage of NPD, the decision to start open innovation is important, and then the seeking and evaluating the technology supplier should be considered. The decision can be described as the firm's willingness to participate in open innovation.

With regard to the switching phase, the following questions will be addressed: (1) Which influential factors should be considered to make decision to either start open innovation or not in the initial stage of new product development? (2) What is the relation among influential factors including the switching cost related to the perception of advantage of open innovation? (3) What is the strategy of facilitating the initiation process in open innovation?

The firm's willingness to participate in open innovation is related to the switching cost (Son et al. 2014; Matos 2009), i.e. the cost of the change from close innovation to open innovation; therefore, the switching costs can be investigated based on a number of different factors, including commitment-trust, research capacity, and the perception of advantage of open innovation. To construct a relevant management strategy, the model for switching costs is constructed. Furthermore, the relations among the switching cost, influential factors, and perception of advantage of open innovation are evaluated based on the proposed model

To analyze the switching cost, the following hypotheses are explored in the present study:

- There would be a positive relationship between trust with the existing research partner and the switching cost.
- There would be a positive relationship between trust with existing research partners and the perception of advantage of open innovation.
- There would be a positive relationship between trust with internal research team and switching cost.
- There would be a negative relationship between trust with internal research team and the perception of advantage of open innovation.
- There would be a positive relationship between research capacity of the firm and switching cost.
- There would be a positive relationship between research capacity and the perception of advantage of open innovation.

- There would be a negative relationship between the switching cost and perception of advantage of open innovation.

The investigation of the above hypotheses will be undertaken based on the survey conducted in the Korean chip industry.

1.5.2. Research questions in the implementation phase

In implementation of open innovation, openness is the key factor to increase the technology ability for NPD. Openness is related to technology characteristics, such as novelty and complexity (Tatikonda and Rosenthal 2000; Vahter et al. 2014; Verhoeven et al. 2016). Thus, the relationship among technology characteristics, openness, technology ability, and firm performance in the biochip industry should be evaluated. Also, breadth and depth of innovation activity are proposed during implementation of open innovation (Laursen et al. 2006; Laursen and Salter 2014; Greco et al. 2016). The factors affecting the breadth and depth of openness in the biochip industry will be investigated.

1.5.2.1. Model for openness related to novelty and complexity of technology

The following questions emerge with regard to openness related to novelty and complexity of technology: (1) Which influential factors should be considered regarding the optimal degree of open innovation during the implementation process in new product development? (2) What is the relation among factors including the technology characteristics with the openness? (3) What is the strategy to control the openness to increase the firm performance?

To construct an appropriate management strategy, the model for openness related to technology- novelty and -complexity is constructed. Furthermore, the relations among openness, technology ability, and firm performance are evaluated based on the proposed model.

To analyze the openness, the following hypotheses are formulated in the present study:

- There would be a positive relation between technology novelty and openness.
- There would be a positive relationship between technology novelty and technology ability.

- There would be a positive relationship between technology complexity and openness.
- There would be a positive relationship between openness and technology ability.
- There would be a positive relationship between technology ability and firm performance

The investigations of the above hypotheses will be undertaken based on the survey in conducted the Korean chip industry.

1.5.2.2. Model for breadth and depth of openness

Openness is an important factor to make NPD. The breadth of openness is related to the number of knowledge sources, while the depth of openness is related to the number of collaboration with one knowledge source. A model for breadth and depth of openness is constructed. Furthermore, the relations among environmental characteristics, firm characteristics, and organization characteristics to openness are evaluated based on the proposed model.

To analyze the breadth and depth, the following hypotheses are formulated in the present study:

- Environmental characteristics would affect the depth and breadth of openness.
- Firm characteristics would affect the breadth and depth of openness.
- Institutional characteristics would affect the depth of openness

The investigation of the above hypotheses will be undertaken based on the survey conducted in the Korean chip industry.

1.5.3. Research questions in the transition phase

After producing NP in the final stage, the firm considers the continuation of open or the transition to close innovation. The decision for close or open innovation is crucial, since it affects the firm performance (Felin and Zenger 2014). The transition tendency depends on knowledge for NP, product development stage, government approval stage, and product innovation stage. Furthermore, the transition tendency depends on willingness of close innovation or the perception of advantage of close innovation. The management strategy to decide the transition of innovation type should be made based on the relation between transition

tendency and the above mentioned factors.

In this context, the following questions emerge: (1) What factors should be considered in making the decision on either closing open innovation or not at the final stage of new product development? (2) What is the relation among factors including the transient tendency related with the perception of advantage of close innovation? (3) What is the strategy to control the openness to increase frim performance?

When commercializable product is made during NPD, a firm in the biochip industry has to decide on the type of innovation. Since all the technology to produce commercial product is acquired, keeping the open status needs more expense and poses a risk of leakage of knowledge. Therefore, to transit to close innovation might be a better choice to increase the interest of the firm. However, considering the modification of product for new application and more improvement of product for advanced function, the open innovation should be preserved. In this study, the relations among transition decision, product stage, and product innovation stage will be evaluated.

To analyze the innovation transition, the following hypotheses will be addressed:

- The transition to close innovation would occur after attaining the commercial-level product.
- The transition tendency of innovation would depend on firm size.
- Emergence of a new innovative product derived from the current new product would affect the repetition of transition tendency.

The investigation of the above hypotheses will be undertaken based on the semi-structured interviews with researchers in the biochip industry.

Based on semi-structured interviews with researchers in the biochip industry, the model based on innovation transition will be proposed. The transition tendency relates to knowledge, product development stage, government approval stage, and product innovation stage. Thus, firm's willingness to change to close innovation and the perception of advantage of close innovation are related to the transition tendency. Although the model is constructed based on research in the biochip industry, the evaluation of model will be done in the bio-pharmaceutical industry for the extension of the model.

To analyze the transition tendency from open innovation to close innovation, the following

hypotheses are formulated.

- There would be a positive relationship between product development stage and accumulation of knowledge.
- There would be a positive relationship between product development stage and transition tendency to close innovation.
- There would be a positive relationship between knowledge and transition tendency to close innovation.
- There would be a negative relationship between product innovation stage and transition tendency to close innovation.
- There would be a negative relationship between government approval stage and transition tendency to close innovation.
- There would be a positive relationship between transition tendency to close innovation and the perception of advantage of close innovation.

The investigation of the above hypotheses will be undertaken based on the survey conducted in the Korean bio-pharmaceutical industry.

Taken together, the case studies outlined above aim to construct the management strategies for open innovation in the Korean biochip industry. Investigation of biochip is important, since the biochip is an emerging high technology product and the product of fusion technologies, such as nanobiotechnology. In this context, a relevant management strategy is urgently needed in the biochip industry for effective new product development.

The overall scheme of the process of innovation and NPD and model- related phases explored in this study is shown in Figure 1.1.

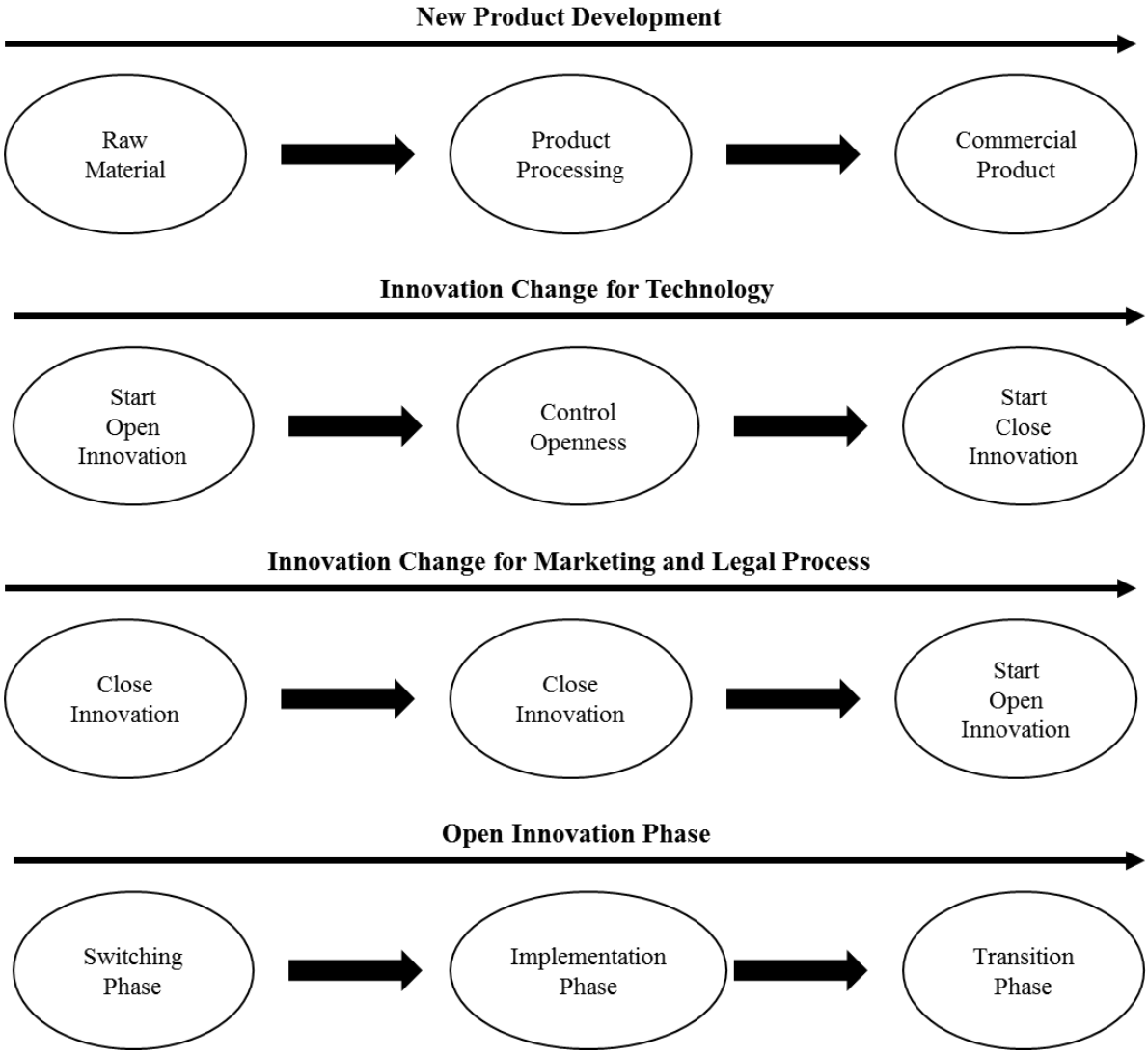

Figure 1.1. Process of open innovation and new product development

Chapter 2. Management Strategy for the Switching Phase of Open Innovation in New Product Development of Biochip

In the initial stage of new product development (NPD) in the biochip industry, due to the technology novelty and complexity of biochip, the need of external technology has emerged. Therefore, open innovation is being considered as an effective innovation method for new product development. Fetterhoff and Voelkel (2006) report managing open innovation in biotechnology based on the experience of open innovation in Roche and the external value chain can be thought of as consisting of five key stages. 'Seeking opportunities' is the first step to be considered here (Fetterhoff and Voelkel 2006). To seek opportunities in open innovation, the decision to start open innovation and seeking of external partners are the first step. This step investigated in this chapter.

At first, in the initial stage of new product development, the firm should decide whether or not to start open innovation. In this paper, this phase is defined as the switching phase, since, in this phase, the innovation mode switches from close to open. Although the firm understands the need for external innovation, the factors and relations to produce value are not clearly understood and then it is difficult to make the decision. Thus, in this chapter, the factors affecting the perception of advantage of open innovation are investigated and the model based on the switching cost is proposed. Based on the results of model evaluation with the data from the Korean biochip firms, the strategy for the decision of open innovation adoption is proposed.

2.1. Introduction

Due to the rapid development of high-tech technology, trends of industrial innovation have rapidly changed. Accordingly, firms have sought to diversify their innovation mode in order to increase profitability from product innovation and to survive in competitive environments. During this process, collaboration between firms, especially in related researching fields, has emerged as an important issue. After the conceptual introduction by Chesbrough (2003), open innovation has received a huge attention of both academic research circles academies and firms. According to Chesbrough (2003), open innovation is the methodology of innovation that opens

the innovation process, including research, development, and commercialization and uses external resources so that to reduce innovation cost, increasing thus the possibility of success and maximizing the added value creation (Chesbrough 2003, 2006a,b).

Both worldwide and in Korea, owing to such characteristics as the need of combining various techniques and limitation of resources in different techniques inside a firm, open innovation has been widely used in the biochip industry (Fuji-Keizai 2008; Kim 2008, 2013; Impact Co 2013; Hyun 2013, Kwon 2015). Since the biochip field is a fusion between biotechnology and information technology, the knowledge distribution should be recognized and the importance of knowledge integration should be considered more than in any other area in biotechnology. Considering that the sources of knowledge are wide-spread and that, unlike specialists in one specific area, experts in fusion technology are rare, the interactive innovation between internal and external experts should be prioritized. Therefore, the innovation in biochip should be done based on the recombinant technology concept, network learning, technology supply chain, and combination of internal and external resources in fused open innovation settings. The innovative product development with hybridization of internal sources and external resources in technology development structure should play the key role in innovation in markets for biochip.

To achieve open innovation in the biochip industry, a systematic strategy of management in radical innovative new product development is needed. To clarify the resources for open innovation, the core network and resources should be depicted, since global networks are a platform for activities that constitute open innovation strategy in innovative product development.

Although most firms understand the need for external innovation, only few of them know how to develop partnerships with excellent external technology providers (Fetterhoff and Voelkel 2006). In this respect, Fetterhoff and Voelkel (2006) suggest that the external innovation value chain consists of five key stages: 1) seeking opportunities; 2) evaluating the market potential and inventiveness of a given opportunity; 3) recruitment potential partners by building a convicting argument; 4) capturing value through commercialization; and finally 5) extending the innovation offering (Fetterhoff and Voelkel 2006). Approaches to increase the likelihood of finding suitable innovation partners include placing multiple technology scouts and allowing first rights on new product development.

In view of the above, as a first step, the decision whether or not to initiate open innovation should be made by considering the current internal and external status of the firm. In this study, the relation with the switching cost and the perception of advantage of open innovation is investigated to provide evidence on this decision. In addition, we also consider the factors that affect the switching cost. The model for relations is proposed and a survey is performed in the Korean biochip firms to evaluate the model. Finally, based on the results of model evaluation, the strategy for decision to start open innovation is suggested.

2.2. Theoretical Considerations

2.2.1. Open innovation in the biotechnology industry

In what follows, some instances of open innovation in the biotech industry are overviewed.

According to Fetterhoff and Voelkel's (2006) report on managing open innovation in biotechnology based on the case study of Roche, on the increasingly competitive landscape, there is a growing demand for companies to be innovative in the bio-pharmaceutical sector. However, the concept of innovation is confused with product innovation. If innovation is defined as the commercialization of an enabling technology that provides the customer with a new capability, then there are two key requisites for innovation: customer insight to identify unmet need, on the one hand, and technology awareness to identify the respective enabling technology, on the other hand. Drivers for innovation can be thought of as any force that uniquely links a customer need with an enabling technology solution; this region of overlap is described as the innovation space. Roche Diagnostics manages the challenges of sourcing external technologies by leveraging these drivers through a comprehensive technology evaluation.

Another relevant company of open innovation in biosciences is InnoCentive[7] (Demir 2003). As mentioned in Chapter 1 of the present paper, InnoCentive was created to foster innovation and efficiency in the area of R&D for major companies around the globe. The company was launched in 2001 as a start-up business venture incubated through a division of Elli Lily and

[7] See www.innocentive.com

Company. InnoCentive is an unbiased knowledge broker between major global companies and the worldwide scientific community, enabling them to collaborate and solve difficult problems. Global companies post their tough R&D problems on the confidential InnoCentive website where more than 22,000 leading scientists and researchers from 125 countries try to solve them for financial reward.

Furthermore, in his report on open innovation in the pharmaceutical industry, Nilsson (2006) notes that, since the pharmaceutical industry is one of the most research-intensive industries as well as a big industry in terms of revenue, it is important to acquire a deeper understanding of the trends in localization of R&D facilities. The open innovation strategy, where companies' R&D crosses over corporate and national borders, becomes popular in the pharmaceutical industry. A challenge in pursuing open innovation strategy is the coordination of R&D sites. In localized R&D sites, it is important to optimize the use of technologies, systems, and processes so that to ensure collaboration across the organization. The partnership and innovation in life science has also been reported by Kleyn et al. (2007) that shows that the government support for partnering between bio-pharmaceutical companies and universities is growing in the UK and some European countries. Partnering helped industry and university to increase innovation in R&D and led them to adopt more open approaches to innovation.

Open innovation approaches in biotechnology, such as bioscience and bioengineering, can be applied for open innovation of biochip to be investigated in this study.

2.2.2. Technology and innovation in biochip

Biochip can be classified to DNA chip, protein chip, and cell chip. DNA chip was first developed from Affymaetrix[8] which, based in Santa Clara, is a pioneer and market leader among the companies developing revolutionary biotechnology that helps doctors identify diseases and develop drugs likely to help patients by analyzing genetic level data. The main product of Affymetrix is DNA chip, also called a gene microarray or gene chip, which is a breakthrough tool that derives from the genetic revolution. Although Affymetrix is a market leader, the market in DNA chip has recently become highly competitive due to the entrance of new venture companies and large companies, such as Agilent and Motorola. Recently, the new

[8] See www.affymetrix.com

applications of DNA chip, such as genome-wide epigenetic analysis and on-chip synthesis, have also emerged (Hoheisel 2006).

In recent years, the markets of protein chip and cell chip have rapidly increased due to the high application fields, such as diagnosis and high throughput screening in drug delivery (Seong and Choi 2003; Zhu and Snyder 2003; El-Ali et al. 2006). Accordingly, markets of nanobiochip and lab-on-a-chip chip based on new nanotechnologies are now emerging and will rapidly grow and expand in the future.

Furthermore, in their report on the open system of innovation in DNA biochip's development, Lenoir and Giannella (2006) note that the open character of network economics is what makes them truly innovative. The emergence of diffusion of microarray technologies, biochip, provides an example of an open system of innovation. The inventors make the biochip to be commercial product based on knowledge resources from all parts of the network. The knowledge spillovers go both ways: at first from industry to academy and then from academy to industry. However, while Lenoir and Giannella's (2006) study focused on knowledge diffusion based on the relation between industry and academy, the strategy of open innovation process in the entirety of internal and external resources has not been reported.

In addition, Verboven and et al. (2004) analyze the innovation in high-tech sector, such as that concerned with medical devices and develop the model of innovation by small firms in high-tech sectors such as biopharmacy, medical devices in healthcare, and nanomaterials. According to the authors, there are two major innovation processes: firstly, product manufacturing, i.e. when fundamentally new knowledge is translated into a first application, and, secondly, strategic shift when new knowledge is applied to other areas, i.e. different from the one where its first application occurred.

The technology status and the analysis of innovation status in the mainstream biochip technology can be applied to construct the strategy of open innovation in the biochip industry.

2.2.3. Switching costs

The term 'switching cost' refers the cost of the change from one system to the other system; the switching cost is reported to be a significant antecedent of both attitudinal and behavioral loyalty (Matos et al. 2009). Specifically, according to Das and Teng (2002), the alliance

constellation should consider the role of generalized exchange partners according to the social exchange theory. Firms are willing to maintain their current relationship and not to move to new ones by replacing the current partner (Dwyer et al. 1987; Weiss and Anderson 1992).

Focusing on switching cost, Matos et al. (2009) develop and empirically test the antecedent, mediating and moderating role of switching costs on the relationship between satisfaction and loyalty. The authors suggest that competing models are proposed based on the investigation of the influence of the switching cost on satisfaction and loyalty (Matos et al. 2009). Their results demonstrate that consumers with different switching cost levels will manifest a distinct relationship between satisfaction and attitudinal loyalty and the moderating effect if the switching cost is stronger in the relationship between satisfaction and behavior royalty. Therefore, the different switching cost level affects the level of change of current goods or relations.

Based on different types of innovation, such as branching innovation (technological innovation along a particular path) and recombinant innovation (fusions of multiple paths), different models of technological transition are constructed (Frenken et al. 2012). For example, Frenken et al. (2012) suggest that recombinant innovations create short-cuts which reduce switching costs, allowing agents to escape a technological lock-in. As a result, recombinant innovation speeds up technological progress, allowing transitions from close innovation to open innovation. Therefore, the reduction of the switching cost relates to speeding up technological progress, allowing transitions based on the connection of internal and external

According to Huang and Hsieh (2012) report that consumer's perceived innovative attributes (such as relative advantage, compatibility, and complexity) directly affect their acceptance behavior, as well as influence their behavior via their perception of the costs (procedural, financial, and relational switching costs). Additionally, complexity is a key antecedent to switching costs. Economides and Katsamaka (2006) report the relation of the switching cost to an expansion of open source program in PC. In their study, the switching cost from dominant Windows operating system is shown to make it difficult for Linux market-share to grow fast. However, the existence of other open source applications (such as OpenOffice, the Mozilla Firefox browser, etc.) may reduce the switching cost to Linux in the long run. Thus, the factors affecting the switching cost should be investigated to find the way to increase the change to a new product.

In a similar fashion, Wu (2014) investigates the service innovation for digital service on loyalty. Specifically, the authors examine service innovation loyalty from the consumer perspective: namely, taking into account technology leadership, service leadership, and switching cost. Wu (2014) proposes that switching costs have a significant positive impact on consumers' loyalty; consequently, higher switching costs can differentiate a service provider from its competitors. The relations among client discretion, switching costs, and financial innovation are further investigated by Bhattacharyya and Nanda (2000). The authors suggest that, due to the large and well-known banks' varied expertise, they may face lower switching costs when they market a product to the clients and that the switching cost would depend on financial exchange. Furthermore, Yi and Lee (2005) investigate the antecedents and consequences of the switching cost by considering the moderating role of service subscription types. The authors demonstrate that switching costs have a positive effect on keeping the current service firm and that the increase of the switching cost is not the only factor to change the current service firm. In view of the above, the factors affecting switching cost should be investigated to find the way to increase the change to a new product. As suggested by the results of previous studies, owing to various influencing factors, switching costs can affect the tendency to maintain the current product or partner.

The switching cost in open innovation refers to the cost of the change from close innovation to open innovation. If the switching cost is high, the willingness of a firm to change would be low. Therefore, evaluating the factors for the switching cost and assessing the relation of the switching cost and the perception of advantage of open innovation can facilitate the decision to start open innovation in the initial stage of NPD in the biochip industry.

2.3. Research Model and Hypotheses

In this study, the three important factors to decide on starting open innovation for the initial stage of new product development are constructed, namely: (1) trust to current internal and external partners; (2) research capacity; and (3) switching cost. Based on this, the model is proposed where the perception of advantage of open innovation is related to (1) level of trust to the current external partner; (2) level of trust to the internal research team; (3) level of internal research capacity; and (4) the switching cost of the change from close innovation to open innovation. The theoretical model is shown in Figure 2.1. In what follows, we provide a

description of the relationships between the variables.

(1) External Trust and Internal Trust

Changing from current alliances, including the current external partner and internal research team, to new alliances for open innovation requires trust to new partners. The trust to alliances is related to the construction of a network and belief for collaboration for a new product development. According to Newell and Swan (2009), trust facilitates the firms to establish inter-organizational networks to overcome the isolation of small and medium enterprises. Likewise, Doney and Cannon (1997) suggest that trust contributes to reducing transactional uncertainty through previous collaborative experience with the third parties and expectation towards untrusted parties. Trust fosters long-term orientation between exchange partners by shifting the focus to future conditions and a strong trust decrease propensity to leave, i.e. the perceived likelihood that a partner will terminate the relationship in near future (Ganesan 1994; Morgan and Hunt 1994). Based on the above results, trust to external partner influences the continuation of current collaboration.

When a firm trusts the existing partner in research capability and innovation capability, the firm wants to keep the current partner, despite the fact that a change to a new partner can result in the new technology and yield economic benefit. Therefore, a firm is reluctant to change from close innovation to open innovation with new partners because of high switching costs. It can be suggested that trust to the current external partner is positively related to the switching cost. Based on the above, the following hypothesis is proposed.

H1: There would be a positive relationship between trust with existing research partner and switching cost.

In addition, the superior research ability of external partner affects the development of new product which makes the economical outcome. When open innovation starts and a new product is developed, the superior research ability of external partner positively affects the development of a new product, which yields economic benefit. Thus, it can be expected that the trust to existing external partner is related with perception of advantage of open innovation. In view of the above, the following hypothesis is proposed.

H2: There would a positive relationship between trust with existing research partner and the perception of advantage of open innovation.

When a firm trusts internal research team in the development of a new product, the firm wants to continue working only with current research team, despite the fact that a change to a new partner through inflow and outflow of technology can result in the new technology and yield economic benefit. Therefore, a firm is reluctant to change from close innovation to open innovation to new external partners because of high switching costs. It can be suggested that the trust to existing internal research team is positively related to the switching cost. Furthermore, the trust to internal research team affects the development of a new product, which yields economic benefit. Accordingly, it can be expected that the trust to internal research team is related to the perception of advantage of open innovation. Based on these considerations, the following hypotheses are proposed.

H3: There would be a positive relationship between trust with internal research team and switching cost.

H4: There would a negative relationship between trust with internal research team and the perception of advantage of open innovation.

(2) Research Capacity

The firm's internal research capability related to technology is essential in new product development, since a new technology or reconfiguration of the current technology are needed for new product development. For the adoption of a technology, the characteristics of internal resources, such as knowledge, are an influential factor (Roth et al. 1996). Specifically, Rogers (1995) suggests that the existing knowledge and internal resources can improve the speed of learning about new technology and lower the amount of extra investment to adopt the technology. Therefore, based on the above, the following hypothesis is proposed.

H5: There would a positive relationship between research capacity of the firm and switching cost.

Absorptive capability can be classified as a firm's internal research capability. Absorptive capability to effectively learn from other firms is related to implementation of open innovation (Vanhaverbeke et al. 2008). Returns from open innovation are the greatest when firms maintain their internal research capacity, employ a dedicated incentive system for innovation, and advocate strong cross-functional collaboration (Tidd and Bessant 2015). Thus, it can be predicted that the firm's internal research capability is positively related to the perception of advantage of open innovation. If internal research capacity is high, firm can absorb the external

technology well after starting open innovation, since internal research team has the ability to accept external technology and make product well. Based on these considerations, the following hypothesis is proposed.

H6: There would be a positive relationship between research capacity and the perception of advantage of open innovation.

(3) Switching costs

As concerns the role of the switching cost in open innovation, Reed et al. (2012) report that open innovation affects the drivers of competitive advantages and that the firm that get advantages from switching risks to lose advantages in open innovation. In new ventures based on open innovation, for instance, in open source software, the market entry barrier is related to the low switching cost for users (Gruber and Henkel 2006). Therefore, Baldwin and Hippel (2011) suggest that a paradigm shift occurs from producer innovation to user and open collaborative innovation, in which open collaborative innovation project avoids the transaction costs. Also, in classical mass production, a change of designs requires a setup of manufacturing facility and associated switching costs; however, in the new collaborative innovation, the switching cost by changing of designs decreases. On line contests for open innovation—i.e. seekers posting innovation projects to which solvers submit solutions—have been developed into a new online commerce model (Yang et al. 2009). According to Yang et al. (2009), choices of solvers in a contest can be estimated by evaluating the switching cost, and a contest with a higher learning cost will have a higher switching cost. The above results suggest that the performance enhancement by open innovation is related to switching cost. Also, the presence of switching costs can lead to insufficient adoption of a new technology (Chen and Foreman 2006). Based on the above, the following hypothesis is proposed.

H7: There would be a negative relationship between the switching cost and the perception of advantage of open innovation.

Based on the above hypotheses and relations, the model is constructed as shown in Figure 2.1.

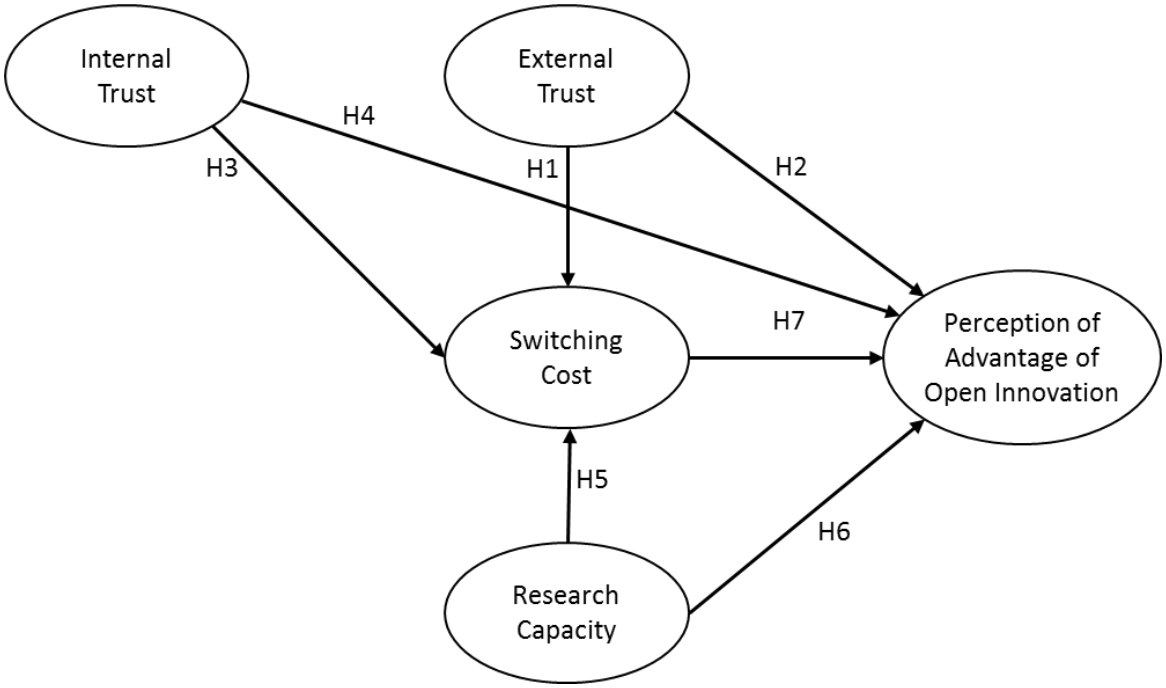

Figure 2.1. Model for relation between switching cost and open innovation

2.4. Research Method

(1) Questionnaire Design

The biochip industry, one of high technology industries, is a fusion of various technologies including biochip, nanotechnology, biosensor, and bioinformatics. In general, due to secure competition for patent and intellectual property, open innovation activity has been hardly accomplished in high technological industries. However, since life cycle of a high technology has recently decreased, the need for open innovation activity has increased in the process of rapid development and commercialization of new products (Ahn and Lee, 2011). In this context, it can be predicted that open innovation has happened in the biochip industry because of its high intensive level of technological research and, for that reason, the biochip industry in Korea is selected as the target industry of the present study.

The aim of this research is to investigate the start of open innovation and switching cost during the initial stage of the new product development process. To achieve this aim and to ensure the validity of findings, a questionnaire survey is done. Previous studies on the switching cost and open innovation have also performed a questionnaire survey, which is an established research technique for technology management studies (Al-Zu'bi and Tsinopoulos

2012; Pick and Eisend 2014, 2016)

The questions were designed as follows. The interview to construct questions was done with three interviewees: CTO of two small biochip firms (BioDiatech and NSB Postech), CTO of one medium-size biochip firm (NanoEnTek), and manager of the biochip team of a large firm (Samsung Advanced Institute of Technology) in Korea, from October 10 to October 24, 2012. The discussion for open innovation in the initial stage of new product development in biochip was held. Specific attention was paid to the factors affecting the start of open innovation so that to find the relation of factors for open innovation and advantage of open innovation. The discussion results for the start of open innovation in the initial stage of new product development of biochip were analyzed and the main variables were classified as three factors (internal trust, external trust, research capacity) switching cost, and perception of advantage of open innovation (see Table 2.1).

The scales used in the survey were seven as used in the literature (Son et al. 2014); however, the scales were later modified for this study. To ensure the validity of questions and scales, a panel of experts consisting of three interviewees and two professors of Sogang University, Korea (major: biochip and biosensor) were asked to review them. This process led to modification and clarification of the questions.

The main question concerns the switching cost to start open innovation in the initial stage of new product development of biochip. Here, three aspects are important to address, namely: (1) Does open innovation start based on switching cost? (2) Do factors such as internal trust, external trust, and research capacity affect switching cost? (3) Does the switching cost relate to the perception of advantage of open innovation? The survey constructed based on these questions is described in the next section.

Table 2.1. Questions for open innovation in initial stage of new product development (NPD).

(1) How would you characterize external trust in the initial stage of NPD?
1.1. External collaborative partners keep the promise with our firm.
1.2. External collaborative partners are honest with us.
1.3. We trust the information provided by our external collaborative partners.
1.4. External collaborative partners are genuinely interested in the business success of our firms.
1.5. External collaborative partners are well aware of our concerns.

(2) How would you characterize internal trust in initial stage of NPD? 2.1. Internal researchers keep the promise with our firm. 2.2. Internal researchers are honest with us. 2.3. We trust the information provided by internal researchers. 2.4. Internal researchers are well aware of our concerns. 2.5. Internal researchers are trustworthy.
(3) What is the level of research capacity in the initial stage of NPD? 3.1. Our firm has well-equipped infrastructure for research and development. 3.2. We have enough researchers to develop our new products. 3.3. We have sufficient capital to develop our new products. 3.4. We have integrated information system for communication between departments.
(4) How would you characterize the switching cost in the initial stage of NPD? 4.1. We are facing obstacles in switching to open innovation. 4.2. Switching to open innovation is costly.
(5) How would you characterize the perception of advantage of open innovation in the initial stage of NPD? 5.1. Open Innovation will provide accurate information at the right time in decision making. 5.2. Open innovation will improve the ability to manage technical knowledge. 5.3. Open innovation will help technological diversification. 5.4. Open innovation will help improve competitiveness. 5.5. Open Innovation allows many researchers to communicate simultaneously.

(2) Survey Administration

The survey in the Korean biochip firms, conducted from October 24, 2011 to November 17, 2012, targeted decision makers in 70 firms. The respondents were contacted by e-mail and visit. At that time, the total number of bio-diagnostics firms in the Korean Association of Bio-diagnostics was about 70. At first, from October 24, 2011 to February 24, 2012, the survey was done for 50 firms; the number of collected surveys was 35, which was not sufficient for data validation. Then, from August 17, 2012 to November 17, the survey was done for additional 20 firms and the number of collected surveys was 15. Thus, the total number of collected surveys

amounted 50 firms. Due to the long period of data collection (approximately one year), there may have a time-related bias, though all firms were alive during one year. Biochip firms included biosensor firms, biochip firms to produce DNA chip, protein chip, cell chip, biosensor array firms, biochip fabrication firms including MEMS (microelectromechanical system), bioinformatics firms, and instrument firms (arrayer and detector). Through the survey, a total of 50 survey results were acquired, reaching the response rate of 71 %, and further analysis was carried out with 47 surveys (in 3 surveys, the responses were incomplete).

(3) Demographic characteristics

Demographic characteristics of the respondents are shown in Table 2.2.

Table 2.2. Characteristics of demography of sample

Division	Content	Number	Percentage (%)
Personal employment term	below 5 years	16	32
	6~10 years	15	30
	11~15 years	13	26
	16~20 years	3	6
	21~25 years	2	4
	above 26 years	1	2
Personal position	CEO	23	46
	Research Director	4	8
	General Manager	11	22
	Deputy General Manager	6	12
	Manager	4	8
	Missing value	2	4
Personal age	20~29	1	2
	30~39	14	28
	40~49	23	46
	50~59	11	22

	Missing value	1	2
Firm's Age	below 5 years	9	18
	6~10 years	14	28
	11~15 years	19	38
	16~20 years	7	14
	Missing value	1	2
Number of employees	below 10	15	30
	11~50	16	32
	51~100	6	12
	101~200	5	10
	200~300	4	8
	1800	1	2
	Missing value	3	6
Number of researchers	1~10	24	48
	11~20	12	24
	21~50	5	10
	51~100	3	6
	above 100	3	6
	Missing value	3	6

(4) Statistical analysis of variables

The definition of variables and measurement method of the variables in the research model are shown in Table 2.3. A seven-point scale was used for the variables.

Table 2.3. Denotation and measurement of variables

ET 1	External collaborative partners keep the promise with our firm.
ET 2	External collaborative partners are honest with us.
ET 3	We trust the information provided by our external collaborative partners.
ET 4	External collaborative partners are genuinely interested in the business success of our frim.
ET 5	External collaborative partners are well aware of our concerns.

IT 1	Internal researchers keep the promise with our firm.
IT 2	Internal researchers are honest with us.
IT 3	We trust the information provided by internal researchers.
IT 4	Internal researchers are well aware of our concerns.
IT 5	Internal researchers are trustworthy.
RC 1	Our firm has well-equipped infrastructure for research and development.
RC 2	We have enough researchers to develop our new products.
RC 3	We have sufficient capital to develop our new products.
RC 4	We have integrated information system for communication between departments.
SC 1	We are facing obstacles in switching to open innovation.
SC 2	Switching to open innovation is costly.
AO 1	Open Innovation will provide accurate information at the right time in decision making.
AO 2	Open innovation will improve the ability to manage technical knowledge.
AO 3	Open innovation will help technological diversification.
AO 4	Open innovation will help improve competitiveness.
AO 5	Open Innovation allows many researchers to communicate simultaneously.

ET: External trust, IT: Internal trust, RC: Research capacity, SC: Switching cost, AO: Perception of advantage of open innovation

Based on the data acquired by the survey, analysis was performed using SPSS 18.0 program and PLS 2.0. The hypotheses were tested by applying the partial last square (PLS) method to the collected data. This study used PLS, rather than other SEM methods (i.e. LISREL, AMOS, etc.), because the PLS approach places minimal restrictions on sample size and residual distribution (Phang et al. 2006). First of all, analysis of descriptive statistics quantity was accomplished and the results were investigated. To verify the reliability of the samples, items measuring each comprising concepts were investigated using Cronbach's alpha test. Also, to verify the validity of the samples, factor analysis was performed in the hypothesis testing process.

2.5. Results

2.5.1. Validation

To validate the model, three types of validity—content validity, convergent validity, and discriminant validity—were assessed. (1) Content validity was evaluated based on Cronbach alpha value (see Table 2.4). Cronbach's alpha test to individual scale and the overall measures was used to assess internal consistency. The threshold value of Cronbach alpha is 0.7 (Nunally and Berstein 1994). As shown in Table 2.4, the Cronbach alpha values were 0.908 for external trust, 0.940 for internal trust, 0.883 for research capacity, 0.841 for switching cost, and 0.928 for the perception of advantage of open innovation. Therefore, all variables are valid.

Table 2.4. Confirmatory factor analysis

Constructs	Composite Reliability	AVE*	Cronbach's Alpha
External Trust (ET)	0.931	0.730	0.908
Internal Trust (IT)	0.952	0.799	0.940
Research Capacity (RC)	0.919	0.741	0.883
Switching Cost (SC)	0.923	0.857	0.841
Perception of Advantage of open innovation (AO)	0.945	0.776	0.928

* Average variance extracted

(2) Convergent validity was assessed by composite reliability and average variance extracted (AVE) from the measures (see Table 2.4). The acceptable values of composite reliability for reliable construct is 0.7 (Chin 1988). The composite reliability values in our sample were 0.931 for external trust, 0.952 for internal trust, 0.919 for research capacity, 0.923 for switching cost, and 0.945 for the perception of advantage of open innovation. Therefore, all variables are valid. The acceptable value of AVE is over 0.5 (Fornell and Larcker 1981). The AVE values in our sample were 0.730 for external trust, 0.799 for internal trust, 0.741 for research capacity, 0.857 for switching cost, and 0.776 for the perception of advantage of open

innovation. Therefore, all variables are valid.

(3) Discriminant validity is verified by evaluating the square root of AVE (Fornell and Larcker 1981; Lee et al., 2014). In our results, the square root of AVE for each construct as greater than the levels of correlation involving the construct (see Table 2.5). Also, each construct showed a larger variance with its own measures than those with other measures (see Table 2.5). Threshold value of absolute value pairwise correlation is 0.6 (Nunally and Berstein 1994) and the highest absolute value of pairwise correlation in our sample was lower than that (0.559). Variance inflation factors (VIF) were calculated to detect the multicollinearity among the explanatory variables. Threshold value of VIF is 10 (Nunally and Berstein 1994) and the highest VIF value in our sample was 0.4.732, which is far lower than 10. Thus, all variables are valid.

Table 2.5. Correlation between constructs

	AO	ET	IT	RC	SC
AO	0.881*				
ET	0.181	0.854*			
IT	0.066	0.559	0.894*		
RC	0.392	0.252	0.113	0.861*	
SC	0.122	0.497	-0.197	0.398	0.926*

* Square root of AVE

Other analyses based on statistical results are as follows. The descriptive statistics including standard deviation are reported in Table 2.6. Kaiser-Meyer-Olkin measure of sampling adequacy was 0.737. The results suggest that 5 factors explain 80.522 % of the total variance (see Table 2.7). Since all 5 factors are well-distributed over 0.6 in factor analysis, the validity requirement was satisfied (see Table 2.8).

Table 2.6. Descriptive Statistics

	N	Min	Max	Mean	Std. Deviation
IT 1	47	1	7	5.72	1.155
IT 2	47	1	7	5.74	1.188
IT 3	47	1	7	5.83	1.167
IT 4	47	1	7	5.72	1.210
IT 5	47	1	7	5.85	1.122
ET 1	47	3	7	4.98	.944
ET 2	47	2	7	4.74	.943
ET 3	47	3	7	4.98	1.032
ET 4	47	2	7	4.70	1.413
ET 5	47	2	7	4.57	1.281
RC 1	47	3	7	5.28	1.192
RC 2	47	1	7	4.57	1.441
RC 3	47	1	7	4.43	1.778
RC 4	47	1	7	5.13	1.361
SC 1	47	-1	6	4.04	1.615
SC 2	47	1	6	4.40	1.378
AO 1	47	2	7	4.79	1.178
AO 2	47	2	7	5.15	1.302
AO 3	47	3	7	5.45	1.157
AO 4	47	1	7	5.53	1.316

AO 5	47	1	7	5.04	1.429
Effective Number	47				

Table 2.7. Total Variance Explained

Extraction Sums of Squared Loadings	Rotation Sums of Squared Loadings				
Total	% of Variance	Cumulative %	Total	4	5
7.068	33.657	33.657	4.293	.008	.046
4.365	20.785	54.441	4.021	-.033	-.295
2.762	13.151	67.593	3.626	-.001	-.275
1.700	8.093	75.686	3.317	.228	-.071
1.016	**4.836**	**80.522**	**1.653**	.248	-.079
				.205	-.077
				-.058	-.107
				-.106	.059
				.067	-.004
				-.168	-.079
				.869	-.145
				.905	-.084
				.872	-.015

				.612	-.265
				-.466	**.694**
				-.140	**.908**
				.082	-.009
				.301	.052
				.250	.170
				-.003	.000
				.092	-.117

Extraction Method: Principal Component Analysis

Table 2.8. Rotated Component Matrix

	Component				
	1	2	3	4	5
ET1	.272	.245	**.789**	.008	.046
ET2	.321	.272	**.723**	-.033	-.295
ET3	.172	.204	**.805**	-.001	-.275
ET4	.289	-.136	**.811**	.228	-.071
ET5	.340	.045	**.757**	.248	-.079
IT 1	**.891**	.095	.099	.205	-.077
IT 2	**.885**	-.028	.281	-.058	-.107
IT 3	**.870**	.005	.243	-.106	.059
IT 4	**.820**	.118	.271	.067	-.004

IT 5	**.842**	-.107	.294	-.168	-.079
RC 1	.030	.173	.060	**.869**	-.145
RC 2	-.053	.104	.154	**.905**	-.084
RC 3	-.147	.172	.040	**.872**	-.015
RC 4	.347	.332	.049	**.612**	-.265
SC 1	-.028	.067	-.407	-.466	**.694**
SC 2	-.082	.049	-.170	-.140	**.908**
AO 1	-.055	**.849**	.167	.082	-.009
AO 2	-.042	**.841**	.123	.301	.052
AO 3	.051	**.866**	.080	.250	.170
AO 4	.025	**.865**	.126	-.003	.000
AO_5	.109	**.823**	-.044	.092	-.117

Extraction Method: Principal Component Analysis

Rotation Method: Varimax with Kaiser Normalization: a. Rotation converged in 6 iterations

2.5.2. Hypothesis testing

To validate the model, the structural equation model was applied and Partial Least Square (PLS) was used. Since PLS requires minimal demands on sample size (Chin 1998) to validate a model and our data set had 47 questionnaires, the PLS method was used to evaluate the proposed model and hypotheses. When t-value is over 1.96, the hypothesis is significant at 5% level of significance (provided the number of surveys is sufficiently large). Cramer suggests that the approximation is usually good for samples larger than 30 (Cramer 1946) and, thus, statistical inference is appropriate for our dataset. As shown in Table 2.9. Only t-values for the relation between external trust and switching cost, the relation between research capacity and switching cost, the relation between research capacity and the perception of advantage of open innovation, and the relation between the switching cost and the perception of advantage of open

innovation were over 1.96 and thus only these four relations are satisfied. Values of path loadings were calculated and the sign related to correlation with the switching cost was reversed, since the reverse coding for switching cost was performed. As R^2 for the switching cost is 0.253 and R^2 for the perception of advantage of open innovation is 0.315, the model is acceptable, since acceptable range of R^2 is over 0.1.

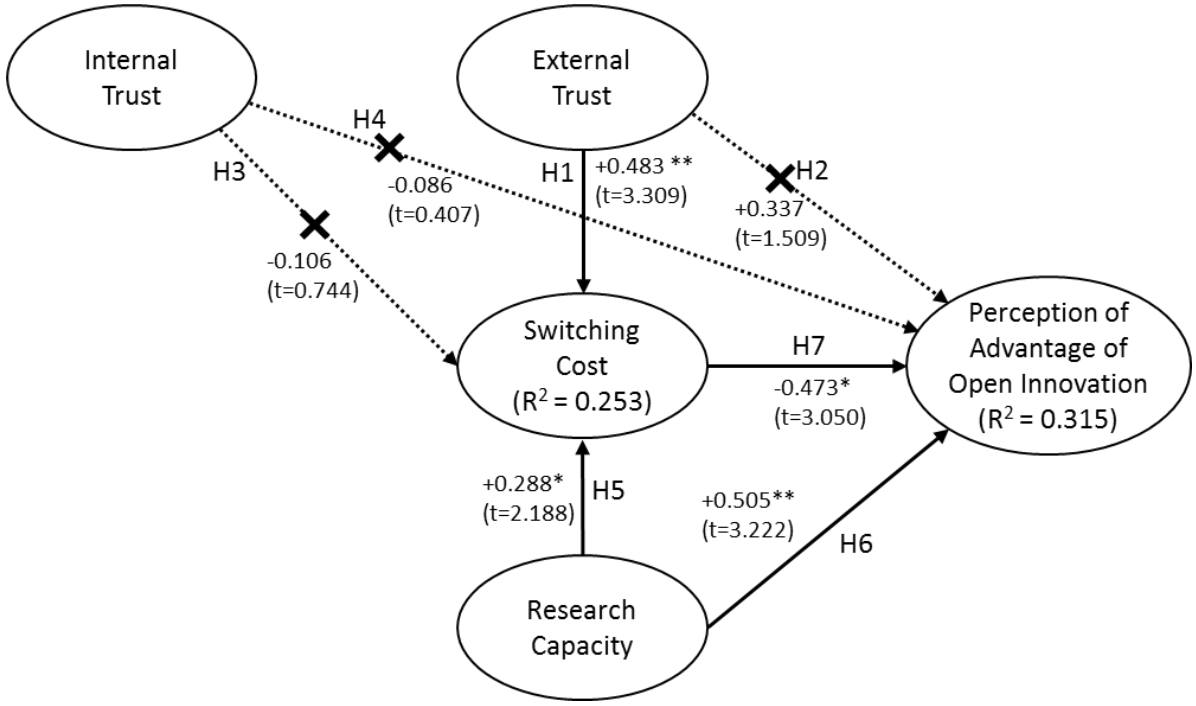

Figure 2.2. Model result for relation between switching cost and open innovation

Table 2.9. Path Coefficients

	Original Sample	Sample Mean	Standard Deviation	T Statistics	P Values
ET → AO	0.337	0.350	0.223	1.509	0.132
ET → SC	0.483	0.489	0.146	3.309	0.001**
IT → AO	-0.086	-0.111	0.212	0.407	0.684
IT → SC	-0.106	-0.086	0.143	0.744	0.457
RC → AO	0.505	0.513	0.157	3.222	0.001**
RC → SC	0.288	0.284	0.132	2.188	0.029*
SC → AO	0.473	0.467	0.155	3.050	0.002*

*** p<0.001, ** p<0.01, * p<0.05

As further analysis for the model, group difference between two groups with different position is conducted. The two group data have 44 values that omitted missing value from initial 47 values as shown in Table 2.10. Group 1 has 23 data (49%), which represented by CEO and Research Director of the firm and Group B has 21 data (51%), which represented by General Manager, Deputy General Manager, and Manager of the firm. In the analysis of Group 1 in Table 2.11, only relation between switching cost and perception of advantage of open innovation is valid since t value is 2.358 and acceptable t value is larger than 2.07 for 23 data. In the analysis of Group 2 in Table 2.12, only relations between external trust and switching cost, and between research capacity and switching cost are valid since t value is 2.816 and 2.080, respectively, and acceptable t value is larger than 2.08 for 21 data. It looks that there might be difference between Group 1 and Group 2. But if the analysis for difference of Group 1 and Group 2 is done, all p-values are not in the acceptable range (p is larger than 0.05) in Table 2.13. This result suggest that there is no difference in the analysis of Group 1 and Group2, and thus the results with 47 data have validity.

Table. 2.10. Group based on position difference

	Content	Number	Percentage (%)
Group 1	CEO	20	42.6
	Research Director	3	6.4
Group 2	General Manager	8	17.0
	Deputy General Manager	2	4.3
	Manager	11	23.4
Missing value		3	6.4
Total		44	100

Table. 2.11. Analysis of Group1.

	Original Sample	Sample Mean	Standard Deviation	T Statistics	P Values
ET → AO	-0.321	-0.155	0.313	1.027	0.305
ET → SC	-0.215	-0.240	0.388	0.554	0.579
IT → AO	0.322	0.187	0.336	0.959	0.337
IT → SC	-0.149	-0.008	0.374	0.400	0.690
RC → AO	0.465	0.406	0.248	1.876	0.061
RC → SC	-0.002	-0.072	0.348	0.006	0.995
SC → AO	0.570	0.547	0.242	2.358	0.018

Table. 2.12. Analysis of Group2.

	Original Sample	Sample Mean	Standard Deviation	T Statistics	P Values
ET → AO	0.703	0.609	0.372	1.892	0.059
ET → SC	-0.671	-0.612	0.238	2.816	0.005
IT → AO	-0.156	-0.135	0.364	0.430	0.667
IT → SC	0.211	0.083	0.233	0.904	0.366
RC → AO	0.697	0.650	0.362	1.925	0.054
RC → SC	-0.467	-0.446	0.225	2.080	0.038
SC → AO	0.572	0.418	0.315	1.814	0.070

Table.2.13. Analysis of difference of Group 1 and 2

	Path Coefficients difference (G1-G2)	p-value (G1-G2)
ET → AO	1.024	0.971
ET → SC	0.456	0.136
IT → AO	0.479	0.164
IT → SC	0.360	0.787
RC → AO	0.231	0.756
RC → SC	0.465	0.117
SC → AO	0.001	0.504

*** p<0.001, ** p<0.01, * p<0.05

In the results of analysis of the model with path coefficient, t-value and R^2 values are reported in Figure 2.2. The results in Figure 2.2 suggest the followings. The trust to current external partner is positively related to the switching cost, which means that as external trust becomes higher, the switching cost to open innovation increases. This result suggests that the firm with strong trust in the current external partner is reluctant to do open innovation with a new external partner. This supports Hypothesis 1. Furthermore, trust to current external partner is not directly related to the perception of advantage of open innovation. Our results suggest that the current external partner does not affect the enhancement of performance by open innovation of firm, since current external partner is not directly related to new external partner. Therefore, Hypothesis 2 has to be rejected.

The trust in current internal research team is not directly related to the switching cost, which means that, although internal trust becomes higher, the switching cost to open innovation is not

changed. Our results suggest that the current internal trust does not affect the enhancement of performance by open innovation of firm, since trust to current research team is less important than the research capacity of current research team. Thus, Hypothesis 3 has to be rejected. Furthermore, trust to current internal research team is not directly related to the perception of advantage of open innovation, meaning that, although internal trust becomes higher, the switching cost to open innovation is not changed. Our results suggest that trust to current external partner does not affect the enhancement of performance by open innovation of firm, since internal trust is not directly related to the transfer of technology from new external partner, which causes the enhancement of performance by open innovation of firm. Therefore, Hypothesis 4 is not supported by our results.

Furthermore, the research capacity is positively related to the switching cost, meaning that, as internal research capacity becomes higher, the switching cost to open innovation increases. The results suggest that the firm with high research ability is reluctant to do open innovation. Therefore, Hypothesis 5 is supported by our data analysis. The research capacity is positively related with the perception of advantage of open innovation, meaning that, as internal research capacity gets higher, the benefit due to increases after open innovation starts. Our results show that the firm with high research ability can get a better result due to being open to external partners. These results suggest that firm with a high research capacity can get, absorb, and adapt external technology. Thus, Hypothesis 6 is substantiated by the results.

Next, the switching cost is negatively related to the perception of advantage of open innovation, meaning that, as the switching cost becomes higher, the perception of advantage of open innovation decreases. A high switching cost means a low willingness to open innovation (Lee et al. 2014). The results provide evidence that, when a firm expects a high switching cost, it is less likely to participate in open innovation, which causes the decrease the perception of advantage of open innovation. Thus, Hypothesis 7 is supported by the results of our analysis.

2.6. Conclusion and Discussion

The summary of the research results is shown in Figure 2.3.

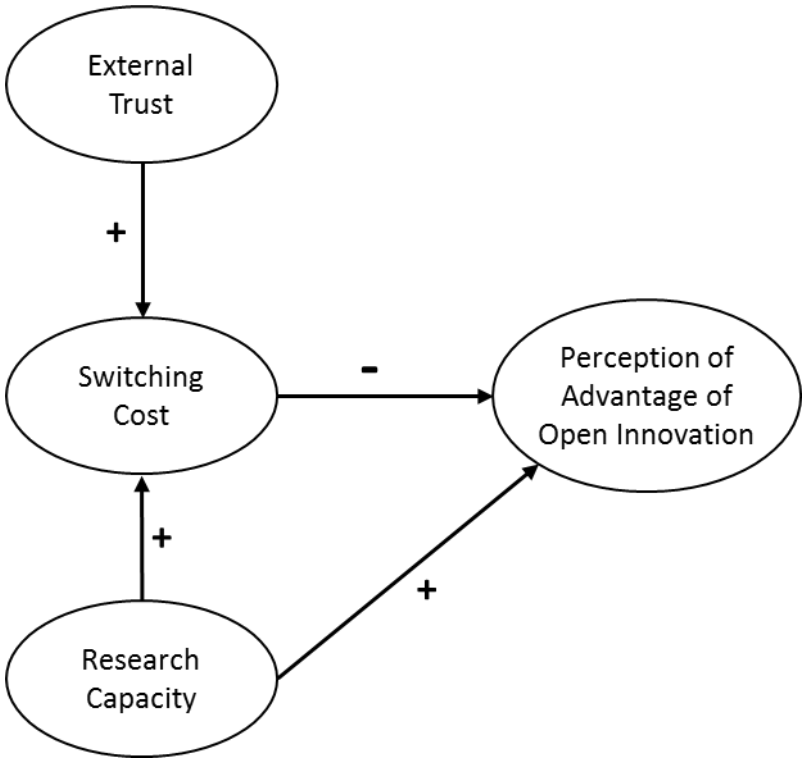

Figure 2.3. Summary of model result for relation between switching cost and open innovation

The purpose of this study is to investigate the factors to decide to start open innovation. The factors that relate the switching cost to the perception of advantage of open innovation affect the decision on new product development. Based on our data analysis results, we can conclude that the switching cost has a negative relation with the perception of advantage of open innovation. If the switching cost is low and thus the perception of advantage of open innovation is high, the firm starts to open and get knowledge from external collaborators, meaning that the technology-sharing and -transfer from current external partner and internal research team decreases. If the switching cost is high and, due to this, the perception of advantage of open innovation decreases, the firm will not want to open the technology flow between inside and outside. In addition, the trust to current external partner and the level of research capacity in the firm affects the switching cost. It is found that trust to current external partner and the level of research capacity in the firm have a positive relation with the switching cost.

The innovation strategy is needed to effectively do innovation, since the problem with

innovation improvement efforts is rooted in the lack of innovation strategy (Pisano 2015). Based on the results reported above, the following strategy to manage open innovation is suggested. The decision to start open innovation or not in the initial stage of new product development should be made based on the consideration of the switching cost and the perception of advantage of open innovation. At first, the factors such as trust to current external partner and internal research capacity to affect switching cost should be considered. If the trust to current external partner or the level of research capacity in the firm is high, the switching cost is too high, the firm should keep the current external partner and internal research team in close innovation.

Alternatively, if the switching cost is within acceptable value, the firm should decide to start open innovation with a new external research partner. The relation with the current external partner should be reduced to reduce the switching cost. The research capacity should be reduced by the reduction of number of researchers or Ph.D. level researchers, which causes a decrease of the switching cost. However, the internal research capacity should be kept over the medium level, since the internal research capacity affects the performance of open innovation activity. Internal research team with a good research capacity can efficiently manage the technology transfer from the outside the firm. By reducing the switching cost, the perception of advantage of open innovation increases, causing an acceleration of implementation of open innovation.

To summarize, the results reported above allow us to draw the following conclusions: (1) Switching should be considered to make decision on starting open innovation or not in the initial stage of new product development; (2) Current internal research capacity and external partner are important factors, since the current situation is the key factor to decide whether or not to start open innovation by introducing new partners; (3) Based on the insights of the relation of current situation with the switching cost and that of the switching cost with the perception of advantage of open innovation, firms decide whether or not to start open innovation.

Since, the extended period of data collection (ca. a year) could have caused a time-related bias in the present study (although all firms that responded to the survey were alive during one year), a reduction of time for the survey is recommended.

Though only trust and research capability are considered as key factors for switching cost in

this study, the various factors to affect switching cost should be encountered for accurate analysis. Switching cost is affected by antecedents such as firm-related, buyer-related and market-related and the relation between antecedents and switching cost is modulated by moderators such as culture, product characteristics and others (Pick and Doreen 2014). Thus in future for biochip industry the effect of market-related antecedents on switching cost should be investigated to clarify the switching to open innovation in the initial stage of new product development.

In this study the internal- and external- trust are selected as the key factors for switching cost since the trust is one of the most important factors for collaboration work due to culture of Korea (Kim et al. 2008). This approach can be considered as reasonable since the cultural variations relate to the effect of relationship variables such as switching cost in and the relationship between switching cost and behavior loyalty is established (Pick and Doreen 2016). But, since the trust is a subjective factor, if more objective factors such as research capability of external partners and current market situation are considered for switching cost, the research findings should be more appropriate and clear to understand the open innovation in the initial stage of new product development.

Chapter 3. Management Strategy for Implementation of Open Innovation in New Product Development of Biochip

Since open innovation is considered to be an effective innovation method for new product development (NPD) of biochip, the start of open innovation can be decided based on the analyses as shown in Chapter 2. After the open innovation process is started, during the implement stage of open innovation, a strategy to increase the firm performance is needed in product development of the biochip industry. During the implementation of open innovation activity, the following questions need be addressed: (1) Does an increase of openness affect firm performance in new product development? (2) Which level of openness is needed for new product development? (3) How can we implement the open innovation process in practice? In this chapter, we seek to answer the above questions by investigating the influential factors affecting openness based on both technological and non-technological points of view.

At first, the firm must decide about the optimal level of openness to enhance its performance. Although the firm understands the need for external innovation, relations between influential factors and openness necessary to enhance firm performance are not clearly understood, making it difficult to make the decision related to the appropriate degree of openness. Thus, in Section 3.1., the factors affecting the openness based on the technical characteristics, such as technology novelty- and -complexity, and the factor's relation to enhance the firm performance, are investigated. The model based on technology characteristics is proposed. Based on the results of model evaluation with the data from Korean biochip firms, the strategy regarding openness and firm's performance enhancement is proposed from the technology point of view.

In the next step, the firm must decide about the way of breadth and depth of open innovation activity. The variety of the external seeking in open innovation is measured by breadth and depth of open innovation. The breadth of open innovation can be measured by a number of collaborators, while the depth of open innovation can be measured by the frequency (number of collaboration) of a single target in open innovation. Laursen and Salter (2006) used the concept of depth and breadth to measure the degree of open innovation. Although the firm may want to implement an open innovation strategy, relations of influential factors necessary to enhance the open innovation activity are not clearly understood yet. Thus, in Section 3.2., the influential factors affecting the open innovation activity will be investigated based on the non-technical characteristics, such as environmental characteristics, firm characteristics, and

institutional characteristics. A set of hypotheses regarding the factors affecting open innovation is proposed. Based on the results of hypotheses evaluation with the data from Korean biochip firms, the strategy for the decision of open innovation will be proposed from the non-technology point of view.

To sum up, in this chapter, the factors affecting open innovation, such as the environmental characteristics, firm characteristics, and institutional characteristics, are investigated for the first time. The goal is to evaluate the effect of these factors on breadth and depth of innovation activity. This case study is also the first to address the breadth and depth of open innovation activity in the biochip industry.

3.1. Openness Based on Technology Characteristics

3.1.1. Introduction

Due to the need of combination of various techniques and limitation of resources in different techniques inside firms, both worldwide and in Korea, as well as the need of external knowledge for new radical product development, open innovation has been widely applied to the biochip industry (Fuji-Keizai 2008; Kim 2008; Impact Co 2013; Kim 2013, Hyun 2013; Kwon 2015). Since the biochip technology results from a fusion between biotechnology and information technology, the knowledge distribution in different types of firms should be recognized and the importance of knowledge integration should be considered more than in other areas of biotechnology.

To achieve open innovation in high technology products, a novel management strategy is needed in order to manage the development of novel and complex technology characteristics (Fetterhoff and Voelkel 2006; Igartua et al. 2010; Pisano 2015; Slowinski and Sagal, 2015; Tidd and Bessant 2015; Vanhaverbeke et al. 2008). Although most companies understand the need for external innovation, only few of them can establish partnerships with external technology providers (Fetterhoff and Voelkel 2006). Fetterhoff and Voelkel (2006) suggest that research external innovation value chain consists of five key stages: 1) seeking opportunities; 2) evaluating the market potential and inventiveness of a given opportunity; 3) recruitment of

potential partners by building a convincing argument; 4) capturing value through commercialization; and finally 5) extending the innovation offering. Furthermore, Slowinski and Sagal (2015) suggest the stages for open innovation as (1) want phase; (2) find phase; (3) get phase; and (4) manage phase to success. Slowinski and Sagal (2015) report that the model, which emerged within the pharmaceutical industry in the 1990s, is developed to bring rational thinking from the fast-paced world of biotechnology industry to chemical industry in open innovation activities. In this model, a firm pursues open innovation activities through a four-phase lifecycle from want- to find- and get- phase. Finally, firm must manage the open innovation relationship to success. Thus, to increase firm's performance and make profit by producing a new product, the management of innovation for success is important in the management phase for commercialization. The management strategy during open innovation is urgently needed for a radical innovative new product development in fusion technology areas, such as the biochip technology.

In the implementation stage of open innovation in new product development (NPD), the decision regarding the level of openness to external partners is important, since open innovation is considered to be an effective innovation method for new product development. In this study, the decision regarding the level of openness based on technology characteristics is investigated in a case study of the Korean biochip industry. Technology characteristics, such as technology novelty and technology complexity, are related to openness and, consequently, the openness and innovativeness in firms has been investigated in previous research (Tatikonda and Rosenthal 2000; Vahter et al. 2014). This study is the first to focus on the relation between openness and technology ability to make commercial products, on the relation between technology ability and firm performance, and, more generally, on open innovation in the biochip industry. A model linking technology characteristics and performance is developed to suggest a relevant management strategy for open innovation during the implementation stage.

The model to link these relationships is proposed and a survey is carried out among the Korean biochip firms to evaluate the model. A total of 47 Korean biochip firms are included in the survey. Finally, a strategy regarding the degree of openness to increase the firm's performance is proposed.

3.1.2. Theoretical Considerations

3.1.2.1. Open innovation in biotechnology industry

Chiaroni et al. (2009) report managing open innovation in bio-pharmaceutical industry based on the experience of open innovation. The authors focus on the adoption of the open innovation paradigm in the bio-pharmaceutical industry and investigate which organizational modes (i.e. collaborations, in- and out-licensing) pertaining to open innovation have been implemented and how those modes are interwoven with the different phases of drug discovery and development processes. Furthermore, Bianchi et al. (2011) discuss how bio-pharmaceutical firms have used different organizational modes (i.e. licensing agreements, non-equity alliance, purchase and supply of technical and scientific services) to enter into relationship with different types of partners (i.e. large pharmaceutical companies, product biotech firms, platform biotech firms and universities) with the aim to acquire (inbound open innovation) or commercially exploit (outbound open innovation) technologies and knowledges.

Similarly, Al-Belushi et al. (2015) argue that, in a knowledge-based high tech industry such as the marine biotechnology industry, the ability to innovate is a key factor for increasing organizational competitiveness and this may be achieved using open innovation. The research results of Al-Belushi et al. (2015) demonstrate that the extent of openness in the marine biotechnology companies is higher towards market side activities and the use of open innovation to increase collaboration between companies, universities, and government research institutes needs to be significantly strengthened. In a similar fashion, Michelino et al. (2015) investigate the relationships between the adoption of open innovation by companies and firm's status, such as internal R&D and financial performances. the authors suggest that open innovation is a very pervasive behavior among smaller and younger companies, for which internal R&D is complementary to openness: still being in the development phase, they drive most of their revenues from open innovation itself and show negative financial performances.

Furthermore, Puslecki (2016) investigates the development of modes of cooperation in the Polish biopharmaceutical industry, referring to the data provided by the Association of Strategic Alliance Professionals. Puslecki (2016) suggests that biopharmaceutical companies try to implement new strategies to transfer their research processes to a higher level, often using open innovation model as an additional tool for developing new products and services.

Liekwise, Slowinski (2004) develops a model based on six steps for open innovation, namely: (1) determining what you need to know; (2) assembling the due diligence team; (3) preparing the partner for the due diligence process; (4) managing interaction between firms; and (5) conducting due diligence on intellectual assets.

According to Nilsson (2006), since the pharmaceutical industry is one of the most research-intensive industries, as well as a big industry in terms of revenue, it is important to acquire a deeper understanding of the trends in localization of R&D facilities. The open innovation strategy where companies' R&D crosses over corporate and national borders has become popular in the pharmaceutical industry. For instance, Kleyn et al. (2007) investigate the partnership and innovation in biopharma companies and find that partnering helps the firm to increase innovation and lets them adopt more open approaches to innovation. On top of that Kleyn et al. (2007) also report that organizational structures to coordinate and support partnerships (flexibility, leadership, developing organizational capabilities of universities) and a creation of enabling environment by governments are critical success factors for partnering.

The results of previous studies overviewed above suggest that, first, the management strategy is urgently needed in the implementation of open innovation in the biotechnology industry and, second, that openness is affected by various factors and is related to firm performance. Therefore, open innovation approaches in biotechnology, such as bioscience and bioengineering, can be applied for open innovation of biochip. These approaches will be investigated in this chapter.

3.1.2.2. Technology novelty and innovation

Technology novelty is an important factor for open innovation implementation, since novelty level can influence the amount of required technology transferred from external partners (Rampersad et al. 2010). Takiconda and Rosenthal (2000) investigate the relation between project characteristics and project outcomes, as well as characterize product development projects in terms of technology novelty and project complexity levels (. the authors report that technology novelty contributes to project task uncertainty and is, in turn, associated with project execution outcomes; at the same time, projects with high levels of technology novelty are associated with special project outcome elements (Takiconda and Rosenthal 2000).

Furthermore, Bogers and West (2012) investigate the managing of distributed innovation projects based on strategic use of open and user innovation. The authors report that a given innovation is typically classified across two orthogonal dimensions of technical novelty, namely: (1) technology novelty refers to whether the innovation constitutes a discontinuous (or radical) or an incremental technology changes; and (2) the scope of novelty refers to whether the innovation is new to the world or new to a specific producer or adopter. Similarly, Verhoeven et al. (2016) propose a more comprehensive measurement of technology novelty with patent-based indicators. Specifically, the authors characterize inventions *ex ante* along the following two dimensions of technology novelty: novelty in recombination and novelty in knowledge origins.

Next, Nieto and Santamaria (2007) focus on the importance of diverse collaborative networks for the novelty of product innovation. This study shows that competition today is driving firms to introduce products with a higher degree of novelty and, consequently, there is a growing need to understand the critical success factors behind more novel product innovations. The role of different types of collaboration networks is analyzed and it is found that the greatest positive impact on the degree of innovation novelty comes from collaboration networks comprising different type of partners (Nieto and Santamaria 2007).

In a different study, Tidd and Hsieh (2004) explore the influences of project novelty on the effectiveness of open service innovation. The obtained results demonstrate that the relationship between the intensity of supplier integration and development outcome varies with different degrees of project newness. Specifically, the authors find that (1) development projects with a higher novelty content are associated with higher levels of interaction with existing suppliers to communicate the requirements of more novel inputs; (2) development projects with a higher novelty content are associated with higher interaction with additional suppliers and new partners to expand the scope and function of new services; and (3) development projects with a higher novelty content are associated with mechanisms that have a higher degree of information richness to exchange and share knowledge with supplier and partners, such as project meeting and/or peer-to-peer discussion (Tidd and Hsieh 2014). Similarly, Mooty and Kedia (2014) report that transfer capability is necessary when there is a low degree of novelty and complexity arising from the lack of incongruence between accessed knowledge domain.

The results of previous studies overviewed above suggest that technology novelty is an important factor to open innovation and the relation between technology novelty and openness

should be clarified. The effect of technology novelty on openness should be investigated and a relevant strategy of open innovation management related to technology novelty should be constructed in the biochip industry.

3.1.2.3. Technology complexity and innovation

Technology complexity is an important factor for open innovation implementation, since complexity level influences the amount of required technology transferred from external partners. In this respect, Wei and Wei (2011) investigate the impact of product complexity and heterogeneity on online open innovation practices and report how product complexity and heterogeneity influence the way in which companies carry out online open innovation. The authors also stress that facilitating communication among innovators is critical to innovation when the product at stake is complex.

Furthermore, Brant and Lohse (2014) suggest that a wide range of factors, including globalization, advances in information and communication technology (ICT), and growing technological complexity, has induced business to increasingly engage in innovation collaborations, i.e. open innovation. This study proposes that key factors driving the ascendance of open innovation models include accelerated globalization, increasing technology complexity, and greater connectivity resulting from the ICT advancements.

Next, in an investigation of project-based perspectives on complex product development in open innovation, Becker et al. (2013) outline the specific nature of complex product development processes and acknowledge the need to rely on external sources of innovation. The authors also focus on the challenges of leveraging, such dispersed knowledge, pointing to the specific problems brought by the crucial role of “leaning by doing” in complex product innovation processes.

In another relevant study, Bahemia and Squire (2010) abstractly examine open innovation on the project level, rather than on the firm level, and develop a conceptual framework of inbound open innovation on the new product development project level to access factors that help determine the degree of openness along three dimensions (see also Tidd 2014). Bahemia and Squire (2010) find that the appropriate calibration of the three dimensions of inbound open innovation is determined by the types of innovation (radical versus incremental), product complexity (discrete versus complex), and the appropriate regime (tight versus weak).

Furthermore, Mooty and Kedia (2014) suggest that the complexity of knowledge exchange arise when the information and knowledge necessary to develop the innovation is new and unfamiliar to the focal firms. According to the results of this study, translation capability is necessary when there is a moderate degree of complexity arising from partial incongruence between accesses knowledge domain, and transformation capability is necessary when there is a high degree of complexity arising from high level of incongruence.

In another research pertinent to the topic, Hobday (1998) reports that complex products and systems (CoPS) affect the innovation and industrial organization and that there is a wide variety of innovation paths in CoPS projects. Adding nuance to these conclusions, Hansen and Rush (1998) report that there has been a shift to complex products and systems in industrially developed countries due to the increase of industrial output.

The results of the studies overviewed above demonstrate that technology complexity is an important factor to open innovation and the relation between technology complexity and openness should be clarified. The effect of technology complexity on openness should be investigated and the strategy of open innovation related to technology complexity should be constructed in the biochip industry, since the biochip itself is very complex product.

3.1.3. Research Model and Hypotheses

In this chapter, the following four important factors related to firm performance in open innovation will be considered: technology novelty, technology complexity, openness, and technology ability. The model is proposed, in which openness is related to (1) level of technology novelty; (2) level of technology complexity; (3) level of technology ability; and, related to (3), we will focus on (4) the level of technology ability. A theoretical model based on the proposed hypotheses is shown in Figure 3.1. In what follows, the relationships between the four variables are described in further detail.

(1) Technology novelty

For new product development in the biochip technology, novelty is very high and thus new technologies must be transferred from external partners. Since the way to get new technologies from external partners is open innovation and considering that a higher novelty in product

demands a higher novelty in technology, the degree of technology novelty affects the quality and amount of external technology flow that, in turn, affects the degree of open innovation. Therefore, it can be predicted that the technology novelty is directly related to openness.

According to Tidd and Hsieh (2014) who investigated the influence of project novelty on the effectiveness of open service innovation, the more novel development projects demand a higher level of interactions with existing suppliers to communicate, while the more novel development projects are associated with interaction with additional suppliers and new partners to expand the scope and function of new services. These results suggest that the technology novelty is related to the level of open innovation and the higher the level of technology novelty, the higher the level of degree of openness. Based on this expectation, the following hypothesis can be formulated:

H1: There would be a positive relationship between technology novelty and openness.

The complexity of knowledge exchange arises when the information and knowledge necessary to develop an innovation is new and unfamiliar to the focal firm due to the high level of technology novelty (Mooty and Keida 2014). The complexity relates to the knowledge exchange capabilities, one of technology abilities. Therefore, technology novelty can be related to the technology ability of a firm. Based on the above, the following hypothesis can be formulated:

H2: There would be a positive relationship between technology novelty and technology ability.

(2) Technology complexity

Complexity level of biochip is very high, since various technologies are combined to produce biochips. In this context, inflows of various external technologies are needed to provide sufficient technologies to make commercial product inside the firm and, in open innovation, the degree of openness can control the amount of various inflowing technologies. Therefore, the technology complexity can be related to the degree of openness. According Wei and Wei (2011) product complexity and heterogeneity influence the ways in which companies carry out online open innovation; when the product is complex, facilitating communication among innovators is essential. Based on the above considerations, the following hypothesis can be formulated:

H3: There would be a positive relationship between technology complexity and openness.

(3) Openness

Dahlander and Gann (2010) clarify the definition of openness currently used in various reports and literature on open innovation and indicate that openness consists of two inbound processes (sourcing and acquiring) and two outbound processes (revealing and selling) Furthermore, Love et al. (2011) investigate the openness, knowledge, innovation and growth in the UK business service and their results underscore the importance of external openness in the initial and exploratory phases of innovation process, as well as the importance of internal openness in the later phase of innovation process. In addition, Love et al.'s (2011) results demonstrate that learning from openness is based on the dynamics of breadth in external innovation linkage and indicate that openness in external knowledge sources includes a process of interaction and information processing.

Furthermore, Roper et al. (2013) investigate externalities of openness in innovation in the Irish plant-level data from the manufacturing industry. The results of this study show that openness can itself generate positive externalities by enhancing knowledge diffusion. The authors also report that externalities of openness in innovation are positively related to the firm's innovation performance. Likewise, in their investigation of the relation between openness and innovation performance, especially with the focus on the difference between in small firms and large firms based on Irish manufacturing plants, Vahter et al. (2014) find that small firms have a lower level of openness due to a lower level of external linkage and a lower level of breadth of openness as compared with those of large firms. Similarly, in a study of the reasons why openness drives innovation in IT companies, States (2003) finds that open culture accelerates the development and diffusion of new technologies.

Next, Lichtenthaler and Lichtenthaler (2009) identify the following six 'knowledge capacities' as firm's critical capabilities of managing internal and external knowledge in open innovation process: inventive, absorptive, transformative, connective, innovative, and desorptive capacity. Innovative firms have to acquire new skills and routines to develop the full real option potential of open innovation practices (Vanhaverbeke et al. 2008). Vanhaverbeke et al. (2008) suggest that a firm has to acquire new skills to materialize the benefits of the extended flexibility. In this context, development of absorption capacity is needed to effectively learn from other firms (Vanhaverbeke et al. 2008). Furthermore, organizing inbound open innovation

in traditional industries requires building absorptive capacity; therefore, the ability to absorb external knowledge has become a major driver of competition (Spithoven et al. 2011). Thus, openness is related to technology ability and the increase of the level of the degree of open innovation causes an increase of technology ability. Therefore, it can be predicted that openness is positively related to a firm's internal technological capability to make commercial products. Based on the above, the following hypothesis can be formulated:

H4: There would be a positive relationship between openness and technology ability.

(4) Technology ability

In a study on Taiwan's electronics industry, specifically, with regard to nonlinear characteristics of accumulation of technology capability, Tsai (2004) reports that the technological capability affects firm performance. The technological innovation increases the long-term firm performance (Dieguez-Soto et al. 2016; Takiconda and Montoya-Weiss 2001). Thus, it can be predicted that a firm's internal research ability is positively related to firm performance. Therefore, the following hypothesis can be formulated:

H5: There would a positive relationship between technology ability and firm performance.

Based on the above hypotheses and relations, the model is constructed as shown in Figure 3.1.

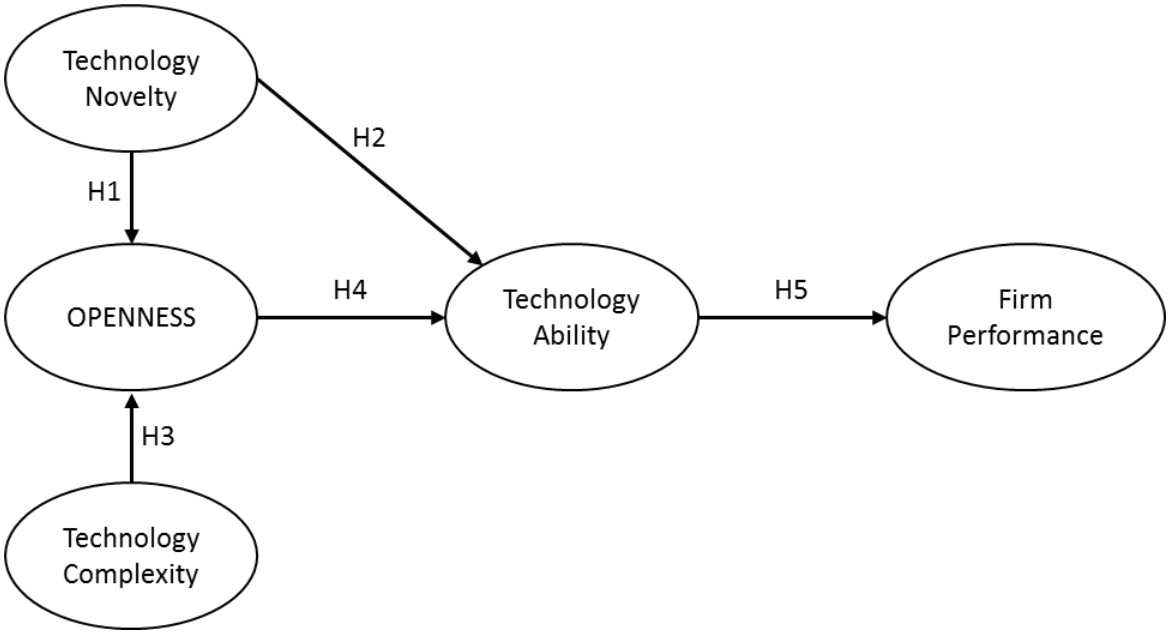

Figure 3.1. Model for relation between technology characteristics and open innovation

3.1.4. Research Method

(1) Questionnaire Design

The biochip industry, one of high technology industries, is a fusion of various technologies including biochip, nanotechnology, biosensor, and bioinformatics. In general, due to secure competition for patent and intellectual property, open innovation activity was barely accomplished in high technological industries. However, in the process of rapid development and commercialization of new products, since life cycle of high technology has recently decreased, the need for open innovation activity has increased (Ahn and Lee, 2011). From this trend, it can be predicted that open innovation has happened in the biochip industry due to its high and intensive level of technological research. For that reason, the biochip industry in Korea is selected as the target industry in the present study.

The aim of this chapter is to investigate the start of open innovation and the switching cost during the initial stage of the new product development process. To achieve this aim and to ensure the validity of findings, a questionnaire survey is done, which is an established research technique for technology management studies (e.g. Al-Zu'bi and Tsinopoulos 2012; Pick and Eisend 2014, 2016).

The questions to be addressed were designed as follows. The interviews to construct questions were carried out with CTO of two small biochip firms (BioDiatech and NSB Postech), CTO of one medium-size biochip firm (NanoEnTek), and a manager of the biochip team of a large firm (Samsung Advanced Institute of Technology). The data collection took place from October 10 to October 24, 2012. Furthermore, the discussion of open innovation activity in the implementation stage during new product development in biochip was held, with the specific focus on the factors affecting openness so that to find the relation of factors for openness and technology ability. In addition, the relation of technology ability to firm performance was discussed during open innovation action. The discussion results for open innovation activity during new product development of biochip were analyzed and the main variables were classified as two factors (technology novelty and technology complexity), openness, technology ability, and the perception of advantage of open innovation (see Table 3.1).

Table 3.1. Questions for openness in implementation stage during new product development (NPD).

(1) How would you characterize the degree of technology novelty? 1.1. How novel is the composition of the product on average? 1.2. How novel is the structure of the product? 1.3. How novel are the production processes on average? 1.4. How novel is the layout of the production process?
(2) How would you characterize the degree of technology complexity? 2.1. Are different types of technologies used for the product?
(3) How would you characterize level of openness? 3.1. Our organization is active in working with others. 3.2. Our organization regularly exchanges information with others. 3.3. Our organization has active interaction with others. 3.4. Our organization is flexible with the creation and abolition of organizations as needed.
(4) How would you characterize the level of technology ability? 4.1. How would you characterize level of overall R&D capability of your company compared with competitors? 4.2. How would you characterize the number of patents of your company, as compared to competitors? 4.3. How would you characterize the number of researchers of your company, as compared to competitors? 4.4. How does level of your research experience with your research staff compare to that of competitors? (Limited to experience in related fields) 4.5. How would you characterize research funding level of your company as compared to competitors? 4.6. How would you characterize research equipment level of your company as compared to that of competitors?

(5) What is the level of firm performance?

5.1. What is the level of increase of revenue?

5.2. What is the level of increase of operating margin?

5.3. What is the level of increase of competitive production cost?

5.4. What is the level of increase of newly invested capital?

5.5. What is the level of increase of number of newly developed products?

5.6. What is the level of increase of royalty income?

The scales used in the survey were seven as used in the literature (Son et al. 2014), and then the scales were later modified for this study. To ensure the validity of the questions and scales, a panel of experts consisting of three interviewees and two professors in Sogang University, Korea (major: biochip and biosensor) was asked to review them. This process allowed us to introduce modifications and clarification to the questions.

The main question addressed in this chapter concerns the openness to start open innovation in the initial stage of new product development of biochip. Specifically, four aspects are of relevance here: (1) Does openness control firm performance? (2) Do factors such as technology novelty and technology complexity affect openness? (3) Does openness relate to technology ability? (4) Does technology ability relate to firm performance? The survey results obtained to the constructed questionnaire are described in the next section.

(2) Survey Administration

The survey in the Korean biochip firms, conducted from October 24, 2011 to November 17, 2012, targeted decision makers in 70 firms. The respondents were contacted by e-mail and visit. At that time, the total number of bio-diagnostics firms in the Korean Association of Bio-diagnostics was about 70. At first, from October 24, 2011 to February 24, 2012, the survey was done for 50 firms; the number of collected surveys was 35, which was not sufficient for data validation. Then, from August 17, 2012 to November 17, the survey was done for additional 20 firms and the number of collected surveys was 15. Thus, the total number of collected surveys amounted 50 firms. Due to the long period of data collection (approximately one year), there may have a time-related bias, though all firms were alive during one year. Biochip firms included biosensor firms, biochip firms to produce DNA chip, protein chip, cell chip, biosensor

array firms, biochip fabrication firms including MEMS (microelectromechanical system), bioinformatics firms, and instrument firms (arrayer and detector). Through the survey, a total of 50 survey results were acquired, reaching the response rate of 71 %, and further analysis was carried out with 47 surveys (in 3 surveys, the responses were incomplete).

(3) Demographic characteristics

Demographic characteristics of the respondents are summarized in Table 3.2.

Table 3.2. Characteristics of demography of sample

Division	Content	Number	Percentage (%)
personal employment term	below 5 years	16	32
	6~10 years	15	30
	11~15 years	13	26
	16~20 years	3	6
	21~25 years	2	4
	above 26 years	1	2
Personal position	CEO	23	46
	Research Director	4	8
	General Manager	11	22
	Deputy General Manager	6	12
	Manager	4	8
	Missing value	2	4
Personal age	20~29	1	2
	30~39	14	28
	40~49	23	46
	50~59	11	22
	Missing value	1	2
Firm's Age	below 5 years	9	18
	6~10 years	14	28
	11~15 years	19	38

	16~20 years	7	14
	Missing value	1	2
Number of employees	below 10	15	30
	11~50	16	32
	51~100	6	12
	101~200	5	10
	200~300	4	8
	1800	1	2
	Missing value	3	6
Number of researchers	1~10	24	48
	11~20	12	24
	21~50	5	10
	51~100	3	6
	above 100	3	6
	Missing value	3	6

(4) Statistical analysis of variables

The denotation of variables and measurement method of the variables in the research model are shown in Table 3.3. A seven-point scale was used for the variables.

Table 3.3. Denotation and measurement of variables

TN1	How novel is the composition of the product on average?
TN2	How novel is the structure of the product?
TN3	How novel are the production processes on average?
TN4	How novel is the layout of the production process?
OP1	Our organization is active in working with others.
OP2	Our organization regularly exchanges information with others.
OP3	Our organization has active interaction with others.
OP4	Our organization is flexible with the creation and abolition of organizations as needed.
TA1	Compared with competitors, level of overall R&D capability of your company

TA2	Compared with competitors, the number of patents of your company
TA3	Compared with competitors, the number of researchers of your company
TA4	Compared with your competitors, level of your research experience with your research staff (Limited to experience in related fields)
TA5	Compared with competitors, research funding level of your company?
TA6	Compared with competitors, research equipment level of your company?
FP1	Level of increase of revenue
FP2	Level of increase of operating margin
FP3	Level of increase of competitive production cost
FP4	Level of increase of newly invested capital
FP5	Level of increase of number of newly developed products
FP6	Level of increase of royalty income
TC1	Number of different types of technologies used for the product

TN: Technology novelty, TC: Technology complexity, OP: Openness, TA: Technology ability, FP: firm performance

The classification of technology complexity is shown in Table 3.4.

Table 3.4. Classification of technology complexity

Type	Subtype	Detail Classification
Bio Fabrication	Substrate material	Glass
		Gold
		Silicon
		Polymer
	Coating	Silanization
		Polymer matrix
	Bio material	DNA
		Protein
		Cell
		Peptide

		Small molecules
	Micro arraying	Pin
		Inkjet
		Photolithography
		Electrical addressing
Lab-on-a-chip	Bio MEMS technology	Silicon machining
		Plastic machining
	Bio MEMS device	Micro channel
		Micro valve
		Micro fluidics
		Dispenser
		Reaction chamber
		Electric device
		Total integrated system
Bioinformatics	Bioinformatics	Image analysis
		Visualization
		Database
		Data mining
		Clustering
Detection	Materials and instruments for detection	Fluorescence material
		F.M. laser scanner
		F.M. Scattering
		F.M. Polarization
		Electrochemical
		SPR
		Mass Spec.
		Magnetic

Based on the data acquired by the survey, analysis was performed using SPSS 18.0 program and PLS 2.0. The hypotheses were tested by applying the partial last square (PLS) method to the collected data. This study used PLS, rather than other SEM methods (i.e. LISREL, AMOS, etc.), because the PLS approach places minimal restrictions on sample size and residual

distribution (Phang et al. 2006). First of all, analysis of descriptive statistics quantity was accomplished and the results were investigated. To verify the reliability of the samples, items measuring each comprising concepts were investigated using Cronbach's alpha test. Also, to verify the validity of the samples, factor analysis was performed in the hypothesis testing process.

3.1.5. Results

3.1.5.1. Validation

To validate the model, three types of validity—content validity, convergent validity, and discriminant validity—were assessed. (1) Content validity was evaluated based on Cronbach alpha value (see Table 2.4). Cronbach's alpha test to individual scale and the overall measures was used to assess internal consistency. The threshold value of Cronbach alpha is 0.7 (Nunally and Berstein 1994). As shown in Table 3.5, the Cronbach alpha values are 0.870 for technology novelty, 1.000 for technology complexity, 0.729 for openness, 0.896 for technology ability, and 0.881 for firm performance. Thus, all variables are valid.

Table 3.5. Confirmatory factor analysis

	AVE	Composite Reliability	Cronbach's Alpha
TC	1.000	1.000	1.000
FP	0.664	0.908	0.881
TN	0.718	0.910	0.870
OP	0.545	0.826	0.729
TA	0.659	0.920	0.896

*Average variable extracted

(2) Convergent validity was assessed by composite reliability and average variance extracted (AVE) from the measures (see Table 3.5). The acceptable value of composite reliability for reliable construct is 0.7 (Chin 1988). The obtained composite reliability values were 0.910 for technology novelty, 1.000 for technology complexity, 0.826 for openness, 0.920

for technology ability, and 0.908 for firm performance. Thus, all variables are valid. The acceptable value of AVE is over 0.5 (Fornell and Larcker 1981). The AVE values in our results were 0.718 for technology novelty, 1.000 for technology complexity, 0.545 for openness, 0.659 for technology ability, and 0.664 for firm performance. Thus, all variables are valid.

(3) Discriminant validity is verified by evaluating the square root of AVE (Fornell and Larcker 1981; Son et al. 2014). The square root of AVE for each construct in our results was greater than the levels of correlation involving the construct (see Table 3.6). Also, each construct showed a larger variance with its own measures than those with other measures (see Table 3.6). Threshold value of absolute value pairwise correlation is 0.6 (Nunally and Berstein 1994); the highest absolute value of pairwise correlation in our data was 0.484, which is lower than 0.6. Variance inflation factors (VIF) is calculated to detect the multicollinearity among the explanatory variables. Threshold value of VIF is 10 (Nunally and Berstein 1994); in our results, the highest VIF value was 3.722, which is far lower than 10. Thus, all variables are valid.

Table 3.6. Correlation between constructs

	Complexity	Firm performance	Novelty	Openness	Technology ability
TC	1.000				
FP	0.064	0.815*			
TN	0.234	0.065	0.848*		
OP	0.073	0.185	0.323	0.738*	
TA	0.244	0.447	0.367	0.484	0.812*

* Square root of AVE

The other analyses based on statistical results are as follows. The descriptive statistics including standard deviation are summarized in Table 3.7. Kaiser-Meyer-Olkin measure of sampling adequacy was calculated to amount to 0.754. The results suggest that 4 factors explain 67.933% of the total variance (Table 3.8). Since all 4 factors are well distributed over 0.6 in factor analysis, the validity requirement was satisfied (see Table 3.9).

Table 3.7. Descriptive Statistics

	N	Min	Max	Mean	Std. Deviation
TN 1	47	1	7	5.19	1.296
TN 2	47	1	7	4.72	1.363
TN 3	47	1	7	4.72	1.314
TN 4	47	2	7	4.60	1.313
OP 1	47	1	4	2.13	1.055
OP 2	47	1	4	3.06	.895
OP 3	47	1	4	2.74	.943
OP 4	47	1	4	1.81	1.014
TA 1	47	1	7	4.72	1.542
TA 2	47	1	7	3.77	1.709
TA 3	47	1	7	3.30	1.743
TA 4	47	1	7	4.38	1.675
TA 5	47	1	7	3.91	1.717
TA 6	47	1	7	4.26	1.738
FP 1	47	1	7	3.32	1.795
FP 2	47	1	7	3.74	1.725
FP 3	47	1	7	4.74	1.621
FP 4	47	1	7	3.15	1.732
FP 5	47	1	7	4.00	1.655
FP 6	47	1	7	2.45	1.515

TC 1	47	1	7	2.94	1.634
Effective Number	47				

Table 3.8. Total Variance Explained

Factor	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loading		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	6.193	32.594	32.594	6.193	32.594	33.657	3.986	20.980	20.980
2	3.253	17.121	49.715	3.253	17.121	54.441	3.564	18.759	39.739
3	1.919	10.098	59.813	1.919	10.098	67.593	3.118	16.412	56.152
4	**1.554**	**8.180**	**67.993**	**1.554**	**8.180**	**75.686**	**2.250**	**11.841**	**67.993**
5	.945	4.973	72.967						
6	.813	4.277	77.243						
7	.757	3.983	81.226						
8	.654	3.445	84.671						
9	.528	2.780	87.954						
10	.475	2.502	89.954						
11	.374	1.969	91.922						

12	.324	1.704	93.626						
13	.270	1.423	95.049						
14	.236	1.242	96.290						
15	.211	1.109	97.400						
16	.174	.917	98.316						
17	.137	.721	99.038						
18	.117	.615	99.653						
19	.066	.347	100.000						

Extraction Method: Principal Component Analysis

Table 3.9. Rotated Component Matrix

	Component			
	1	2	3	4
TN 1	.107	.116	**.778**	.145
TN 2	.141	-.034	**.812**	.181
TN 3	.126	-.046	**.880**	.003
TN 4	.126	-.096	**.840**	.077
OP 1	.157	.050	.262	**.672**
OP 2	.362	-.071	.144	**.607**
OP 3	-.008	.140	.015	**.787**
OP 4	.262	.055	.045	**.742**

TA 1	**.830**	.120	.080	.054
TA 2	**.837**	.056	.082	.166
TA 3	**.754**	.291	.078	.231
TA 4	**.687**	-.012	.036	.163
TA 5	**.758**	.252	.289	.107
TA 6	**.695**	.281	.388	.171
FP 1	.081	**.912**	-.024	.141
FP 2	-.063	**.881**	-.100	.058
FP 3	.355	**.758**	.099	.076
FP 4	.253	**.707**	.060	.099
FP 5	.109	**.763**	-.043	-.103

Extraction Method: Principal Component Analysis, Rotation Method: Varimax with Kaiser Normalization. a. Rotation converged in 5 iterations

3.1.5.2. Hypothesis testing

To validate the model, the structural equation model was applied and Partial Least Square (PLS) was used. Since PLS requires minimal demands on sample size (Chin 1998) to validate a model and our data set had 47 questionnaires, the PLS method was used to evaluate the proposed model and hypotheses. When t-value is over 1.96, the hypothesis is significant at 5% level of significance (provided the number of surveys is sufficiently large). Cramer suggests that the approximation is usually good for samples larger than 30 (Cramer 1946) and, thus, statistical inference is appropriate for our dataset. As shown in Table 3.10, only t-values for the relation between technology novelty and openness, the relation between openness and technology ability, and the relation between technology ability and firm performance were over 1.96 and thus only these three relations were satisfied. The values of path loadings were then calculated. Since R^2 for openness, technology ability and firm performance was 0.104, 0.284,

and 0.200, respectively, the proposed model is acceptable, since minimum acceptable range of R^2 is 0.1. The results of the analysis of the model with path coefficient, t-value, and R^2 are shown in Figure 3.2.

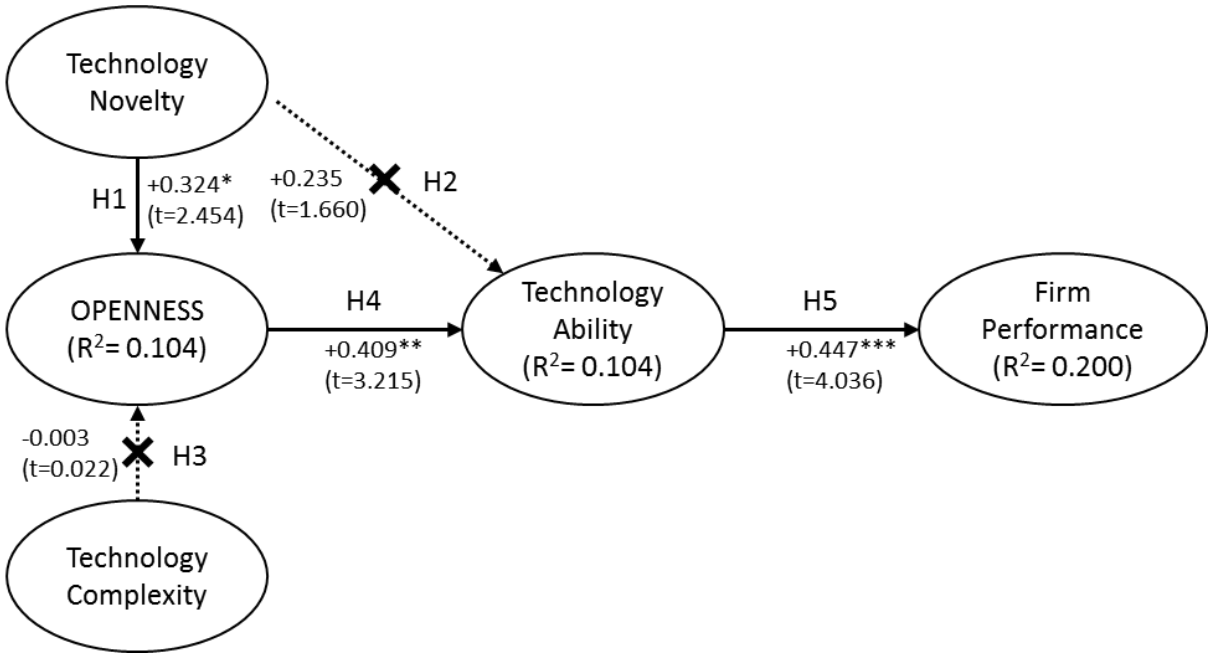

Figure 3.2. Model result for relation between technology characteristics and open innovation

Table 3.10. Path Coefficients

	Original Sample	Sample Mean	Standard Deviation	T Statistics	P Values
TC → OP	-0.003	0.009	0.145	0.022	0.983
TN → OP	0.324	0.358	0.132	2.454	0.014*
TN → TA	0.235	0.215	0.141	1.660	0.097
OP → TA	0.409	0.430	0.127	3.215	0.001**
TA → FP	0.447	0.497	0.111	4.036	0.000***

*** p<0.001, ** p<0.01, * p<0.05

The results reported in Figure 3.2 suggest the following. The technology novelty is

positively related to openness, meaning that, as technology novelty becomes higher, the degree of open innovation and openness increase as well. The result suggests that the firm becomes more open to get a new technology from outside to make a novel product if technology novelty is high and the new product is novel. Thus, Hypothesis 1 is confirmed. If only path coefficients in Table 3.10 are considered, the technology novelty is positively related to the change of technology ability of firm, meaning that, as technology novelty becomes higher, the technology ability of firm increases. However, since t value is not in the acceptable range, the relation between technology novelty and change of technology ability of firm is not established. Thus, technology novelty does not directly relate to technology ability of firm and Hypothesis 2 has to be rejected.

If only path coefficient is considered, the technology complexity is positively related with openness, meaning that as technology complexity becomes higher, the openness increases. However, since t-value is not in the acceptable range, the direct relation between technology complexity and openness is not established. It is reported that a firm has to become more open to get complex technology from outside and then it can make new complex product with complex technologies (Bogers and West 2012; Nieto and Santamaria 2006). However, according to Mooty and Kedia (2014), the relation between complexity and performance has a reverse U-curve shape and, thus, it is difficult to make just a positive or a negative relation between technology complexity and openness, which is related to firm performance. In the case of biochip investigated in this study, to make biochips, many different kinds of technologies should be combined, since a biochip is basically a product of complex technology (Table 3.4); therefore, an increase of complexity cannot significantly affect the increase of open activity in firm due to the intrinsic high complexity of the biochip industry. Therefore, there is no positive relation between technology complexity and degree of open innovation in biochip production and Hypothesis 3 has to be rejected.

The openness is positively related to technology ability, meaning that, as the degree of open innovation becomes higher, the technology ability in firm increases. The results suggest that, if the firm becomes more open and gets more new technology from the outside, the technology ability to make new product increases due to acquiring a new technology. Thus, Hypothesis 4 is supported by our data analysis.

The technology ability of firm is positively related to firm performance, meaning that, as level of technology ability in firm becomes higher, firm performance (such as revenue,

operating margin, competitive production cost, number of newly developed product, and royalty income) becomes better. The obtained results suggest that, if the firm becomes more open and gets more new technology from the outside, the technology ability to make new product increases due to the firm's acquiring a new technology. Thus, Hypothesis 5 is supported by our data analysis.

Although openness is reported to directly affect directly innovation performance (Vahter et al. 2014), in this study, openness is directly related to the change of technology ability and then, sequentially, technology ability is directly related to firm performance. The change of technology ability becomes a mediator factor between openness and firm performance, since the biochip is a technology-concentrated product. This constitutes a newly developed relationship in open innovation for high-tech products.

3.1.6. Conclusion and Discussion

The summary of the research results reported above is shown in Figure 3.3.

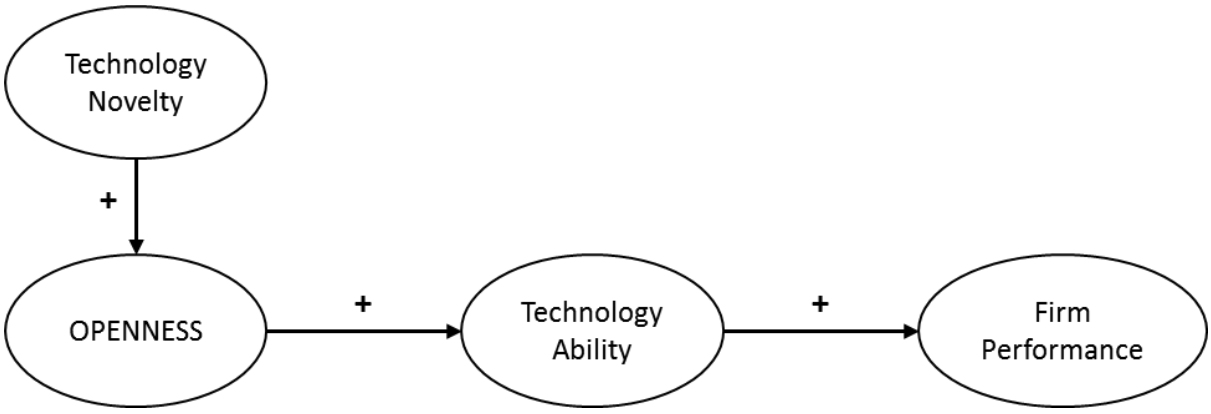

Figure 3.3. Summary of model result for relation between technology characteristics and open innovation

The purpose of this chapter was to investigate the factors affecting openness during implementation of open innovation. The factors, such as the technology characteristics, technology novelty and technology complexity, were investigated. We found that technology novelty has a positive relation with openness. If the technology novelty is high and new product is a very creative one, the degree of open innovation should be increased, meaning that the firm

should become more open to get more external technologies. However, due to the intrinsic nature of biochip technology, our results demonstrate that the technology complexity is not directly related to openness.

A factor that affects the change of firm's technology ability in new product development is openness. Our results show that the openness is positively related to firm's technology ability. If the openness becomes high during the development of a new product and the degree of open innovation increases, more external technologies are necessary and should be acquired from the outside; thus, the technology ability to make a new product increases. As openness and inflow of external technologies increase, more technology ability inside the firm is achieved. As firms becomes more open and more inflow of external technologies occurs, more increase of technology ability inside firm is achieved.

A factor that affects the change of firm's technology ability in new product development is firm's ability. Our results show that a firm's technology ability has a positive relation to firm's performance. If the firm's technology ability increases because of openness increase, during the development of a new product, there is a corresponding increase of revenue, operating margin, competitive production cost, number of newly developed products, and royalty income, which positively affects firm's performance. Thus, an increase of openness improves a firm's technology ability and then, sequentially, an increase of technology ability causes an increase of firm's performance.

An innovation strategy is needed to effectively do innovation, since the problem with innovation improvement efforts is rooted in the lack of an innovation strategy (Pisano 2015). Based on the results from this study, the following strategy to manage open innovation during implementation of open innovation is suggested. At first, the novelty of technology for a new product is carefully examined. If the technology novelty is high, the degree of open innovation should be increased. If the technology novelty is very low, the firm should decide to decrease the open innovation activity with an external research partner. The technology complexity is not much considered to decide on the degree of open innovation and openness.

As more open innovation is implemented due to novelty, the more technology flows in. By controlling the degree of open innovation, the technology flow can be controlled, which, in turn, affects the technology ability of firm to produce new products. As a second step, the degree of open innovation should be decided based on the level to which firm wants to increase

its internal research ability. Then, an increase of the research ability of firm causes the increase of firm performance, leading to more profit. As a third step, the balance between the expense of open innovation and profit of firm due to openness should be considered and then the degree of open innovation can be decided based on the balance. The relations among openness, technology ability, and firm performance should be simultaneously evaluated.

In this study, the technology is center to value offering and can control the openness and firm performance. However, in the real world, to improve firm performance, a firm has to consider at least six factors, including technology, organization, environment, market, business model, and expansion in the innovation process (Henderson et al. 2016). The start of the process is often technology, from which we create value and then end with market – the source of need and place where value is realized (Henderson et al. 2016). Thus, to make strategy for open innovation, the above-mentioned variables should be considered simultaneously with the technology viewpoint.

The results of this study are follows: (1) Influential factors affecting the degree of open innovation during the implementation process in new product development are identified; (2) The relations among influential factors including the technology characteristics to openness are clarified; (3) Strategy to control the openness is proposed to increase firm performance. Technology characteristics and technology ability in firm are key factors to decide on the degree of openness with external partners. Based on the insights regarding the relations of openness with firm performance from the technology point of view, the decision to control the degree of openness should be taken.

Since, the extended period of data collection (ca. a year) could have caused a time-related bias in the present study (although all firms that responded to the survey were alive during one year), a reduction of time for the survey is recommended.

3.2. Analysis of Influence Factors on Breadth and Depth in Open Innovation Activity

3.2.1. Introduction

After a conceptual introduction by Chesbrough (2003), open innovation has received a huge

attention from both academic research and firms. According to Chesbrough (2003, 2006a,b), open innovation is the methodology of innovation used by firms to open the innovation process, including research, development, and commercialization; in open innovation, external resources are used for reduction of innovation cost, increasing the possibility of success, and maximization of added value creation. Due to the globalization of firm's market, open innovation has been widely used in various fields. The reason to believe that open innovation is important for efficient management of firm can be found in the rapid change of knowledge environment surrounding the firm. Following Chesbrough (2003), Kim et al. (2008) suggest the following three reasons for the emergence of open innovation in R&D). First, after the end of large firms' monopoly on knowledge, sources of knowledge creation have been widened, including universities and venture firms. This means that big firm-cored monopolistic management becomes impossible, because creative knowledge is being developed in various fields. The second reason is mobility of human resources and the development of venture capital. The mobility of human resources here means that knowledge and know-how move with each other in a firm and the channel of technological commercialization is extended with the rapid development of venture capital. The last reason is the growth of cost for technological development and the minimization of product cycle. As the time of initiative for technology has been shorten, firms should invest resources into the development of follow-up technology.

Specifically, in the case of Korea, the investment for R&D part has rapidly grown; however, most results of R&D have not been commercialized yet (Bock and Lee 2008). As mentioned by Bock and Lee (2008), 61.1 % of patents possessed by Korean firms are in the state of dormancy. Thus, the effort for innovation strategy is needed for an effective R&D investment and empowerment in Korea. Open innovation has been considered as an effective measure to solve the above problem (Kim et al. 2008). To apply open innovation to firms, the analysis of factors in innovation activity should be performed. Although open innovation is an important issue, studies on the factors affecting innovation activity remain scarce.

Generally, in most previous studies, open innovation in firms has been investigated through case studies (Chiaroni et al. 2009). However, while various statistical studies have been conducted, due to the use of only the data related to open innovation from technological innovation activity, these studies, as suggested by Laursen and Salter (2006), have not considered various factors for tactical decisions of open innovation Therefore, further research on the various factors affecting innovation activity in open innovation should be undertaken.

In this chapter, the influential factors of the breadth and depth of external seeking are investigated with the aim of suggesting an appropriate strategy of open innovation to increase firm performance. The breadth and depth of external seeking are related to openness that affects firm's performance. Factors affecting open innovation activity are classified as the follows: environmental characteristics surrounding firm, firm characteristics including research ability and organizational culture, and institutional characteristics for technological innovation activity. These three factors are investigated to see how they affect open innovation activity. To this end, a survey is conducted in the Korean biochip firms to analyze innovation activity in open innovation.

3.2.2. Theoretical considerations

3.2.2.1. Concept of open innovation activity

As shown in the introduction section, open innovation refers to the methodology of firm innovation that maximizes the value added by reducing the innovation cost and enhancing the possibility of success through opening a series of innovative processes in research, NPD development, and commercialization. According to Chesbrough (2006a,b), the open innovation is that a firm uses internal and external knowledge flow to accelerate inner innovation and to expand outer market of innovation. The open innovation process refers to the implementation of a system whereby which internal and external ideas are integrated and this open knowledge system is resonant with the company's business models. Specifically, as a category of open innovation, all things regarding technology innovation that are in exchange with the outside of the firm are defined as open innovation. Besides, whether or not there is collaboration with the outside, only cooperative relationship in the process of technological innovation is open innovation. In a large category, open innovation exists as the outward and inward type of innovation activity.

In this regard, as proposed by Kim et al. (2008), technology purchase, collaborative research, research contract, cooperative venture foundation, venture investment, firm takeover, solution public participation, user innovation, and collective intelligence are classified as

activities of inward type, while technology sale and new dividing firm from inside are classified as activities of outward type (see Table 3.11).

Table 3.11. Types and activities of open innovation

Type	Concept	Example
Inward Type	Acquiring technologies or ideas of firm from outside during technology innovation process	Technology purchase, collaborative research, research contract, cooperative venture foundation, venture investment, firm takeover, solution public participation, user innovation and collective intelligence
Outward Type	Letting technology to outside	Technology sales, spin-off firm

Furthermore, Gassman and Enkel (2004) classified open innovation as three models or core processes. First, inward process refers to the integration of supplier, customer, and outside knowledge. The knowledge inflow from outside organizations like universities and common laboratories is an example here. Second, outward process refers to the firm's supplying ideas, selling intellectual properties to the outside, and knowledge transfer. Technology holding firm, new dividing firm, and licensing are relevant examples here. Third, integrated process is the process that integrates outward and inward processes and could be classified by mutual knowledge exchanges and joint investments for technology integration.

Laursen and Salter (2006) further analyze the effects of open search on the results with 2707 manufacturing firms in the UK. Considering the open search as activities that accelerate open innovation, the authors measure how deeply and widely firm's research was done among the 16 outside information sources. With these considerations, the authors find that the open search enhances the results of technology researches. Also, the depth of research enhances rapid innovation, while the breadth enhances gradual innovation. Furthermore, the effects of open action have limitations, because it shows a reversed U-shape when the activity of open

innovation is above some level.

3.2.2.2. The research on the factors affecting open innovation

There are many reasons why firms conduct open innovation. In an analysis of the industrial characteristic effects in various cases, Kim et al. (2008) observe that the relation in the industry between position of firm, exclusive possession method of technology, maturity of industry, transition progress, and relief in industry affect open innovation. Furthermore, using the data of manufacturing business, Lee and Choe (2006) find that there is a decision factor of collaborate research related to business scale and technology knowledge inflow from universities or research centers.

Likewise, based on a thousand of Spanish manufacturing firms, Arranz and Arroyabe (2008) analyze decision factors of open innovation activity and conclude that the types of cooperative activities can be classified into vertical cooperation, horizontal cooperation, and cooperation with public institutions. In this research, the high-tech field, business scale, existence of R&D organization, and policy funds support are confirmed as decision factors for horizontal cooperation. Finally, James and Ropper (2002) note that the decision of cooperation type of R&D is based on facility scale, R&D investment cost, and market structure environment.

3.2.3. Research model

3.2.3.1. Research model and hypothesis

In order to analyze the factors of affecting open innovation activity, we divide them into firm's internal and external factors. Ahn and Lee (2011) analyzed the decision factors of the open innovation by classifying them into environmental characteristics, business characteristics, and institutional characteristics. In the present research, the classification of fundamental independent variables is based on Ahn and Lee's (2011) approach; however, some variables were added or edited based on industrial characteristics on the chip industry. Specifically, the factors are classified into environmental characteristics (novelty of technology, degree of market competition, and government support), industrial characteristics (research

capability, organization culture), and institutional characteristics (existence of dedicated group to derive open innovation and firm's location in industrial cluster for business exchange). With the above classification, outside business environment factors, inside business capability factors, and institutional factors are considered using the integrated strategic view. The reason to make this classification is that effects of variables on open innovation can be found by investigating firm's technical capacity and culture of firm that accepts open innovation. Also, by considering institutional system needed for open innovation, as well as technical capability and firm culture, an integrated view to analyze open innovation inside the firm can be proposed.

The variety of external networks of collaboration in open innovation is measured by breadth and depth of open innovation. Breadth of open innovation can be measured by the number of targets, while the depth is measured by the frequency of a single target. Laursen and Salter (2006) used the concepts of depth and breadth to measure the degree of open innovation by evaluating how much, or how closely, outside information sources cooperate on the basis of open innovation data.

Based on the results of the studies overviewed above, it can be predicted how environmental, industrial, and institutional characteristic variables could affect depth and breadth of open innovation; furthermore, these variables can help decide whether or not to pursue cooperation with new objects or existing objects. With regard to this research model, the hypotheses outlined below can be formulated.

(1) The relation between environmental characteristic factor and open innovation activity

The degree of market competition among environmental characteristics refers to high uncertainty of the market (Einsenhardt and Schoonhoven 1996). As the existence of firm might be threatened if uncertainty of market becomes higher, to overcome this threat, cooperation through the open innovation is expected to increase. It appears that the more competitive firms are, the more technology from outside they can acquire. In other words, it means that open innovation would grow up more when the degree of market competition becomes higher. Stafford (1004) calls this taking a safety strategy when market is uncertain. Considering depth and breadth of open innovation activity, to enhance cooperation with the currently cooperating object is a safer strategy than finding another object. Therefore, the following hypothesis can

be formulated:

H1-1: With an increase of the intensity of market competition, the depth of open innovation activity would increase.

Normally, it is reported that governmental R&D support positively affects innovative degree of technology development. For example, Arranz and Arroyabe (2008) report that policy fund support meaningfully affects horizontal open innovation. Therefore, the following hypothesis can be formulated:

H1-2: With an increase of the degree of government support, the depth of open innovation activity would increase.

Appearance of new technology means that research about new knowledge is required. According to Belderbos et al. (2004), the cooperation with various research subjects to develop and introduce technology is increased with the transition of technology. Similarly, an increase of effort to find various knowledge sources is expected as a new technology is evolved. Therefore, the following hypothesis can be formulated:

H1-3: With an increase of the novelty of technology, the breadth of open innovation activity would increase.

(2) The relation between firm characteristic factor and open innovation activity

The quality of researchers is an important factor for research cooperation. High technology capacity means that more advantages are expected in cooperation with outside subjects. High quality of research ability in firm makes cooperative research effective, rather than just facilitates importing or transferring the technology with outside (Link and Bauer 1987). Thus, by high quality researchers, it tends to maintain cooperation subjects narrowly and closely. Therefore, the following hypothesis can be formulated:

H2-1: With an increase of the research capability based on the number of Ph.D. staff in R&D, the depth of open innovation activity would increase.

Increase of research investment means an increase of research capacity of the firm. For a continuous increase of firm's research capacity, aggressive investment should be done and the investment for development is related to seeking of new knowledge resources. During the

process of strategic investment of a firm, the factors affecting seeking of new knowledge resources should be investigated and the diversity of knowledge sources should be examined. Therefore, the following hypothesis can be formulated:

H2-2: With an increase of the investment for R&D, the breadth of open innovation activity would increase.

The factors related to openness of the organization culture could be found by open innovation example of P&G (Huston and Sakkab, 2006). Furthermore, openness and flexibility of the organization culture was suggested to be an important factor promoting wide open innovation activity. Therefore, the following hypotheses can be formulated:

H2-3: With an increase of the flexibility in organization culture increase, the depth of open innovation activity would increase.

H2-4: With an increase of the openness in organization culture, the breadth of open innovation activity would increase.

(3) The relation between institutional characteristic factor and open innovation activity

In the open innovation in Hyundai Motor Co in Korea, the organization to control open innovation is key in the success of innovation (Kim et al. 2008). To control open innovation activity the organization controls the management strategy for innovation, as well as planning for collaboration with external technology supplier. If a dedicated group to drive open innovation is established in a firm, this group acts as a facilitator that connects business units with potential sources of innovation (Noble et al. 2014). Thus, the establishment of a dedicated group for open innovation could be an effective way of management strategy for open innovation. Therefore, the following hypothesis can be formulated:

H3-1: If dedicated group for open innovation exists, the depth of open innovation activity increases.

Presence of technical and institutional system for information sharing is an important factor for open innovation, which can be correlated to firm's location in industry cluster, since there are large chances for information sharing and collaboration with near external technology resources in the industrial cluster. Industrial cluster is defined as a manufacturing network of

independent firms including specialized suppliers for establishing productive facilities in the same location (Roelandt and Hertog 1999). In industry cluster, the chance for collaboration might increase due to the easiness of spatial and geographic cooperation. Networks between various firms for technology innovation may be developed and, thus, it will be easier to acquire the collaboration results. For example, in Osong Bioindustry Cluster of Korea,[9] various information exchanges and research cooperation has been done among biotechnology firms.

H3-2: If firm is located in an industrial cluster, the breadth of open innovation activity increases.

Based on the above relations the model for effect of influential factors on open innovation activity is proposed as shown in Figure 3.4.

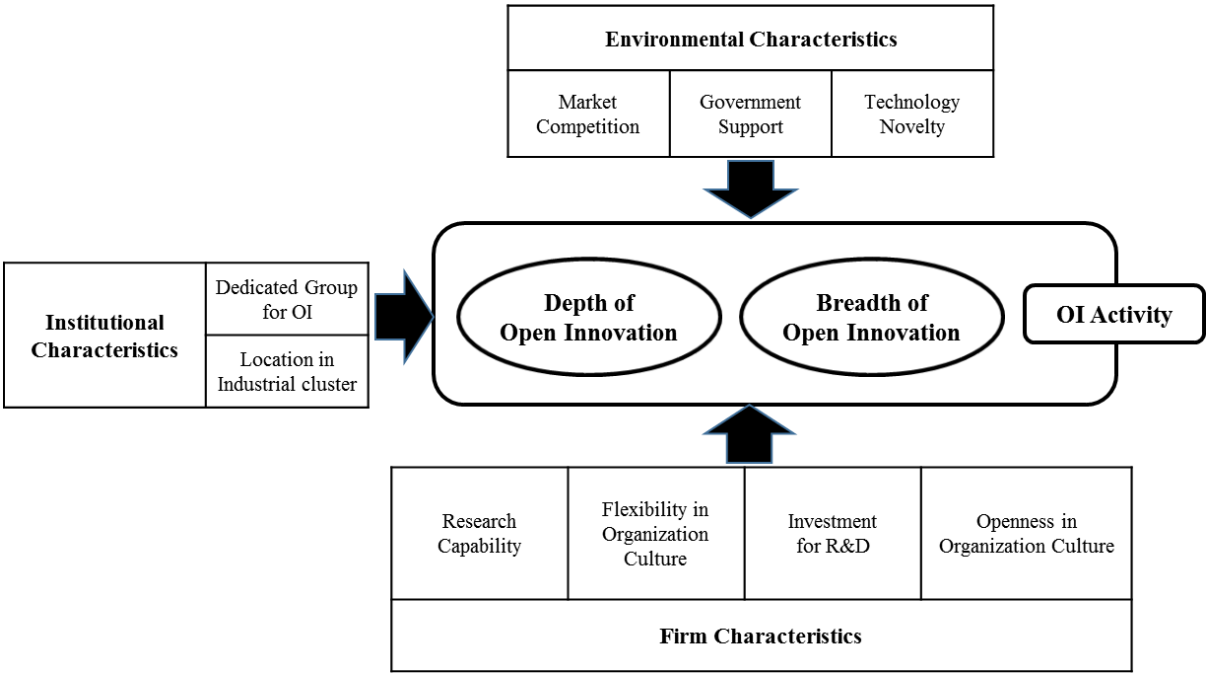

Figure 3.4. Model for effect of influential factors on open innovation activity

[9] For further detail, see http://www.osong-bio.kr/home/

3.2.3.2. Variables and measurement

The definition of variables and measurement method of the variables in the research model are shown in Table 3.12.

Table 3.12. Definition and measurement of variables

Variable / dimension			Definition	Measurement
Environmental characteristics	Technology Novelty		- The novelty degree in structure of product - The novelty degree in production process - The novelty degree in production process layout	7 point metric
	Market competition		- Market maturity degree - The degree of market competitor - Predictability degree of product demand	7 point metric
	Government support		- The degree of research project to receive from the government in the past three years	5 point metric
Firm characteristics	Research capability	R&D staff (Ph.D.)	- Number of researchers to have Ph.D.	Number metric
		Total R&D staff	- Number of researchers in R&D	Number metric
		R&D staff / overall staff	- R&D Staff / Total Staff	Ratio metric
		R&D investment (2010)	- logarithm value of R&D investment	Money amount
	Organizational culture	Openness	- Aggressiveness degree in cooperation with other departments - Information exchange degree with other departments	7 point metric

			- Personnel interaction degree with other departments	
		Flexibility	- Flexibility degree of creation or close of organization - Autonomy degree of recruitment and relocation of human resource	7 point metric
Institutional characteristics	Presence of dedicated group		- Presence of dedicated group for open innovation	Nominal metric
	Presence of institutional system		- Presence of technical and institutional system for information sharing	Nominal metric
	Location in industrial cluster		- Firm's location in industrial clusters composed university and other technological firms	Nominal metric
Open innovation activity	Depth of open innovation		- Degree of frequency to collaborate with private research institutes / universities/national institutes / industrial associations/ competitors/ non-competitors/ equipment suppliers/ demand companies	4 point metric
	Breadth of open innovation		- Degree of collaborator number such as private research institutes/ universities/ national institutes/ Industrial associations/ competitors/ non-competitors/ equipment suppliers/ demand companies	4 point metric

3.2.4. Analysis

3.2.4.1. Survey and analysis method

(1) Survey

A survey in Korean biochip firms was performed. Biochip industry, a high technology industry, derives from the fusion of various technologies, including biochip, nanotechnology,

biosensor, and bioinformatics. In general, due to secure competition for patent and intellectual property, open innovation activity has barely been accomplished in high technological industry. However, since life cycle of high technology has recently decreased, the need for open innovation activity has increased in the process of rapid development and commercialization of new products (Ahn and Lee, 2011). Based on these results, it can be predicted that open innovation has occurred in the biochip industry with a highly intensive degree of technology and, for that reason, the biochip industry in Korea is selected as the target industry in the present study.

A survey was conducted to target decision makers in 50 firms from October 24, 2011, to November 17, 2012 by e-mail and visit. At that time, the total number of firms in the Korean Association of Bio-diagnostics was 50. Through the survey, a total of 45 survey results were acquired and further analysis was performed based on these results.

(2) Method for analysis

Based on the data acquired by survey, statistical analyses were performed using SPSS 18.0 program. First of all, the analysis of descriptive statistics was accomplished and the results were investigated. To verify the reliability of the samples, items measuring each comprising concepts were investigated using Cronbach's alpha value. Also, to verify the validity of samples, factor analysis was performed. In the hypothesis testing process, multiple regression analysis was used.

3.2.4.2. Descriptive statistics quantity analysis

(1) Demographic characteristics

Demographic characteristics of the respondents are shown in Table 3.13. As to age distribution, 51.1 % of the respondents were in their forties, 28.9 % of the respondents were in their thirties, and 20.0 % of the respondents were in their fifties. As to the distribution by rank, 47.7 % of the respondents were for directors, 20.0 % of the respondents were executive officers, 8.9 % of the respondents were section chiefs, 6.7 % of the respondents were managers, 6.7 % of the respondents were assistant managers, and 4.4 % of the respondents were deputy heads. The rate of missing values was 6.7 %. Concerning the distribution by length of years in the position, 33.3 % of the respondents worked in their positions for under 5 years, 31.1 % between

6 ~ 10 years, 24.4 % between 11 ~ 15 years, 6.7 % between 16 ~ 20 years, and 4.4 % between 21 ~ 25 years.

Table 3.13. Characteristics of demography of sample

Classification		Frequency(number)	Composition ratio (%)
Age	30s	13	28.9
	40s	23	51.1
	50s	9	20.0
	Total	45	100.0
Rank	Missing value	3	6.7
	manager	3	6.7
	section chief	4	8.9
	deputy head	2	4.4
	executive officer	9	20.0
	manager	3	6.7
	director	21	46.7
	Total	45	100.0
Years of service	Under 5 years	15	33.3
	6 - 10 years	14	31.1
	11 - 15 years	11	24.4
	16 - 20 years	3	6.7
	21 - 25 years	2	4.4
	Total	45	100.0

(2) Statistical analysis of variables

The variables in this study include actual metrics and nominal metrics. Each descriptive statistic is shown in Tables 3.14 and 3.15.

Table 3.14. Descriptive statistic of actual metrics

Classification	No.	Average	Standard deviation	Etc.
Novelty of technique	45	4.67	1.19	7point metric
Degree of market competition	45	4.54	1.26	
Degree of government support	43	2.79	1.28	5point metric
R&D staff (Ph.D.)	42	5.60	15.44	Metric value
R&D staff	42	23.36	34.19	
R&D staff / overall staff	42	.53	.25	
R&D investment (2010)	38	1,176,946,549	1,753,929,021	
Openness	45	5.04	1.01	7 point metric
Flexibility	45	4.79	1.27	
Presence of organization for open innovation	45	1.20	.40	Nominal scale
Presence of institutional system	45	1.42	.50	
Presence of industrial cluster	43	2.16	.81	

Depth of open innovation	45	1.15	1.90	8 point metric
Breadth of open innovation	45	5.47	2.34	

Table 3.15. Descriptive statistic of nominal metric

Presence of dedicated organization		Without dedicated organization	With dedicated organization	Total
	Frequency	36	9	45
	%	80.0	20.0	100.0
Presence of institutional system		Without institutional system	With institutional system	Total
	Frequency	26	19	45
	%	57.8	42.2	100.0
Presence of industrial cluster		Inside industrial cluster area	Near industrial cluster	Outside industrial cluster	Total
	Frequency	11	14	18	43
	%	24.4	31.1	40.0	95.5

3.2.4.3. Reliability and validity of variables

First, exploratory factor analysis was conducted to verify the validity. Principal component analysis was used to extract all the measured variables from structured factors, and orthogonal rotation was adopted to simplify factor loading. If the coefficient of reliability (Cronbach's alpha) was 0.6 or more, the reliability analysis was considered as a reliable measurement tool. In validity analysis, if the factor loading value is 0.4 or more, it is adopted as a meaning of a significant factor. Variables in this study include the metric measurement factor, nominal scale

factor, and multiple response factor. Accordingly, metric and nominal measurement factors do not need to take reliability and validity verification, the only multiple response factor needs to take the reliability and validity verification.

The results are based on the validity and reliability verification (see Table 3.16). Total variance was found to be 72.91%. As the initial intention, four factors were extracted. The extracted factors were named novelty of technique, openness, degree of market competition, and the flexibility of the organization. Finally 11 questions were used for the analysis. However, flexibility of organization showed a rather low confidence value.

Table 3.16. Reliability and validity analysis result of impact factor in open innovation

	factor analysis				reliability
	novelty of technique	openness	degree of market competition	flexibility of the organization	Cronbach α
TN_4 TN_3 TN_2	0.931 0.915 0.777				0.856
CUL_2 CUL_3 CUL_1		0.897 0.796 0.745			0.748
MU_2 MU_5 MU_4			0.917 0.834 0.599		0.743
CUL_4 CUL_8				0.785 0.741	0.481
Eigen-value	2.392	2.050	2.034	1.545	
Variance (%)	21.743	18.632	16.494	14.046	

Factor extracting method: Principal component analysis.

Rotation method: Kaiser normalized VARIMAX.

3.2.4.4. Hypothesis Verification

For hypotheses verification, multiple regression analysis method was used regarding ‘depth of open innovation' and 'breadth of open innovation' as dependent variables. Regression analysis and hypothesis verification were performed after separating the included variables from independent variables, such as environmental characteristics, firm characteristics, and institutional characteristics.

(1) Environmental characteristic factors and open innovation activity

For the analysis of the relationship between environmental characteristic factors and open innovation activity, multiple regression analysis was performed for 'depth and breadth of open innovation activity’ related to the technology novelty due to environmental characteristics, degree of market competition, and degree of government support. The independent variable measured as a parameter was introduced to the mean of the values as valid items.

Table 3.17. Regression analysis result for environmental characteristic and depth of open innovation

model	unstandardized coefficient		standardized coefficient	t	significance probability	collinearity statistic	
	B	standard error	β			tolerance	VIF
(constant)	-3.519	1.609		-2.188	.035		
novelty of technology	.328	.234	.198	1.403	.169	.976	1.025
degree of market competition	.482	.213	.318	2.264	.029**	.989	1.011
degree of government support	.475	.211	.317	2.254	.030**	.986	1.014
R^2=0.239, Adjusted R^2=0.198, F=4.084**, p=0.013							

**p<0.05

First, the results of a regression analysis on the depth of open innovation and environmental characteristic variables, the statistical significance was confirmed (R^2 = 0.239, F = 4.084 **, p <0.05; see Table 3.17). In multicollinearity diagnostics, values of the tolerance limit are higher than 0.1 and, thus, there was no problem in our results. In the relationship between environmental characteristic variable and depth of open innovation, the degree of market competition and degree of government support showed a positive (+) significant relationship with a significance level of 0.05. The degree of effect of market competition was nearly the same as that of government support, since β value of market competition (0.318) and government support (0.317) are nearly identical.

Table 3.18. Regression analysis result for environmental characteristic and breadth of open innovation

model	unstandardized coefficient		standardized coefficient	T	significance probability	collinearity statistic	
	B	standard error	B			tolerance	VIF
(constant)	3.386	2.017		1.679	.101		
novelty of technology	-.195	.293	-.101	-.665	.510	.976	1.025
degree of market competition	.466	.267	.264	1.746	.089	.989	1.011
degree of government support	.354	.264	.203	1.343	.187	.986	1.014
R^2=0.120, Adjusted R^2=0.052, F=1.768, p=0.169							

Second, in the regression analysis on the breadth of open innovation and environmental characteristic variables, the statistical significance was not confirmed (R^2 = 0.120, F = 1.768, p =0.169 (p >0.05); see Table 3.18). According to the above regression analysis results, the verification of hypothesis is evaluated for the relation of three influencing factors of environmental characteristic to the depth and breadth of open innovation activity. The degree of market competition and the degree of government support have a positive (+) significant

relationship with the depth of open innovation activity. Therefore, both hypotheses H1-1 and H1-2are confirmed are supported by our data analysis.

On the other hand, the novelty of technology has shown that there is no statistical significance in relation to the breadth of open innovation. Therefore, hypothesis H1-3has to be rejected. This result indicates that the breadth of open innovation activity is not directly related to the introduction of new technologies in the Korean biochip industry.

(2) Firm characteristic factors and open innovation activity

To analyze the relationship between firm characteristic factor and open innovation activity, the multiple regression analysis was run separately for the organizational culture factor and the research capability factor. In the case of R&D investment, the analysis was done by taking the logarithm on R&D investment in 2010, because the collinearity statistics has the problem due to the big deviation and then the multiple regression analysis could not be done if the measured value is inserted without computation. For number of Ph.D. staff in R&D and the total number of R&D staff, the measured values without computation were used; however, for the ratio of number of R&D staff to the total number of staff in firm, measured values with computation were used.

Table 3.19. Regression analysis result for research capacity and depth of open innovation

model	unstandardized coefficient		standardized coefficient	t	significance probability	collinearity statistic	
	B	standard error	β			tolerance	VIF
(constant)	-6.731	5.365		-1.255	.219		
logarithm on R&D investment	.896	.627	.290	1.428	.163	.489	2.044
R&D staff (Ph.D.)	.214	.082	.531	2.614	.014**	.488	2.047
total R&D staff	-.011	.013	-.197	-.833	.411	.360	2.775
total R&D staff / total staff in firm	-.412	.953	-.062	-.433	.668	.988	1.013
R^2=0.354, Adjusted R^2=0.273, F=4.383*** p=0.006							

First, in the regression analysis of research capabilities and the depth of open innovation, the statistical significance was confirmed (R^2= 0.354, F= 4.383 ***, p<0.01; see Table 3.19). In multicollinearity diagnostic, values of the tolerance limit are higher than 0.1, and thus there is no problem. In the relationship between 'research capabilities' and ‘depth of open innovation', the number of Ph.D. staff in R&D affects positive (+) at the significance level of 0.05. Degree of affecting is appeared as β = 0.531. Thus hypothesis H2-1, ‘As the research capability based on the number of Ph.D. staff in R&D increases, depth of open innovation activity increases', is confirmed.

Second, in regression analysis on the breadth of open innovation and research capacity, the statistical significant was confirmed (R^2= 0.282, F= 3.135 **, p<.05; see in Table 3.20). At multicollinearity diagnosis, the values of tolerance are larger than 0.1 and thus there is no problem. In the relationship between research capacity and the breadth of open innovation, the number of Ph.D. staff in R&D shows a significantly positive(+) effect and total number of R&D staff a shows negative(-) effect (p=0.05). In addition, it is confirmed that the logarithm value of R&D investment shows a significant positive (+) effect with the significance level of 0.1. Thus, Hypothesis H2-2 is confirmed. The level of degree to affect the breadth of open innovation is the number of Ph.D. staff in R&D (β = .552), investment in R&D (β = .432), and the total number of R&D staff (β = -. 731).

Table 3.20. Regression analysis result for research capacity and breadth of open innovation

Model	unstandardized coefficient		standardized coefficient	t	significance probability	collinearity statistic	
	B	standard error	β			tolerance	VIF
(constant)	-9.875	7.671		-1.287	.207		
logarithm on R&D investment (2010)	1.809	.897	.432	2.017	.052*	.489	2.044
R&D staff (Ph.D.)	.302	.117	.552	2.577	.015**	.488	2.047
total R&D staff	-.053	.018	-.731	-2.928	.006**	.360	2.775

total R&D staff / total staff in firm	-.725	1.362	-.080	-.532	.598	.988	1.013
R^2=0.282, Adjusted R^2=0.192, F=3.135**, p=0.028							

Third, in a regression analysis on the depth of organizational culture and open innovation, the statistical significance was confirmed (R^2= 0.166, F= 4.177 **, p <0.05; see Table 3.21). In multicollinearity diagnostic, the values of tolerance are larger than 0.1, and then there is no problem. Therefore, Hypothesis H2-3 is confirmed. Flexibility in organization culture affects the depth of open innovation activity with β = 0.364 at p<0.05.

Table 3.21. Regression analysis result in organizational culture and depth of open innovation

model	unstandardized coefficient		standardized coefficient	t	significance probability	collinearity statistic	
	B	standard error	β			tolerance	VIF
(constant)	-2.257	1.555		-1.452	.154		
openness	.229	.272	.122	.843	.404	.954	1.048
flexibility	.546	.216	.364	2.521	.016**	.954	1.048
R^2=0.166, Adjusted R^2=0.126, F=4.177** p=0.022							

Fourth, in regression analysis on the depth of organizational culture and open innovation, the statistical significance was confirmed (R^2= 0.149, F= 3.672 **, p<0.05, see Table 3.22). In multicollinearity diagnostic, the values of tolerance are larger than 0.1 and, thus, there is no problem. The openness affects the breadth of open innovation activity with β = 0.299 at p <0.05. Thus, Hypothesis H2-4 is confirmed.

Table 3.22. Regression analysis result in organizational culture and breadth of open innovation

model	unstandardized coefficient		standardized coefficient	t	significance probability	collinearity statistic	
	B	standard error	β			tolerance	VIF
(constant)	.305	1.933		.158	.875		
openness	.694	.338	.299	2.051	.047**	.954	1.048
flexibility	.348	.269	.188	1.292	.204	.954	1.048
R^2=0.149, Adjusted R^2=0.108, F=3.672**, p=0.034							

(3) Institutional characteristic factors and open innovation activity

In order to investigate the relationship between institutional characteristics and open innovation activity, multiple regression analysis was performed with relation to institutional characteristics factors, such as the existence of organization for open innovation, the presence of institutional system for open innovation, firm's location in industrial cluster to depth and breadth of open innovation activity. Regression analysis was run for the three influential characteristics factors.

First, in regression analysis of institutional characteristic factors and depth of open innovation activity, the statistical significant was confirmed (R^2= 0.286, F= 5.216, p <0.01; see Table 3.23). In multicollinearity diagnostic, all VIF values are below 2.0 and thus it was confirmed that there is no problem. In the relationship between institutional characteristic factors and depth of open innovation activity, we found that the existence of a dedicated group to drive open innovation shows a significant positive (+) effect (p <.001).. However, the effects of the presence of an institutional system and firm's location in industrial cluster were not significant. The existence of a dedicated group for open innovation affects the depth of open innovation activity with β= .471. Therefore, Hypothesis H3-1, 'is confirmed.

Table 3.23. Regression analysis result in institutional characteristics and depth of open innovation

model	unstandardized coefficient		standardized coefficient	t	significance probability	collinearity statistic	
	B	standard error	β			tolerance	VIF
(constant)	-1.965	1.296		-1.517	.137		
existence of dedicated group	2.310	.744	.471	3.104	.004***	.795	1.258
presence of institutional system	.482	.587	.124	.820	.417	.795	1.258
firm location in industrial cluster	.035	.328	.015	.108	.914	.959	1.042
R^2=0.149, Adjusted R^2=0.108, F=3.672**, p=0.034							

Second, in regression analysis of institutional characteristic and breadth of open innovation activities, with the coefficient of determination $R^2 = 0.066$, F = 0.921, the statistical significance was not confirmed ($R^2 = 0.066$, F = 0.921, p = 0.44 (p>0.05; see Table 3.24). Thus, Hypothesis H3-2 has to be rejected. This result might be due to the fact that there are very few biochip firms in an industrial cluster, like Osong Bioindustry cluster in Korea and, thus, the chances to do information sharing and collaboration might not dramatically increase, though the firm is in industrial cluster.

Table 3.24. Regression analysis result in institutional characteristics and breadth of open innovation

model	unstandardized coefficient		standardized coefficient	t	significance probability	collinearity statistic	
	B	standard error	β			tolerance	VIF
(constant)	2.927	1.690		1.732	.091		

existence of dedicated group	.917	.971	.164	.945	.351	.795	1.258
presence of institutional system	.496	.766	.112	.648	.521	.795	1.258
presence of industrial cluster	.431	.427	.159	1.009	.319	.959	1.042
R^2=0.066, Adjusted R^2=-0.006, F=0.921, p=0.440							

3.2.5. Conclusions and Discussion

The summary of the research results is shown in Table 3.25 and Figure 3.5.

Table 3.25. Relation with influential factors and open innovation activity

Variable scope		Contents of hypothesis	Confirmed or Rejected
Environmental characteristic		H1-1: As the intensity of market competition increases, the depth of open innovation activity increases.	Confirmed
		H1-2: As the degree of government support increases, the depth of open innovation activity increases.	Confirmed
		H1-3: As the novelty of technology increases, the breadth of open innovation activity increases.	Rejected
Company characteristic	Research capability	H2-1: As the research capability based on the number of Ph.D. staff in R&D increases, depth of open innovation activity increases.	Confirmed
		H2-2: As the investment for R&D increases, breadth of open innovation	Confirmed

		activity increases.	
	Organizational culture	H2-3: As the flexibility in organization culture increases, depth of open innovation activity increases.	Confirmed
		H2-4: As the openness in organization culture increases, breadth of open innovation activity increases.	Confirmed
Institutional characteristic		H3-1: If dedicated group for open innovation exists, depth of open innovation activity increases.	Confirmed
		H3-2: If firm is located in industrial cluster, breadth of open innovation activity increases', is not adopted.	Rejected

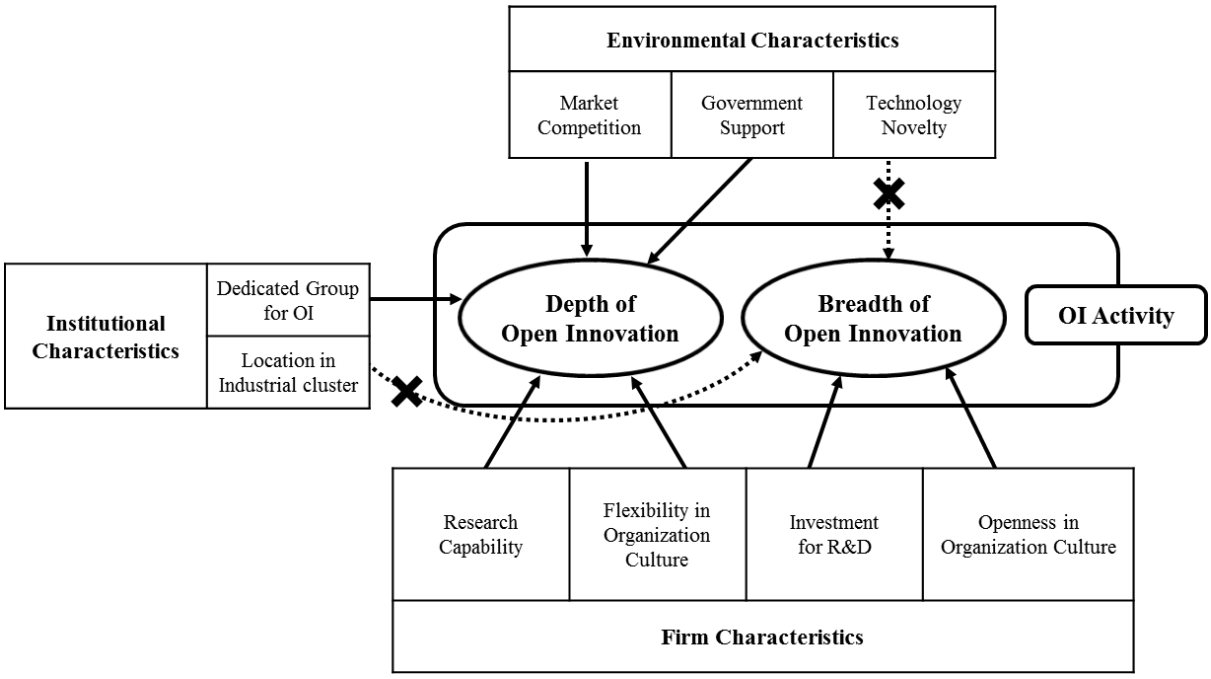

Figure 3.5. Results of model for effect of influential factors on open innovation activity

In this chapter, the factors affecting open innovation activity in the Korean biochip companies are investigated. The results of our analyses are as follows. First, the market

competition and governmental support show a statistically significant positive relationship with the depth of open innovation activity. This result suggests that the firm enhances the collaboration with external partner due to the reinforcement of competition, in the case of the necessity of strengthening competency. Therefore, a firm in high intensity of market competition should focus on the collaboration with the current external partner firm when the firm takes the open innovation. In addition, the firm focuses on collaboration with current collaborators if governmental support the firm is stronger, which leads the firm to enhance open innovation.

Second, the higher number of doctoral researchers in R&D staff in firm, the higher depth of open innovation is achieved. This result is consistent with the results previously reported by Link and Bauer (1987) who suggested that the growth of the capacity of internal research promotes the cooperation while maintaining core technologies. Therefore, it is necessary to increase the number of doctoral researchers in order to enhance the depth of open innovation activity while pursuing core competencies. In this respect, the quality of the researchers is more important than their number. In addition, there is a statistically significant (+) positive relationship between the amount of R&D investment and the breadth of open innovation. Based on the cash flow in firm, our results show that more investment partners are sought as the research and development expenses are invested. In the biochip industry where human resources in R&D are essential, it is necessary to continuously invest and expand human resources to increase the breadth of open innovation activity. Of note, in the case of government investment as one of environmental characteristic variables, it increases the depth of open innovation, while the R&D investment is more related to the breadth of open innovation.

Third, the flexibility of organizational culture is positively related to the depth of open innovation activity, and the openness of organizational culture is positively related to the breadth of open innovation. Therefore, it is needed that the firm tries to make the flexible organizational culture, and how to act to other external collaborators should be considered based on organizational culture flexibility. In addition, open organizational culture makes the firm more open in open innovation activity. Therefore, in order to make a relationship with various external entities, at first, it will be necessary to make efforts to have openness in the organizational culture.

Fourth, our results confirm that the presence of the dedicated group for open innovation has a statistically significant (+) relation with the depth of open innovation activity. In order to

achieve open innovation, the presence of a dedicated group in firm is an important factor. If the research capacity of firm is higher than a level at which the firm can make commercial product by itself, it is strongly recommended to establish a dedicated group for open innovation to enhance open innovation activity.

The significance of our results and the insights they provide for further research are as follows. First, in this chapter, a survey for open innovation is conducted for a single industry group, the biochip industry. Only few previous studies on open innovation have been conducted within a single industry group. Therefore, we assume that more detailed and accurate analyses have been done through the research on open innovation activity in just one (relatively small but innovation-intensive) industry. In particular, the analysis from the research plan to the research target to focus consistently on open innovation is very meaningful for practical application of open innovation. From the academic point of view, our results are meaningful in that the influential factors are depicted and the investigation for breadth and depth for open innovation activity related to these factors is undertaken.

Second, our results provide implications for the strategies that should be adopted to promote open innovation activity based on the analysis of the influential factors. From a practical point of view, where and how to get external knowledge from a new external collaborator through open innovation activity in real industrial field are shown to be strategically important questions that can be addressed by using the model proposed here. Our results are also meaningful for practitioners in firm, as this study suggests the strategic choice for open innovation through the analysis of the effects of the influential factors on the breadth and depth of open innovation activity.

Chapter 4. Management Strategy for Transition Phase of Open Innovation in New Product Development of Biochip

Since open innovation is considered to be an effective innovation method for new product development (NPD) of biochip, it has been discussed in Chapter 2. At the final stage of new product development, the application of open innovation raises a number of questions, namely: (1) Do we still need open innovation, now that we have sufficient knowledge for new product development? (2) How can we decide if and when the transition to close innovation should be done? (3) If the transition to close innovation happens, which level of closeness is needed for the final stage of new product development? To answer the above questions, this chapter investigates the following aspects based on the technology point of view.

At first, the firm should decide whether open innovation is still needed at the final stage of product development. Although the firm understands the advantages of close innovation, closeness and relations to enhance firm performance are not clearly understood, making it difficult to make the decision regarding the degree of closeness. Thus, in this chapter, the factors affecting the transition toward close innovation are investigated based on, first, the technology point of view, such as knowledge related to the product development stage and the product innovation stage, and second, to the non-technology point of view, such as the government approval stage. Furthermore, we investigate whether the transition to close innovation in the final stage of NPD causes an advantage, such as a decrease of cost for management process and prevention of leakage of technology to the outside. Structured interviews with three large firms and three small firms in the Korean biochip industry were conducted in order to analyze the factors related to the transition from open to close innovation. A model based on interview results is proposed.

As a next step, the application of the proposed model is extended to the Korean bio-pharmaceutical industry. The model is evaluated with the data from Korean bio-pharmaceutical firms and a strategy concerning the decision about close innovation transition with the aim of enhancing firm performance is investigated from the technology point of view. While the firm should decide about the time to start close innovation and the degree of close innovation activity, there is no guide for transition to close innovation. If a firm wants to implement a close innovation strategy, relations to enhance the close innovation activity should he understood, and then the decision to start close innovation can be made. Thus, in this study, factors affecting

the open-close innovation transition (based on the factors by technological point of view, such as the knowledge related to the product development and product innovation stages) are investigated. Hypotheses regarding factors affecting the open-close innovation transition are formulated and, based on the results of hypotheses evaluation with the data from bio-pharmaceutical firms, a strategy concerning the decision about open-close innovation transition is proposed from the technology point of view.

This study is the first to evaluate the effect of factors such as knowledge, product development stage, product innovation stage, and government approval stage on the open-close innovation transition. A model of the relationship between the open-close transition and perception of advantage of close innovation is proposed and then evaluated based on the survey results.

4.1. Introduction

Open innovation has been applied to the biochip industry due to the need for external knowledge for radical new product development. This is because of the characteristics, such as the need to combine various techniques and the limitation of existing resources in mastering the required techniques necessary for new product development (Fuji-Keizai 2008; Kim 2008; Impact Co 2013; Kim 2013; Hyun 2013; Kwon 2015). Since the biochip field results from a fusion of technologies developed in biotechnology, nanotechnology, and information technology, knowledge distribution should be recognized and the importance of knowledge integration should be considered, probably more than in any other areas in biotechnology.

To achieve open innovation for products in the bio-pharmaceutical industry, it is necessary to develop a management strategy that takes into account their novel and complex technological characteristics (Fetterhoff and Voelkel 2006; Igartua et al. 2010; Pisano 2015; Slowinski and Sagal, 2010; Tidd and Bessant 2015; Vanhaverbeke et al. 2008). Since bio-pharmaceutical industry includes the pharmaceutical industry and the biotechnology industry (with the latter including the biochip industry based on the industry sector classification), the management strategy for open innovation in the biochip industry can relate to that of the bio-pharmaceutical industry.

Fetterhoff and Voelkel (2006) suggest five key stage for open innovation: 1) seeking opportunities; 2) evaluating the market potential and inventiveness of a given opportunity; 3)

recruitment potential partners by building a convicting argument; 4) capturing value through commercialization; and finally 5) extending the innovation offering. Furthermore, Slowinski and Sagal (2010) suggest the following four stage stages in open innovation: (1) want phase; (2) find phase; (3) get phase; and (4) manage phase to success. In the present study, we propose the transition of innovation type in final stage of NPD as a part of the manage phase. Until now, an analysis of open innovation for the final stage of NPD has not been done and management strategy at that stage has not been suggested. In this study, the model for transition of innovation type in the final stage of NPD is proposed and then evaluated for validation.

The transition stage is the stage when a firm may want to change from open innovation to close innovation. The transition stage occurs towards the new product development. Since the firm has acquired sufficient technology for commercial product at the final stage of new product development, the firm may want to reduce the inflow of technology from external partner by reducing the degree of open innovation. Thus, from the technology point of view, the change from open innovation to close innovation is motivated. However, collaboration with external partners for marketing and government approval process is still needed, although the reasons are non-technological. Thus, in the transition stage, a close innovation approach is implemented with regard to technology inflow, whereas open innovation is done in marketing and other legal aspects, which means that partial (mix of open and close) innovation is done overall.

In view if the above, in order to develop a management strategy for the final stage of new product development, it is necessary as a first step to decide whether to close open innovation so that to control the technology inflow for value capture and success. In this study, the relation with knowledge, product development stage, product innovation stage technology characteristics, and government approval stage with the transition tendency to close innovation is investigated to provide the evidence for the decision to close. The transition tendency is the degree of move to close innovation by firm. The transition tendency relates to the perception of advantage of close innovation, including an increase of firm performance, which is investigated to see how close innovation affects firm performance. Structured interviews with experts in the Korean biochip firms are performed and a management strategy is suggested. Based on the interview results, a model for relations affecting transition tendency is proposed for the Korean biochip industry. As a second step, the proposed model is applied to the bio-pharmaceutical industry. Hypotheses concerning the factors that relate to the open-close

transition are proposed and a survey is done in the Korean bio-pharmaceutical firms to evaluate the model. Finally, a strategy concerning the decision to close innovation in the transition stage is suggested with the aim of increasing firm performance based on the results of model evaluation.

4. 2. Theoretical Considerations

4.2.1. Open innovation in nanobiotechnology

Biochip is an intrinsically an interdisciplinary technology that integrates various technologies such as electronics, material engineering, biotechnology, and nanotechnology. One of the key technologies for biochip is nanobiotechnology, which is an integration of nanotechnology and biotechnology (Thaxton and Mirkin 2004; Vega et al. 2007). Also, products in bio-pharmaceutical industry can be made by the integration of various technologies, such as chemistry, biology, biotechnology, and nanotechnology. Specifically, nanobiopharmaceutical technology has emerged for applications of biotechnology, while nanotechnology has emerged for drug discovery (Thaxton and Mirkin 2004; Vega et al. 2007). To evaluate the innovation process for biochip and biopharmaceutical products, the innovation in the nanobiotechnology and bio-pharmaceutical industries should be considered. This sections focuses on open innovation in nanobiotechnology (see Section 3.1.3 for a count of open innovation in the biotechnology industry).

At first, based on previous reports, the relation between open innovation and product development in nanotechnology area is reviewed to understand the managing methods in the nanotechnology industry. Social networks are pivot to understand the explosion of nanoscience knowledge and, therefore, management is needed to control the information flow among social networks (Aiman-Smith et al. 2006). Aiman-Smith et al. (2006) suggest that open innovation based on networks efficiently facilitates the emergence of fundamental nanotechnology to manufacture commercializable products. Also, open innovation is necessary to improve communication strategies, increase the impact of new knowledge, and accelerate innovation. In his study on open innovation applied to develop new products based on nanotechnology in Buckman, Anstey (2005) notes that partnerships help to turn the science of nanotechnology into a practicable technology and that management of open innovation in nanotechnology can

help nanotechnology to become a viable technology in order to make commercial product.

Furthermore, in their investigation of the diversity of collaborative network in nanotechnology system, Pandza et al. (2011) report that the participating members need to manage research within diverse networks. Likewise, Miyazaki and Islam (2010) analyze the nanotechnology system in different countries based on industry and academic research activities and their findings are useful to inform the strategies for nanotechnology. Islam and Miyazaki (2010) also note regional strengths and weaknesses in nanotechnology domains for various countries. For example, the U.S. has notable strengths in the nanobiotechnology area, whereas other regions are stronger in nanomaterials. Thus, collaboration contributes to nanotechnology management across different regions. Furthermore, Rampersad et al. (2010) underscore the importance of managing innovation networks and the need of strategies for managing inter-organizational innovation incentives. Next, Shea (2005) reports the future management research directions in nanotechnology based on a case study approach (Shea 2005). Taken together, these research results suggest that management strategy in nanotechnology is crucial for managing innovation networks related to open innovation activity.

As a second step, the innovation management in the nanobiotechnology industry is investigated to understand the management strategies based on previous reports. In an analysis of two nanobiotechnology drugs, Maine et al. (2014) propose three kinds of innovation management strategies: importing ideas, creating environment, and technology-marketing match. Furthermore, in a study of how the university-industry collaboration network affects innovation in the nanobiopharmaceutical field based on the weighted patent-value as an index of innovation performance, Guan and Zhao (2013) find that the formation of stable platforms for collaboration and effective institutional arrangements should be done as a strategy for university-industry collaboration network. These research results suggest that management strategy in nanobiotechnology is related to managing importing ideas, creating environment, technology-marketing, and collaboration networks.

Evolutionary path of technology fusion is investigated for nanobiotechnology case and the development trajectories of technology fusion is analyzed (No and Park 2010). By observing changes in the trajectory patterns of fusion through time, fusion pattern is evolved based on the following rules: (1) Technology development focuses more on niche technologies in fusion and (2) the technologies that do not join in fusion are eliminated during development process. Furthermore, in the analysis of the innovation trajectories of technology based on analysis for

patents and publications in nanobiopharmaceutical technology such as nano-enabled drug discovery, Kwon et al. (2016) report that analyzing research publications and patents simultaneously constitutes a good approach to understand the innovation trajectories. This contributes to the development of a strategy for innovation management. These research results suggest that management strategy in nanotechnology is related to technology characteristics such as evolution trajectories and innovation trajectories.

Taken together, the results by previous studies overviewed above show that a management strategy for nanobiotechnology industry is needed to make nanobiotechnology more viable to manufacture commercial products. Such strategy should be based on the need to manage collaboration networks and technology characteristics, such as evolution trajectories and innovation trajectories. In this study, the management strategy for the biochip industry related to nanobiotechnology is investigated by considering the above suggestions.

4.2.2. Open innovation and product development stage

Since biochip products are usually made by combining technologies from different fields, in each step of product development, the kind and amount of knowledge vary for different product development stages. Thus, during new product development in biochip, the integration of various technologies is needed from the start to the end of the production process. In this section, by reviewing previous reports, the relation between open innovation to inflow of external technology and the product development stage are examined.

First, Gronlund and et al. (2010) propose a new and revised model for new product development to help the application of open innovation to the stage-gate process and then related to the product development stage. The proposed model gives the strategy in transformation process towards a more open and systematic approach in new product development. Furthermore, Cooper (2016) suggests how a firm can do open innovation within the stage-gate model and shows the customized stage-gate to incorporated open innovation. In Cooper's (2016) research, the process for stage-gate is divided into the ideation or discovery stage, building the business case, development stage, and launch or commercialization stage. The open innovation helps firms to redesign the idea-to-launch process and new product development process becomes more agile. In addition, Stosic and Milutinovic (2014) propose the 'open stage-gate model' by connection of basic elements of open innovation and stage-gate

model. The capability for applying open innovation to stage-gate model is investigated to make more flexible phase and gates in the new product development stage. These results suggest that the strategy of open innovation varies depending on the stage of new product development, which will be applied to construct a model for innovation in the present study.

In a similar fashion, Caetento et al. (2011) investigate the relation of open innovation and the technology development process based on partnership establishment and note that a firm changes the technology development process based on the firm's level of adequacy to open innovation. Dassault Systemes India (2016) shows that an open innovation strategy can be effectively used to accelerate product development and to make it smarter. In this research, the adoption of open innovation, together with product life cycle management, are reported to enable a higher profitability and a faster product delivery. These results suggest that the integration of open innovation with product management strategy for the technology development process and product life cycle makes the product production faster and more profitable.

In addition, in their investigation of the application of open innovation to biopharmaceutical companies, Marcello et al. (2015) open innovation is shown to have high success in later-phase clinical trials, which is the last stage of the product development process. Likewise, with the focus on the action of open innovation practice according to the stage of new product development, Rubera et al. (2016) propose that open innovation activity can be classified into two types related to the product development stage (development-centric open innovation for development stage, and commercialization-centric open innovation for commercialization stage). Taken together, these results suggest that the open innovation is related to the stage of new product development and a different open innovation strategy is needed for each stage of new product development, which will be applied to construct a model for innovation in the present study.

4.2.3. Open versus close innovation

As discussed in the previous section, open innovation strategy should be different for each stage of new product development. Change between open and close innovation occurs based on the stage of new product development. In this section, we overview previous research on the advantages of open and close innovation so that to facilitate decision on the innovation type

needed for each stage of new product development.

In this respect, in a study on the advantages afforded by open innovation as compared to close innovation, Almirall and Rammon (2010) demonstrate that open innovation is helpful for discovery in product development; however, if an external partner has divergent goals, open innovation makes it difficult for the focal firm to establish an effective technological trajectory for new product development. Since open innovation may cause problems in new product development, the focal firm should consider the advantages and disadvantages of open innovation when deciding on the innovation type. Cassiman and Valentini (2015) report that the inflow and outflow of knowledge in open innovation should be counted to understand the drivers of actual cost of open innovation. Furthermore, Lowman and et al. (2012) suggest that open innovation faces risks in pharmaceutical new product development due to the emergence and rapid growth of Clinical Research Organization (CRO). With an increase of the role of CRO in clinical trials and clinical development process, firms increasingly depend on CRO in the drug development process. Thus, as the firm loses knowledge and a lack of ability occurs in drug development, the firm faces the risk of innovation management for integration of the new product development activity and basic technologies for future research. These results suggest that there are disadvantages of open innovation in new product development in the bio-pharmaceutical industry.

Other studies suggest that the choice of open or close innovation depends on culture of units and governance forms. For instance, in their study of the differences between open innovation and close innovation based on the specificity of the problem to solve and governance forms, which are characterized by different benefits and costs, Felin and Zenger (2014) suggest four governance forms for open innovation (markets, partnerships, contests, and user or community) and two governance forms for close innovation (authority and hierarchy), providing thus the comparative framework for managing innovation. Herzog and Leker (2010) suggest that open and close innovation have different cultures for different strategies. In this research, the culture difference that exists between open and close innovation units and thus the management strategy and choice of innovation type are considered and linked to the culture of business units.

Another group of previous studies shows that the choice of innovation type depends on science and non-technological factors, such as marketing and organization. For instance, in their investigation of the relation between open innovation and organizational boundaries based on task decomposition and knowledge distribution, Lakhani et al. (2012) find that task

decomposition and problem-solving knowledge distribution constitute strategic choice that influences the choice of innovation type, open or close. If modularity increases and communication cost decreases, open innovation is preferred; however, if modularity decreases and communication cost increases, close innovation becomes the preferred innovation choice. Likewise, Caraca et al. (2009) suggest that role of science has changed in the innovation process from a linear to a chain-linked model. In their research, though the key element to make high value product is scientific knowledge, the science is just one type of knowledge to create high value product. Understanding market and organization are also important factors to increase value of products; therefore, science and other factors are intrinsically related.

When a new product is produced and comes to the commercial stage with open innovation activity in a biochip firm, the firm should decide on a continuation of current innovation type (open innovation) or a change of innovation type to close innovation. Since the choice about the innovation type depends on science and non-technological factors (Caraca et al. 2009), there are many factors affecting the decision at this stage. To clarify these factors, the opinions of experts, such as directors of research teams, CTOs and CEOs in biochip firms, are needed. In the present study, to obtain the opinions of experts in biochip firms, the structured interview is conducted. Furthermore, since the opinion of big and small firm like start-up companies may vary, we select as the interviewees the three largest firms in Korea (Samsung Electronics, LG Biotechnology, and SK Telecom) and three representative small firms in Korea (two start-up companies, BioDiatech and NSB Postech, and one mid-size company, NanoEnTeck).

4.3. Research Method

4.3.1. Structured interviews

The structured interviews were conducted with the experts in the biochip industry from May 6tto July 20, of 2013. The experts in three big firms including Samsung Electronics, LG Biotechnology, and SK Telecom and three small firms including BioDiatech, NSB Postech and NanoEnTeck were interviewed. Interview time was generally three hours for each firm.

The interview questions were designed as follows. The discussion to construct interview questions were held with I (biochip major), a professor in Business School at Sogang University,

Korea (technology management major), and a former head of Bioanalysis Division in Samsung Advanced Institute of Technology (bioanalytical chemistry major). The discussion results for innovation type change in final stage of new product development in biochip were then analyzed and the main factors were classified as nine factors (see Table 4.1).

Table 4.1. Interview questions for transition of innovation in biochip industry.

(1) Does intellectual property (IP) for new product development (NPD) affect innovation type change? 1.1. Does the firm have many patents needed for NPD? 1.2. Does the firm have qualified patents needed for NPD? 1.3. Does the firm have enough patents needed for NPD?
(2) Does knowledge in firm for NPD affect innovation type change? 2.1. Does the firm have enough research ability (mastering the technology) needed for NPD? 2.2. Does the firm have the accumulated relevant technology needed for NPD? 2.3. Does the firm have research competency needed for NPD?
(3) Does product development stage affect innovation type change? 3.1. Is New Product (NP) in commercial stage? 3.2. Is NP in suboptimal stage? 3.3. Is NP made for improvement after commercial stage? 3.4. Is NP made for little modification for application after commercial stage?
(4) Does government approval stage affect innovation type change? 4.1. Is NP in clinical trial stage? 4.2. Is NP in stage of approval process management? 4.3. Is NP in post approval stage?
(5) Does product innovation stage affect innovation type change? 5.1. Is NPD done for emergence of total new product application? 5.2. Is NPD done for expansion of current application? 5.3. Is NPD done for new successive product?
(6) How to measure transition tendency to close innovation? 6.1. Does cost happen to change from open innovation to close innovation? 6.2. Is it easy to change from open innovation to close innovation? 6.3. Is system change needed to change from open innovation to close innovation?

(7) What is the process to quit collaboration? 7.1. Is cost to quit collaboration high after producing NP? 7.2. Is it easy to quit collaboration after producing NP? 7.3. Is system change needed to quit collaboration after producing NP?
(8) How to act for close innovation? 8.1. Does technical knowhow of NP to outside close? 8.2. Does information for marketing of NP to outside close? 8.3. Does willingness to close increase?
(9) What is the advantage of close innovation? 9.1. Is technology leakage decreased due to close? 9.2. Is cost for NP decreased due to close? 9.3. Is management process decreased due to close?

The main interview questions concerned the transition point between open and close innovation in new product development of biochip. The questions addressed the following four aspects: (1) Does innovation type change as product development stage changes? (2) Does a transition point exist between open and close innovation in new product development? (3) Is there a difference between big and small firm in the change of innovation type? (4) Does the repetition of innovation type change depending on the emergence of new innovative product based on the extension of previous technology? For example, the emergence of protein chip, a new innovative product based on the extension of previous DNA chip technology, causes open innovation and then closes innovation, as done in the DNA chip case. The answers and other opinions obtained in the interviews are described in Section 4.3.2.

The interview questions were coded (see Table 4.2) as suggested elsewhere (Saunders et al. 2003; Plowman et al. 2007). The coding scheme based on major factors was devised and then the interviews were conducted. Codes were allocated to subsequent factors to group them as nine major factors. The notification codes of each factor to be mentioned by each interviewee were listed for each interviewed firm. Based on the listed codes for the interviewee's answers, the findings for innovation type change in final stage of new product development in biochip were extracted.

Table. 4.2. Coding scheme to classify interview questions

Code	Subsequent factors	Grouping of factors
1.	Firm size	General information
2.	New product development	
3.	Open innovation	
4.	Total patent number	Patent for new product
5.	Qualified patent number	
6.	Required number of patent	
7.	Research ability	Knowledge for new product
8.	Accumulated relevant technology	
9.	Research competency	
10.	Commercial stage	Stage of new product
11.	Suboptimal stage	
12.	Improvement after commercial stage	
13.	Modification for application	
14.	Clinical trial stage	Government approval
15.	Approval process management	
16.	Post approval stage	
17.	Emergence of new application	Product innovation stage
18.	Expansion of current application	
19.	New successive product	
20.	Start of close innovation	Transition tendency to close
21.	Easy to change to close innovation	
22.	System change for close innovation	
23.	Cost to quit collaboration	Process to quit collaboration
24.	Easiness to quit collaboration	
25.	System change needed	
26.	Close of technical knowhow	Way of close innovation
27.	Close of marketing information	
28.	Willingness to close	
29.	Decrease of technology leakage	Advantage of close innovation

30.	Decrease of cost	
31.	Decrease of management process	

To check the accuracy of the findings, the codes and findings were discussed with the experts involved in the construction of interview questions (a professor in Business School at Sogang University, Korea, and a former head of Bioanalysis Division in Samsung Advanced Institute of Technology). This led to a reinterpretation of answers and some corrections as to how the firms decide on the transition of innovation type.

4.3.2. Interview results

(1) Samsung Electronics

The interview was conducted with a former team leader of biochip research lab in Samsung Advanced Institute of Technology supported by Samsung Electronics. The total number of codes was 27, including 3 codes for general information and 24 codes for 9 groups. Based on code classification, the interview results were analyzed. The interviewee suggested that there is change of degree of open innovation from the start to end of new product development. Therefore, big firm like Samsung Electronics start open innovation, since they control few of the needed technologies and, consequently, firms need to acquire technologies for new products. Thus, big farm start to work with external partner, like universities and small venture firms by investing in research and providing funds to them. Based on the intellectual property (IP) such as patent and know-how, the innovation change occurs. The innovation step can be divided in four stages similar to the four modules based on the IP (see Figure 4.1). Based on the initial IP that firm has, each module needs a different IP. To get IP, collaboration is done for IP licensing, cross IP licensing, IP acquisition, and right for IP execution. To get different types and amounts of IP, a different degree of openness is required in each step. In the second stage, open innovation activity increases to get more IP for product development.

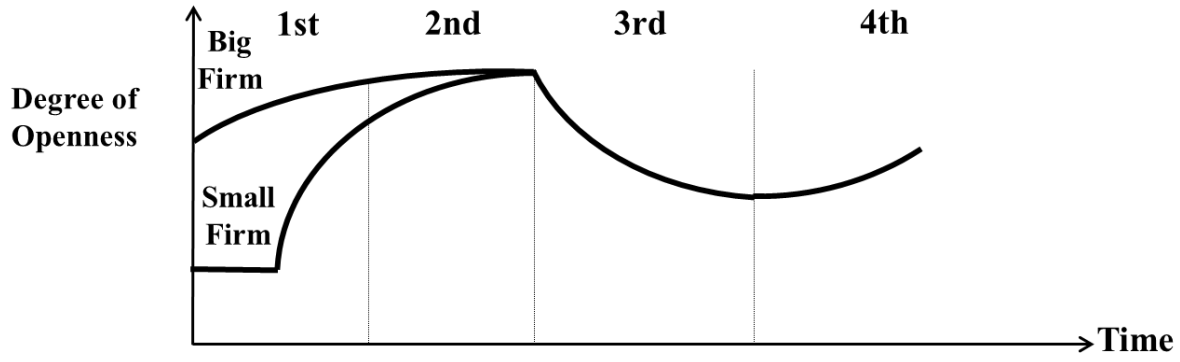

Figure 4.1. Change of openness in new product development of biochip in Samsung Electronics

In the third stage, a big firm has sufficient knowledge to make commercial product and then decreases open innovation activity. By decreasing open activity, the amount of research funds devoted to external partners decreases, which increases the profit of the firm. IP protection to prevent outflow of knowledge is very important in the commercial product stage. Thus, the firms do close innovation due to the perception of advantage of close innovation. In the fourth stage, the commercial product is made and then the government approval is needed before starting commercialization. To sell the biochip, for patient usage, a premarket approval (called 510K) is needed based on the clinical trials from US Food and Drug Administration in the U.S. case. However, for usage as laboratory equipment, clinical tests and 510K are not needed. To get the government approval, collaboration with law firms or hospitals is needed to do the legal process, as well as clinical trials in collaboration with an internal research team, which increases the open activity of firm. In addition, the collaboration is needed for the improvement of product and wide modification of product for new application in the fourth stage. Thus, even in the third and fourth stages, there is a low degree of openness and, thus, there will be no completely close innovation. From the start stage to the final stage of product development, the degree of openness changes, causing a wave-type oscillation in the degree of openness.

Based on the experience of the team leader in Samsung Electronics to do collaboration with small firms, in the first stage of the of product development process, a small firm fears leakage or outflow of its knowledge. Thus, small firms focus on developing their own IP and getting patents, and then start to do open innovation to get external technology. The other innovation process is the same as that of a big firm.

In the biochip technology, the first chip to emerge was the DNA chip, which exploited technologies based on DNA immobilization and the optical detection technique of DNA. The second chip to be developed was the protein chip. It was partly based on the DNA chip technology, with the addition of other technologies, such as protein immobilization and signal detection technology from protein. After protein chip, the cell chip technology emerged based on the DNA/protein chip technology and other technologies, such as cell immobilization and signal detection technology from cell. Finally, the organ-on-a chip emerged, which was based on the cell chip technology (see Figure 4.2). As new innovative biochip emerges based on the previous chip generation technology, the same pattern of innovation change can be observed (see Figure 4.3). The repetition of transition of innovation occurs in new innovative product development.

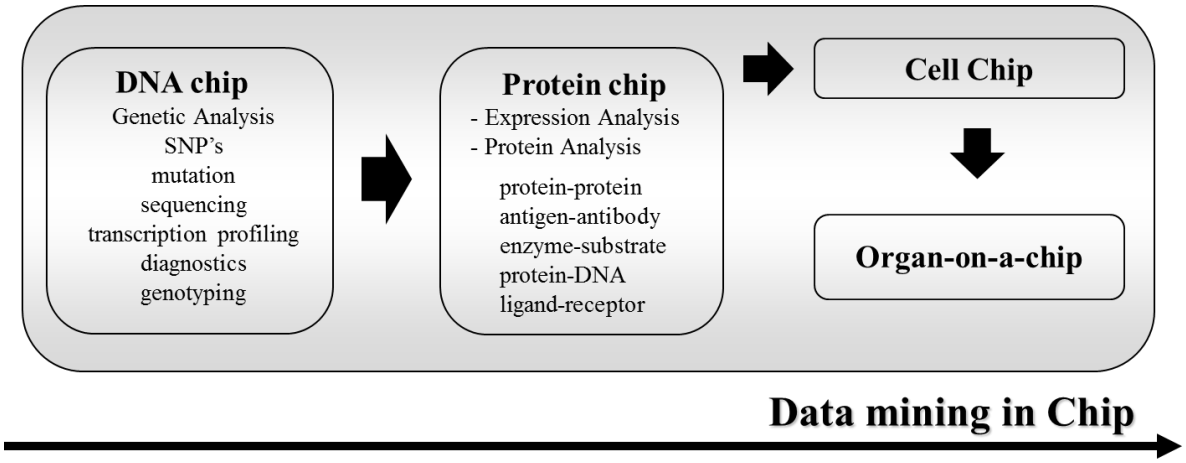

Figure 4.2. The development of biochip

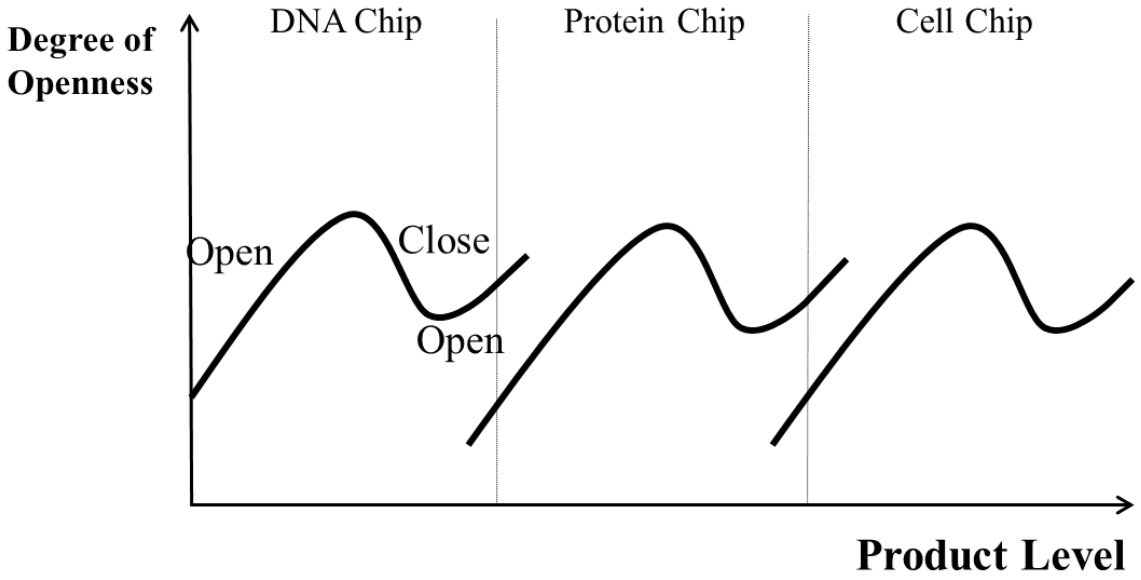

Figure 4.3. Change of openness by emergence of innovative product in Samsung Electronics

(2) LG Biotechnology

The interview was conducted with a former head of Sales Department to sell biosensor and biochip in LG Biotechnology. LG is the second largest conglomerate in Korea including LG Electronics and LG Biotechnology. The total number of codes was 26, including 3 codes for general information and 23 codes for 9 groups. Based on code classification, the interview results were analyzed. The interviewee agreed with the concept of transition of innovation type (see Figure 4.1), but the transition of innovation is mainly based on knowledge, not just IP. The interviewee insisted on the importance of collaborative innovation. He suggested that collaborative innovation is not just open innovation, since, in collaborative innovation, the collaboration starts from planning of a project. It means that mutual collaboration between internal researchers and external partners starts from the initial stage to the final stage. In the fourth stage, the commercial product is made and then the collaboration for marketing is needed before selling the product. Thus, to distribute the product to the market, collaboration with other firms is needed in marketing, which also increases the open activity of the firm. the interviewee agreed with the concept of innovation for new innovative product to be proposed for the same pattern of innovation change (see Figure 4.3). Since LG Biotechnology and Samsung Electronics are big firms and have sufficient knowledge due to the long history of biosensor and biochip development, it can be concluded that the experts in both firms converge

in their views on the transition of innovation for new product development.

(3) SK Telecom

The interview was conducted with a research fellow in Healthcare Group of SK Telecom. SK is the third largest conglomerate in Korea including SK Telecom and SK Energy. Healthcare Group does research for bioanalysis systems including biosensors. The total number of code was 21, including 3 codes for general information and 18 codes for 9 groups. Based on code classification, the interview results were analyzed. The interviewee insisted that the open innovation is the main research innovation activity for new product development in Healthcare Group of SK Telecom. From the planning to production of a product, collaboration innovation is carried out with external partners. Thus, there is no transition to close innovation in the firm's overall innovation status, but just a slight decrease of openness due to the decrease of knowledge needed for commercialization (see Figure 4.4). As open innovation activity is performed for a long time since the initial stage, the internal research ability increases. Based on the interviewee's experience with small firms, small firms keep closeness to prevent leakage of knowledge in the first step and then increase open innovation activity rapidly (see Figure 4.4). After the third stage, small firms keep a high level of open innovation in their collaboration with external partners. When a new innovative product emerges, the repetition of innovation occurs, but, ion overall firm level, innovation is preserved open since the open innovation activity is preserved in each product (see Figure 4.5). These results suggest that there is no transition to close innovation in this firm.

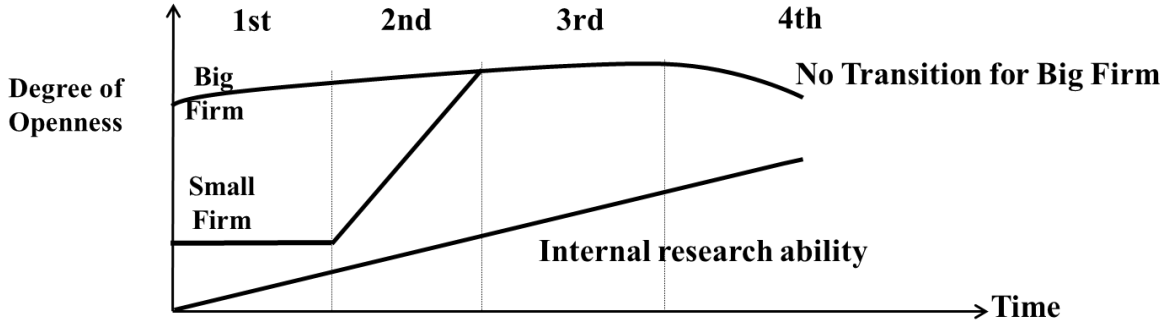

Figure 4.4. Change of openness in new product development of biochip in SK Telecom

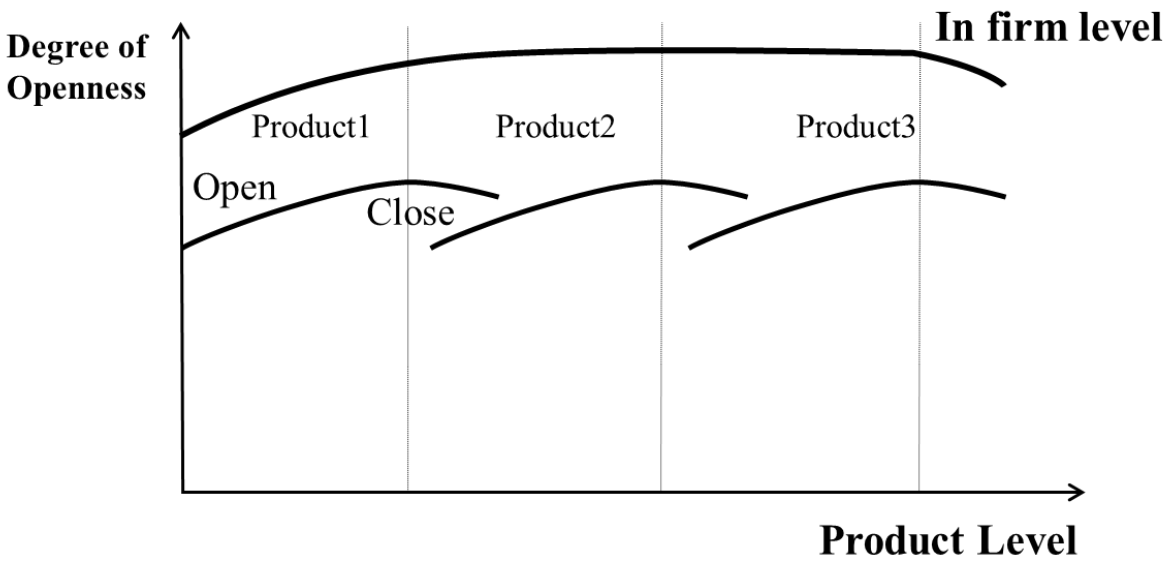

Figure 4.5. Change of openness by emergence of innovative product in SK Telecom

The pattern of innovation activity in Healthcare Group of SK Telecom is very different from those of Samsung Electronics and LG Biotechnology, though all three firms are big. The reason might be that the research history of Healthcare Group of SK Telecom is shorter and the firm wants more technologies, since this firm has insufficient knowledge from the start stage, as compared with the other two farms that have a long research history and many patents.

(4) BioDiatech

The interview was conducted with a former CEO and founder of BioDiatech, a venture company. The main product of BioDiatech is the biosensing device to detect myocardial infarction. The total number of code was 24, including 3 codes for general information and 21 codes for 9 groups. Based on code classification, the interview results were analyzed. The interviewee agreed with the concept of transition of innovation type (see Figure 4.1), but the transition of innovation is mainly based on the understanding of technology perfectness to make commercial product, not just by IP from the first to the second stage. In the second stage, the change of the degree of openness is done based on knowledge for commercial product. In the third stage, the company has acquired sufficient knowledge for commercial product and, consequently, it decreases the degree of openness and starts to close the technology inflow. In

the fourth stage, the open innovation activity concerning marketing and government approval process increases rapidly (see Figure 4.6). These results suggest that there is transition tendency to close innovation in this firm.

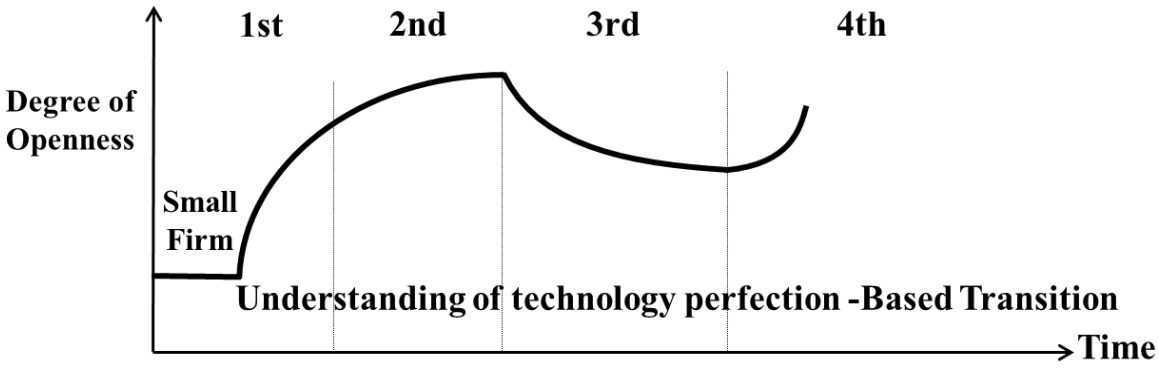

Figure 4.6. Change of openness in new product development of biochip in BioDiatech

The interviewee agreed with the concept of innovation for innovative products (see Figure 4.3). However, he indicated that the overall innovation status of a small firm is different from that of a large firm and open innovation level in a small firm is the same in the overall development process as shown in Figure 4.7. The reason might be that small firms want open innovation in technology for the product development stage and more open innovation in marketing and government approval process due to the shortage of infrastructure in marketing and law areas.

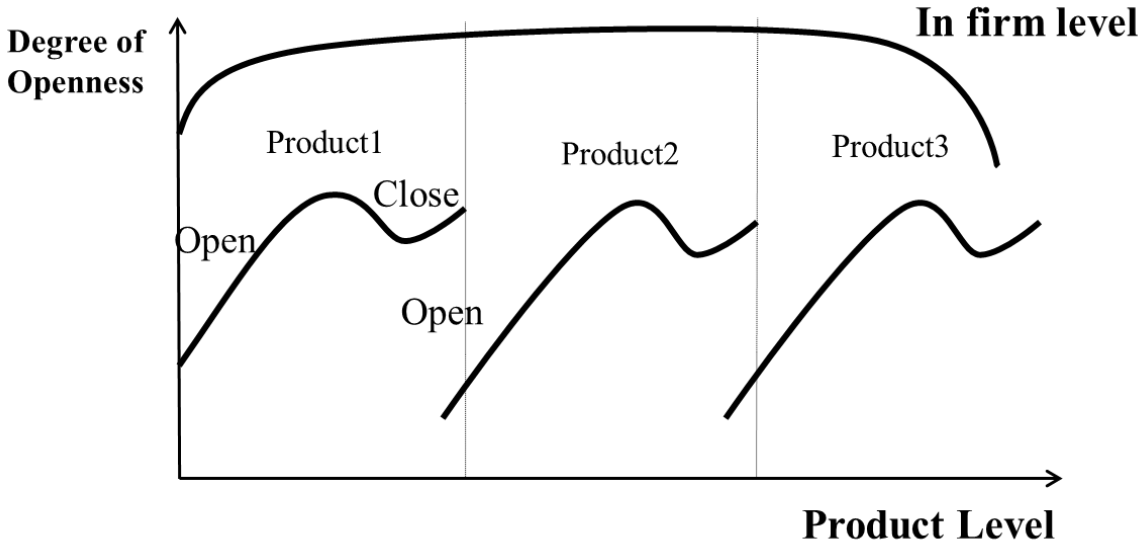

Figure 4.7. Change of openness by emergence of innovative product in BioDiatech

(5) NSB Postech

The interview was conducted with a CEO and founder of NSB Postech, a venture company. The main product of NSB Postech is the substrate used for immobilization of proteins in Protein Chip. The total number of code was 25, including 3 codes for general information and 22 codes for 9 groups. Based on code classification, the interview results were analyzed. The interviewee agreed with the concept of transition of innovation type shown in Figure 4.1. However, in the first stage, a small firm like NSB Postech does not adopt open innovation at all, since it wants to have exclusive ownership of the technology. In the second stage, open innovation starts for collaboration for clinical assay. The reason might be that the firm must work with customers, such as bioanalytical firms and hospitals, in developing the product. In the third stage, the firm wants open innovation for the government approval process, but does not want open innovation in technology inflow. Thus, overall, the degree of openness decreases (see Figure 4.8). According to the interviewee, in the fourth stage, open innovation is not needed, since improvement of a product or a modification for a new application for the product can be done inside the firm.

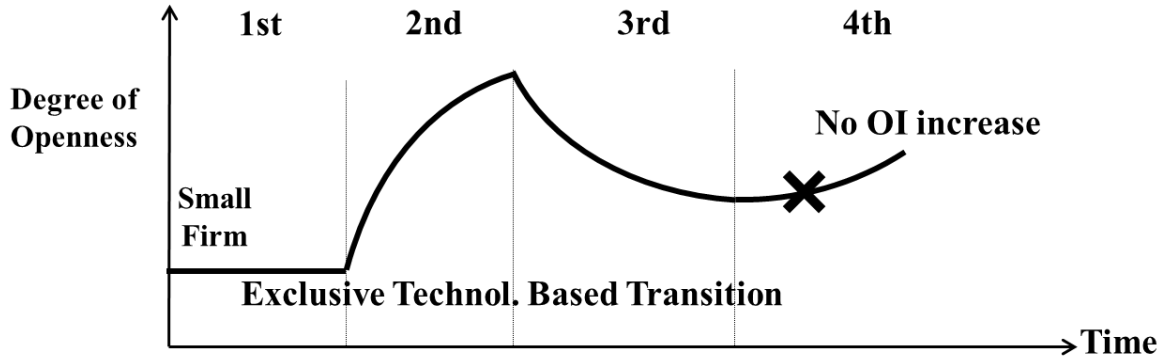

Figure 4.8. Change of openness in new product development of biochip in NSB Postech

The interviewee agreed with the concept of innovation for innovative products shown in Figure 4.3. However, he indicated that the overall innovation status of small firm is slightly different from that of large firm and open innovation is kept continuously in the overall level of degree of open innovation in the firm (see Figure 4.9). The reason might be the same as the

one proposed in the interview with BioDiatech. The inflow of external technology in early stage and collaboration for marketing and government approval process are needed.

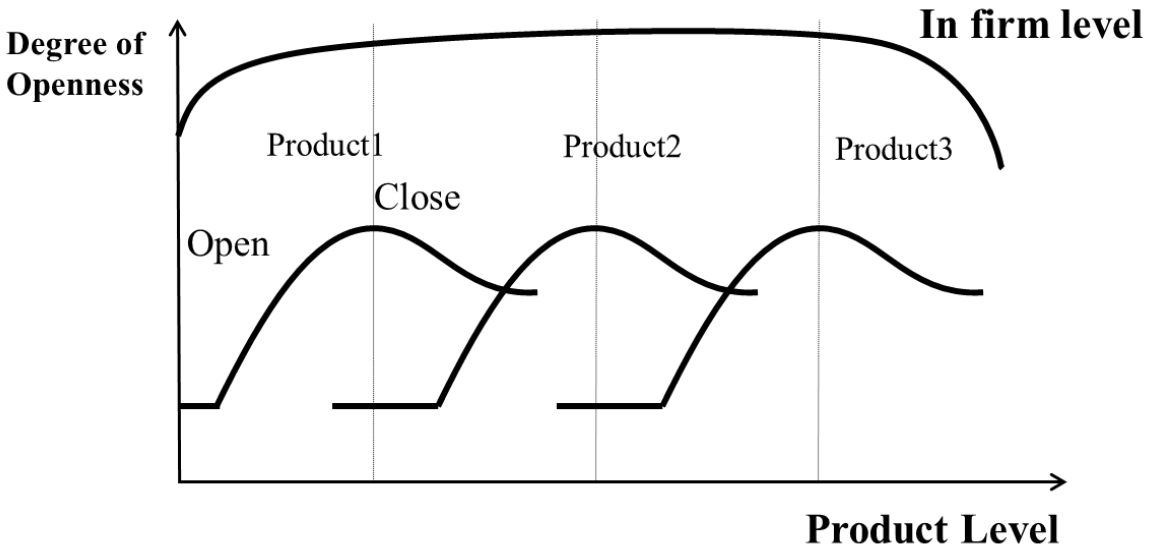

Figure 4.9. Change of openness by emergence of innovative product in NSB Postech

(6) NanoEnTek

The interview was conducted with a CEO and founder of NanoEnTek, a small technology company. The main product of NanoEnTek is the immunoassay analyzer consisting of lab-on-a chip based on nano-scale Bio-MEMS (microelectromechanical system) technology. The total number of code was 26, including 3 codes for general information and 23 codes for 9 groups. Based on code classification, the interview results were analyzed. The interviewee did not agree with the concept of transition of innovation type shown in Figure 4.1. Instead, he suggested that the firm does not want to collaborate with external partners until all technology for product is developed internally in the first and second stages. The value of intellectual property (IP) is important, not just number of IP in a firm, since most IP in firm is not valuable. Research, technology development and production should be done inside the firm, i.e. close innovation. In the third and fourth stages, open innovation is needed for collaboration so that marketing and the government approval process increase value (see Figure 4.10). Thus, the transition of innovation should be done based on consideration of value chain and value calculation. The interviewee also suggested that development of technology is made in a close innovation mode,

whereas activities such as marketing, service, government approval process and consulting may be carried out in an open innovation mode. Also, the interviewee suggested that the degree of openness is affected by the character of CEO and business area.

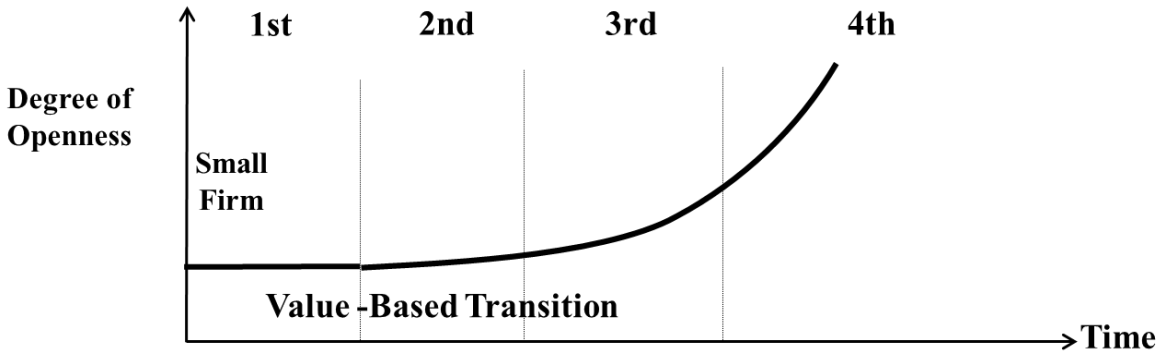

Figure 4.10. Change of openness in new product development of biochip NanoEnTek

The interviewee agreed with the concept of innovation for innovative products shown in Figure 4.3. In the emergence of each new innovative product, the repetition of innovation type change is observed (see Figure 4.11). The interviewee suggested that the repetition of innovation related to value creation occurs and, thus, if the value to be created in product development stage in firm is low, the degree of open innovation increases to increase the value. The interviewee suggested that, if a new innovative product is a very creative product to cause disruptive innovation, the degree of open innovation should increase to acquire more new knowledges from the outside.

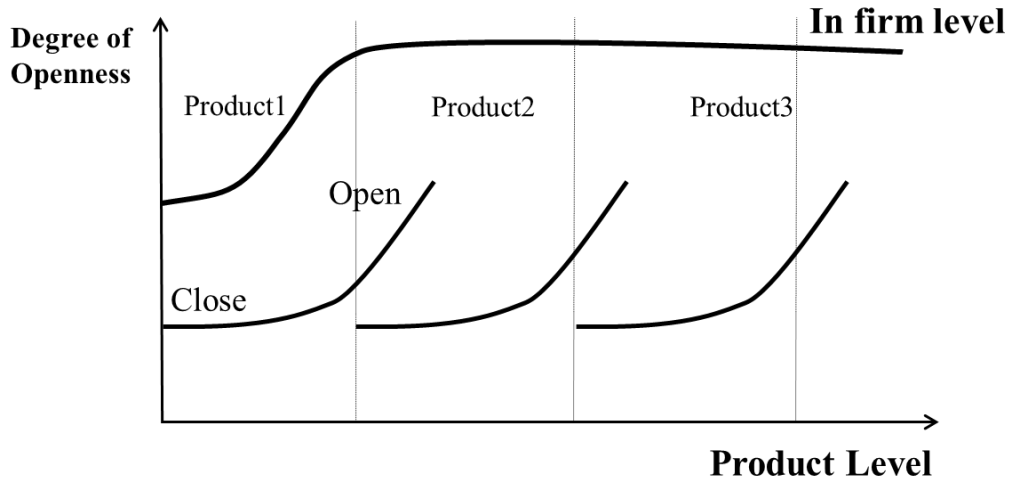

Figure 4.11. Change of openness by emergence of innovative product in NanoEnTek

(7) Relations of factors based on interview analysis

The concept of change of innovation in the product development stage is well adopted by two large firms (Samsung Electronics and LG Biotechnology) and two small firms (BioDiatech and NSB Postech). However, SK Telecom's approach is entirely open innovation-based, whereas NanoEntek is entirely based on close innovation. All interviewees agreed on the point that transition of innovation type occurs as shown in Figure 4.12. At first, a firm starts open innovation to get external knowledge. As time goes by, the focal firm acquires sufficient knowledge or more knowledge than the external partner, such as a university and other firms. At this point, the focal firm decides to decrease open innovation activity and moves to close innovation. The general pattern of innovation in the cases of DNA chip, protein chip, and cell chip was suggested by interviewees and all of them agreed on the point that repetition of transition of innovation type occurs as shown in Figure 4.13.

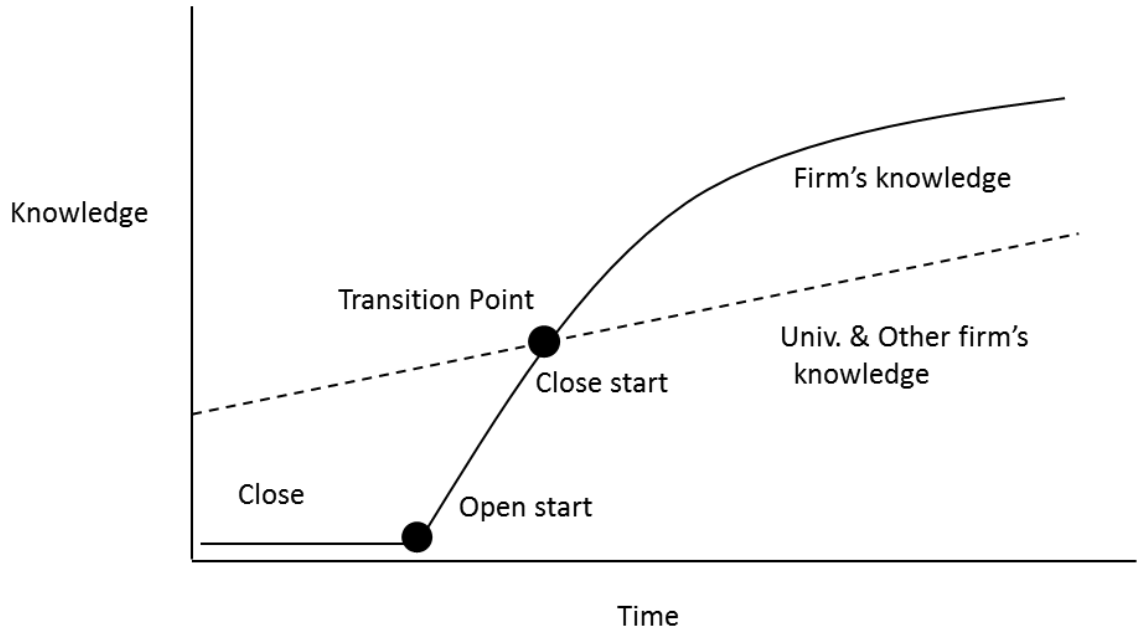

Figure 4.12. Transition of innovation type in new product development of biochip

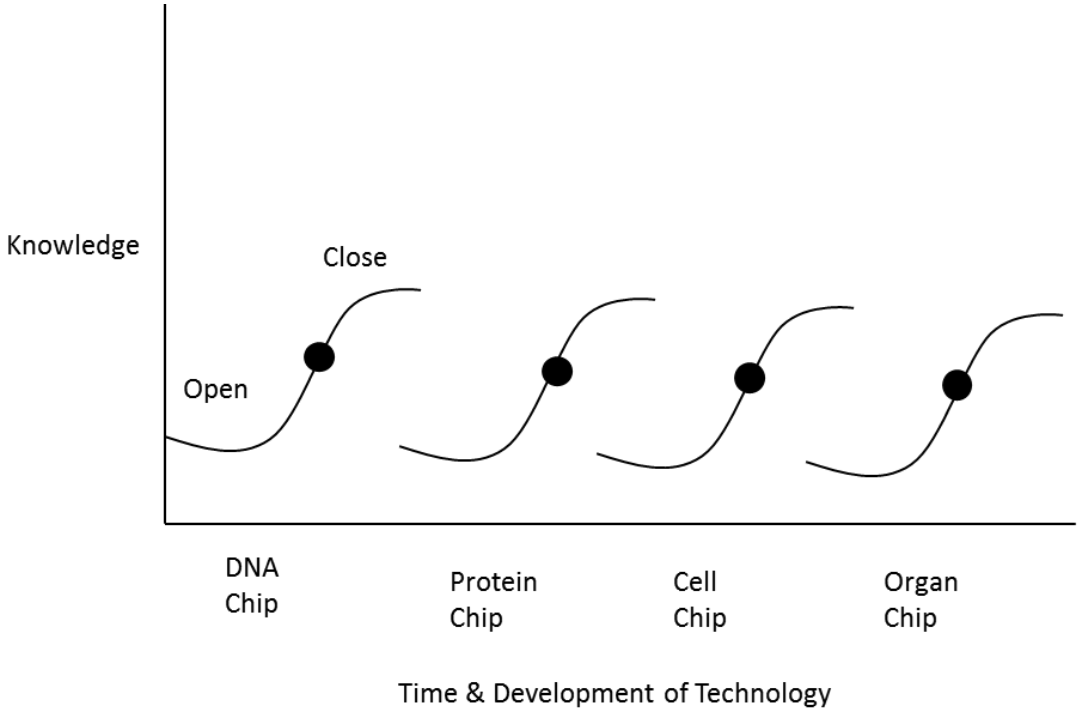

Figure 4.13. Repetition of transition of innovation type in new product development of biochip

The interviews converged in the following general level points. Based on interview results, the product development stage and the product innovation stage are related to the emergence of new innovative product. Furthermore, knowledge and the government approval stage are related to transition tendency of innovation. Also, the product development stage is related to the knowledge possessed by the focal firm. Due to the change to close innovation, the firm can get a better performance, such as an increase of profit, which can be described as the perception of advantage of close innovation. Although marketing is a factor affecting the open-to-close transition, the proposed model is formulated taking into account only technological factors. Thus, six factors (product development stage, product innovation stage, knowledge, government approval stage, transition tendency to close innovation, and the perception of advantage of close innovation) are related in the final stage of new product development (see Figure 4.14).

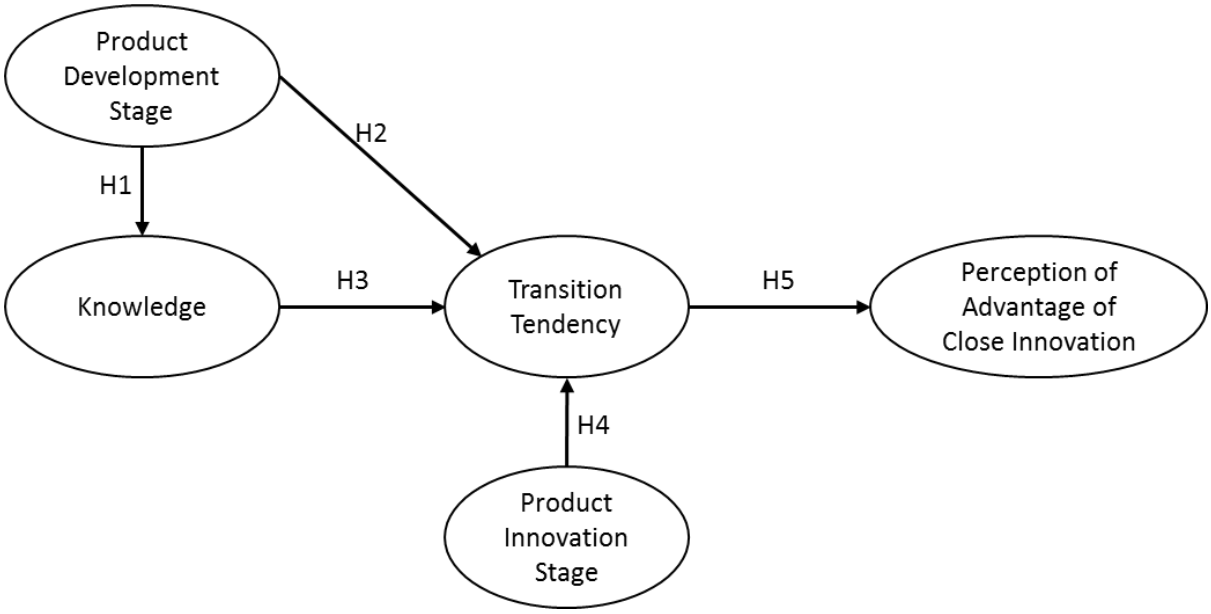

Figure 4.14. Relationship between factors based on structured interview in biochip firm

4.4. Research Model and Hypotheses

For the bio-pharmaceutical industry, a model with hypotheses for transition tendency to close innovation is proposed based on the results of interviews. Although the model is based on the interviews carried out in the biochip industry, the model with hypotheses is tested in the bio-pharmaceutical industry, as, largely speaking, the bio-pharmaceutical industry includes the biochip industry. The generality of the proposed model is evaluated by extension to the bio-pharmaceutical industry. In the model, the transition tendency is affected by the following factors: (1) product development stage; (2) level of knowledge; (3) product innovation stage; and (4) the government approval process. Then, the transition tendency to close innovation is related to the perception of advantage of close innovation. The relationships between variables and related hypotheses are described below.

(1) Product development stage

The product development stage is related to the innovation type. For a new product development in the biochip technology, novelty is very high and, therefore, new technologies must be transferred from external partners. At the initial stage of new product development, the open innovation activity starts and a large amount of external knowledge flows into the firm. Thus, the product innovation stage is positively related to knowledge in the firm. The literature confirms that the import of know-how and technology should be carefully considered

in each stage of open innovation (cooperated stage-gate mode) of new product development (Gronlund et al. 2010; Cooper 2008). These studies demonstrate different levels of know-how and technology flow into the firm at each stage of new product development, suggesting that the product innovation stage is related to level of knowledge. To make a product commercial, more know-how and technology have to be accumulated in the firm as the stage of product development progresses increases. Based on the above, the following hypothesis is formulated.

H1: There would be a positive relationship between product development stage and accumulation of knowledge.

For the firm to have the capability to make the commercial product in the final stage of product innovation, the firm must have accumulated sufficient knowledge and hence it does not need external knowledge any longer. Thus, the firm starts to move towards close innovation, since no more external knowledge is needed. Rubera et al. (2016) report that the development-centric open innovation (development stage of product) is related to high R&D, as well as an increase the technology and know-how in the firm. However, the commercialization-centric open innovation (commercialization stage of product) is related mainly to marketing, not with technology and know-how, i.e. knowledge. Thus, in the commercialization stage, close innovation is preferred from the technology point of view. Therefore, at the end of product development stage, the transition tendency to close innovation increases. Accordingly, the following hypothesis is formulated.

H2: There would be a positive relationship between product development stage and transition tendency to close innovation.

(2) Knowledge

Knowledge is closely related with open innovation activity. Diversified knowledge affects the impact of technology innovation in drugs and technology industry (Rosenzweig 2016). In knowledge-based high-tech industry, the knowledge is the key source for firm's competitiveness in technological innovation (Castro 2015). Especially the strategic decision to profit is needed to acquire external scientific knowledge, since knowledge acquisition from foreign countries causes an increase of performance and unblocks the innovation potential (Kafouros and Forsans 2012). Knowledge capability relates to asymmetric knowledge capabilities in open innovation (Cooke 2005).

More technology and know-how, i.e. knowledge, are accumulated in the firm as

development goes on, since various technologies are combined to produce bio-pharmaceutical products. Inflow of various external technologies is needed to support relevant technologies to manufacture the product through open innovation; during open innovation activity, the degree of openness can control the amount of inflowing various technologies. As more knowledge is accumulated in the firm, the firm wants to stop the inflow of external knowledge, which causes the initiation of close innovation and increases the transition tendency to close. Therefore, the following hypothesis is formulated.

H3: There would be a positive relationship between knowledge and transition tendency to close innovation.

(3) Product innovation stage related to emergence of new innovative product

Biochip has developed from DNA chip to protein chip, and cell Chip based on the emergence of new application and technology (Kafi and Choi 2014). As new innovative biochip emerges based on previous chip technology, the repetition of transition of innovation type occurs (see Figures 4.2 and 4.13). Kafi and Choi (2004) define that each stage of emergence of a new innovative product is called the product innovation stage. The product innovation stage is related only to the emergence of a new innovative product, not just to that of a modified product for a new application. In the bio-pharmaceutical industry, as new technology emerges based on previous knowledge and new knowledge, new innovative products emerge (Robbins-Roth 2000). Since the new innovative product emerges, the firm wants to get new knowledge from external partners. Thus, the open innovation activity increases and the transition tendency to close innovation decreases. Thus, it can be predicted that the high product innovation stage and the high level of emergence of a new innovative product decrease close innovation. Therefore, the following hypothesis is formulated.

H4: There would be a negative relationship between product innovation stage and transition tendency to close innovation.

(4) Government approval stage

In the government approval stage, such as clinical tests I, II, and III for FDA, open innovation between hospitals and firms is highly needed in bio-pharmaceutical firms (Bianchi et al. 2010; Chiaroni et al. 2009; Schuhmacher et al. 2013). The role of the government is very important in open innovation in other industries (Lee et al. 2012; Park et al. 2016). Although open innovation activity exists in target identification and validation, lead identification, and pre-

clinical stage, in the clinical test stage, more and diverse types of open innovation are needed (Bianchi et al. 2010; Chiaroni et al. 2009). Furthermore, for legal process to get the governmental approval, the collaboration with law firm is needed. Thus, as the product arrives in the government approval stage, more open innovation activity is needed. Therefore, it can be predicted that the government approval stage decreases the tendency to close innovation. Therefore, the following hypothesis is formulated.

H5: There would be a negative relationship between the government approval stage and transition tendency to close innovation.

(5) Transition tendency to close innovation

Although it has been reported that open innovation has many advantages, open innovation has adverse effect on firm's R&D capability. The decrease of internal innovation potential, divergence of research goal, and increase of relevant costs for open innovation are suggested as disadvantages of open innovation (Almirall and Casadesuss-Masanell 2010; Kafouros and Forsans 2012; Cassiman 2015). Furthermore, there are differences in open and close innovation in terms of organizational culture, problem solving and the governance, and task decomposition and knowledge distribution (Herzog and Leker 2010; Felin and Zenger 2014; Lakhani et al. 2012). Innovation risks of outsourcing in open innovation occur in pharmaceutical new product development (Lowman et al. 2012). Since the dependence on other organizations leads to knowledge loss and creates a lack of ability in integration of new product development (Lowman et al. 2012), the open innovation causes a decrease in firm's profit. In the above cases, the decrease of open innovation (i.e. increase of transition tendency to close innovation) increases the advantage of close innovation activity, such as firm's profit and increase of internal research capability. Thus, it can be predicted that the transition tendency to close innovation is positively related to the perception of advantage of close innovation activity. Therefore, the following hypothesis is formulated.

H6: There would be a positive relationship between and transition tendency to close innovation and the perception of advantage of close innovation.

Based on the above hypotheses and relations, the model is constructed (see Figure 4.15).

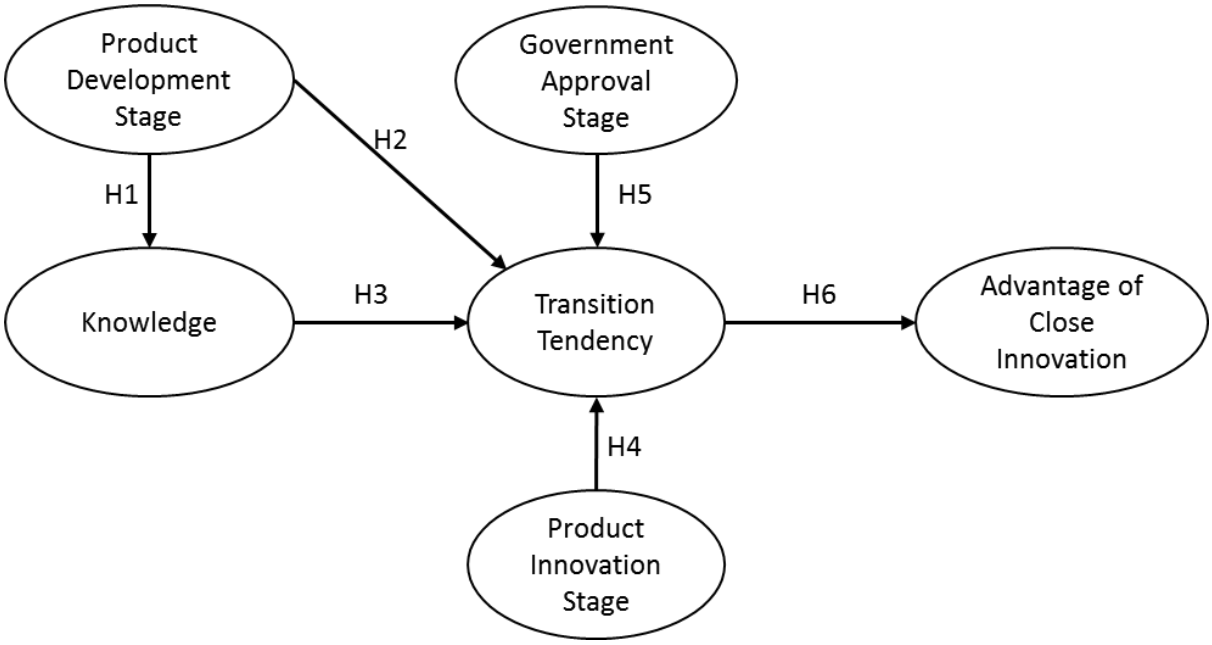

Figure 4.15. Model with hypotheses regarding factors affecting transition of innovation type in bio-pharmaceutical firm

4.5. Research Method

(1) Questionnaire Design

The biotechnology industry, a high technology industry, is the fusion industry of various technologies, including biotechnology based drug (biodrug), nanobiotechnology, genetic engineering, and cell engineering. The pharmaceutical industry is mainly related to the development and production of new drugs or biosimilar drugs. In general, ue to the need to secure intellectual property, open innovation activity was barely accomplished in high technological industry. However, since life cycle of high technology has recently decreased, the need for open innovation activity has increased in the process of rapid development and commercialization of new product (Ahn and Lee, 2011). Based on these results, it can be predicted that open innovation will increasingly spread in the bio-pharmaceutical industry with a high intensive degree of technology. However, it can also be predicted that open innovation activity will decrease toward the end of new product development to reduce expenses and to avoid leakage of internal knowledge concerning innovative products. Thus, the bio-pharmaceutical industry in Korea is selected in the present study as the target industry to investigate the change of innovation type.

The aim of this research is to investigate the transition of innovation type at final stage of new product development process. To meet this aim and ensure the validity of findings a questionnaire survey is done. Studies for pharmaceutical industry in past have done also questionnaire survey and questionnaire survey has been used as an established research technique for technology management studies (Fleuranceau-Morel 2002, Lotfi et al. 2015, Al-Zu'bi and Tsinopoulos 2012)

The questions were designed as followings. The interviews to construct questions were done with CTO of two medium-sized biotechnology firms, and manager of a team manager of large pharmaceutical firm in Korea, from October 10th to October 24th in 2012. Expert interviews in bio-pharmaceutical companies has been used as a method for open innovation analysis in bio-pharmaceutical firm (Bianchi et al. 2011). The discussion for close innovation activity in final stage of new product development in biodrug was done. The findings in section 4.3.2 were used as the basic data to understand the transition of innovation type. Especially the factors to affect the transition of innovation type were discussed to clarify the transition tendency. And the relation of transition tendency to advantage of close innovation was discussed during action of innovation type change. The discussion results for close innovation activity in final stage of new product development were analyzed and the main variables were classified as four factors, openness, transition tendency, and perception of advantage of close innovation as depicted in Table 4.3.

Table 4.3. Questions for transition to close innovation in final stage of new product development (NPD).

(1) How is the degree of knowledge?
1.1. We have enough research ability (mastering the technology) needed for NPD.
1.2. We have the accumulated relevant technology needed for NPD.
1.3. We have research competency needed for NPD.
(2) How is the degree of product development stage?
2.1. New Product is in commercial stage.
2.2. New Product is in suboptimal stage.
2.3. New Product is made for improvement after commercial stage.
2.4. New Product is made for little modification for application after commercial stage.

(3) How is the degree of product innovation stage? 3.1. New product development is done for emergence of total new product application. 3.2. New product development is done for expansion of current application. 3.3. New product development is done for new successive product.
(4) What is important in change to close innovation? 4.1. It is easy to change from open innovation to close innovation 4.2. System change is needed to change from open innovation to close innovation. 4.3. System change is needed to quit collaboration after producing new product. 4.4. Cost to quit collaboration is high after producing new product.
(5) What is the advantage of close innovation? 5.1. Technology leakage is decreased due to close. 5.2. Cost for new product is decreased due to close. 5.3. Management process is decreased due to close.

The scales used in the survey were seven as used in the literature (Son et al. 2014) but the scales were later modified for this study. To ensure the validity of question and scales I asked a panel of experts consisted of the above three interviewees and two professors in Sogang University, Korea (major: chemical-pharmaceutics and bio-pharmaceutics) to review them. This process made modification of questions and resulted in clarification of questions.

The main question concerns the transition of innovation type in final stage of new product development of biodurg. Questions concern three aspects: (1) Does transition of innovation type happen? (2) Does factors such as knowledge, product development stage, government approval stage, and product innovation stage affect transition tendency to close innovation? (3) Does openness relate to technology ability? (4) Does transition tendency relate to perception of advantage of close innovation? Survey based on constructed questions is described in the following section.

(2) Survey Administration

The survey was conducted to target decision makers in 410 firms from November 3 to November 29, 2016, by fax, e-mail and assisting telephone by Telsearch Co. in Korea. Bio-pharmaceutical firms include biotechnology firms, pharmaceutical firms, and bioanalysis instrument firms. Through the survey, a total of 54 survey results were acquired, reaching the

response rate of 13.2%; further analysis was done with 48 surveys with considerable values. However, the government approval stage in the model could not be analyzed, since the number of respondents was only 20 (out of 48).

(3) Demographic characteristics

Demographic property of respondents is shown in Table 4.4.

Table 4.4. Characteristics of demography of sample

Division	Classification	Number	Percentage (%)	Accumulated percentage (%)
Firm Type	Biotechnology firm	31	64.6	64.6
	Pharmaceutical firm	11	22.9	87.5
	Bioanalytical firm	6	12.5	100
Firm size	Venture firm	19	39.6	39.6
	Small firm	11	22.9	62.5
	Medium firm	17	35.4	97.9
	Large firm	1	2.1	100
Personal position	Staff	15	31.3	31.3
	Manager	25	52.1	83.4
	Director	5	10.4	93.8
	CEO	3	6.2	100

(4) Statistical analysis of variables

The definition of variables and measurement method of the variables in the research model are shown in Table 4.5. A seven-point scale was used for the variables.

Table 4.5. Definition and measurement of variables

KNW 1	We have enough research ability (mastering the technology) needed for NPD*.
KNW 2	We have the accumulated relevant technology needed for NPD.
KNW 3	We have research competency needed for NPD.

PDS 1	New Product is in commercial stage.
PDS 2	New Product is in suboptimal stage.
PDS 3	New Product is made for improvement after commercial stage.
PDS 4	New Product is made for little modification for application after commercial stage.
PIS 1	New product development is done for emergence of total new product application.
PIS 2	New product development is done for expansion of current application.
PIS 3	New product development is done for new successive product.
TTC 1	It is easy to change from open innovation to close innovation.
TTC 2	System change is needed to change from open innovation to close innovation.
TTC 3	System change is needed to quit collaboration after producing new product.
TTC 4	Cost to quit collaboration is high after producing new product.
ACI 1	Technology leakage is decreased due to close.
ACI 2	Cost for new product is decreased due to close.
ACI 3	Management process is decreased due to close.

*New product development

Based on the data acquired by the survey, analysis was performed using SPSS 18.0 program and PLS 2.0. The hypotheses were tested by applying the partial last square (PLS) method to the collected data. This study used PLS, rather than other SEM methods (i.e. LISREL, AMOS, etc.), as the PLS approach places minimal restrictions on sample size and residual distribution (Phang et al. 2006). First of all, analysis of descriptive statistics was accomplished and the results were investigated. To verify the reliability of samples, the items measuring each concept were investigated using Cronbach's alpha test. Also, to verify the validity of the samples, factor analysis was run in the hypothesis testing process.

4.6. Model Results

4.6.1. Validation

To validate the model, three types of validity—content validity, convergent validity, and discriminant validity—were assessed. (1) Content validity was evaluated based on Cronbach alpha value (see Table 4.6) Cronbach's alpha test to individual scale and the overall measures to assess internal consistency were sued. The threshold value of Cronbach alpha is 0.7 (Nunally and Berstein 1994). As shown in Table 4.6., the Cronbach alpha values in our results were 0.913 for knowledge, 0.868 for product development stage, 0.769 for product innovation stage, 0.810 for transition tendency to close, and 0.850 for perception of advantage of close innovation. Thus, all variables are valid.

Table 4.6. Confirmatory factor analysis

	Cronbach's Alpha	Composite Reliability	Average Variable Extracted(AVE)
Knowledge (KNW)	0.913	0.945	0.852
Product development Stage (PDS)	0.868	0.909	0.715
Product innovation Stage (PIS)	0.769	0.817	0.607
Transition tendency to close (TTC)	0.810	0.874	0.644
Advantage of close innovation (ACI)	0.850	0.906	0.763

(2) Convergent validity was assessed by composite reliability and average variance extracted (AVE) from the measures (see Table 4.6). The acceptable values of composite reliability for reliable construct is 0.7 (Chin 1988). The composite reliability values in our dataset were 0.945 for knowledge, 0.909 for product development stage, 0.817 for product innovation stage, 0.874 for transition tendency to close, and 0.906 for the perception of advantage of close innovation. Thus, all variables are valid. The acceptable value of AVE is over 0.5 (Fornell and Larcker 1981). The AVE values in our data were 0.852 for knowledge, 0.715 for product development stage, 0.607 for product innovation stage, 0.644 for transition

tendency to close, and 0.763 for the perception of advantage of close innovation. Thus, all variables are valid.

(3) Discriminant validity was verified by evaluating the square root of AVE (Fornell and Larcker 1981; Son et al. 2014). The square root of AVE for each construct was greater than the levels of correlation involving the construct (see Table 4.7.) Also, each construct showed a larger variance with its own measures than those with other measures (see Table 4.7). Acceptable threshold value of absolute value pairwise correlation is 0.6 (Nunally and Berstein 1994) and the highest absolute value of pairwise correlation in our dataset was 0.606, which is very close to 0.6. Variance inflation factors (VIF) is calculated to detect the multicollinearity among the explanatory variables. Threshold value of VIF is 10 (Nunally and Berstein 1994) and the highest VIF value in our dataset was 6.139, which is considerably lower than 10. Thus, all variables are valid.

Table 4.7. Correlation between constructs

	Advantage of close innovation	Knowledge	Product development Stage	Product innovation Stage	Transition tendency to close
ACI	0.873*				
KNW	0.409	0.923*			
PDS	0.135	0.464	0.846*		
PIS	0.180	0.172	0.473	0.779*	
TTC	0.491	0.606	0.226	0.230	0.802*

* Square root of AVE

Other analyses that were performed are outlined below. The descriptive statistics including standard deviation is depicted in Table 4.8. Kaiser-Meyer-Olkin measure of sampling adequacy was calculated to amount to 0.671. Overall, 5 factors explained 78.756% of the total variance (Table 4.9). Since all 5 factors have well-distributed over 0.6 in factor analysis, the validity requirement was satisfied (see Table 4.10).

Table 4.8. Descriptive Statistics

	N	Min	Max	Mean	Std. deviation
KNW 1	48	2	7	5.02	1.211
KNW 2	48	1	7	4.83	1.449
KNW 3	48	1	7	4.94	1.522
PDS 1	48	1	7	3.67	2.025
PDS 2	47	1	7	3.91	1.976
PDS 3	48	1	7	3.73	1.608
PDS 4	47	1	7	3.79	1.429
PIS 1	48	1	7	3.73	1.512
PIS 2	48	1	7	3.69	1.446
PIS 3	48	1	7	3.89	1.433
TTC 1	48	1	7	4.04	1.414
TTC 2	48	1	6	4.52	1.429
TTC 3	48	1	6	3.67	1.3 26
TTC 4	48	1	5	3.25	1.345
Effective Number	48				

Table 4.9. Total Variance Explained

Factor	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loading		
	Total	% of Variance	Cumulative%	Total	% of Variance	Cumulative%	Total	% of Variance	Cumulative %
1	5.926	34.858	34.858	5.926	34.856	34.856	3.238	19.047	19.047
2	2.716	15.976	50.832	2.716	15.976	50.832	3.047	17.922	36.969
3	1.877	11.041	61.873	1.877	11.041	61.873	2.532	14.896	51.865
4	1.482	8.720	70.592	1.482	8.720	70.592	2.471	14.538	66.402
5	**1.388**	**8.164**	**78.756**	**1.388**	**8.164**	**78.756**	**2.100**	**12.354**	**78.756**
6	.779	4.583	83.339						
7	.577	3.396	86.735						
8	.529	3.113	89.849						
9	.417	2.455	92.303						
10	.355	2.088	94.392						
11	.256	1.509	95.900						
12	.200	1.178	97.078						
13	.162	.950	98.028						
14	.115	.679	98.707						
15	.106	.625	99.333						
16	.063	.371	99.704						
17	.050	.296	100.00						

Extraction Method: Principal Component Analysis

Table 4.10. Rotated Component Matrix

	Component				
	1	2	3	4	5
KNW 1	.182	**.907**	.116	.156	.098
KNW 2	.224	**.838**	.132	.000	.137
KNW 3	.353	**.760**	.104	.302	.029
PDS 1	**.871**	.138	.099	-.043	.145
PDS 2	**.878**	.222	.053	-.078	.020
PDS 3	**.887**	.080	-.068	.140	.135
PDS 4	**.685**	.231	.220	.132	.256
PIS 1	.055	.164	-.109	.038	**.871**
PIS 2	.384	-.047	.388	.045	**.635**
PIS 3	.187	.070	.064	.130	**.845**
TTC 1	.103	.408	**.774**	-.020	.018
TTC 2	-.079	.542	**.698**	.153	.057
TTC 3	.177	-.164	**.793**	.165	.050
TTC 4	-.002	.472	**.588**	.331	.019
ACI 1	.105	.248	.080	**.860**	-.054
ACI 2	-.018	.063	-.005	**.881**	.282
ACI 3	.014	.080	.438	**.784**	.022

Extraction Method: Principal Component Analysis, Rotation Method: Varimax with Kaiser

Normalization, a. Rotation converged in 5 iterations

4.6.2. Hypothesis testing

To validate the model, the structural equation model was applied and Partial Least Square (PLS) was used. Since PLS requires minimal demands on sample size (Chin 1998) to validate a model, and our data set is 48, the PLS method was used to evaluate the proposed model and hypotheses. When t-value is over 1.96, the hypothesis is significant at 5% level of significance if the number of samples is sufficiently large. Cramer (1946) suggests that the approximation is usually good for samples larger than 30; thus, statistical inference is appropriate for this study with our 48 data set. However, Hypothesis 5 could not be tested, since the number of respondents was only 20 (out of 48). As shown in Table 4.11, only t-values for the relation between knowledge and transition tendency to close innovation, the relation between product development stage and transition tendency to close innovation, and the relation between transition tendency to close innovation and the perception of advantage of close innovation were over 1.96; thus, only these three relations were satisfied. Furthermore, the values of path loadings were calculated. Since R^2 for knowledge, product development stage, and the perception of advantage of close innovation amounted to 0.215, 0.401, and 0.241, respectively, the proposed model is acceptable, since minimum acceptable range of R^2 is 0.1. The results of the analysis of the model with path coefficient, t-value and R^2 are shown in Figure 4.16.

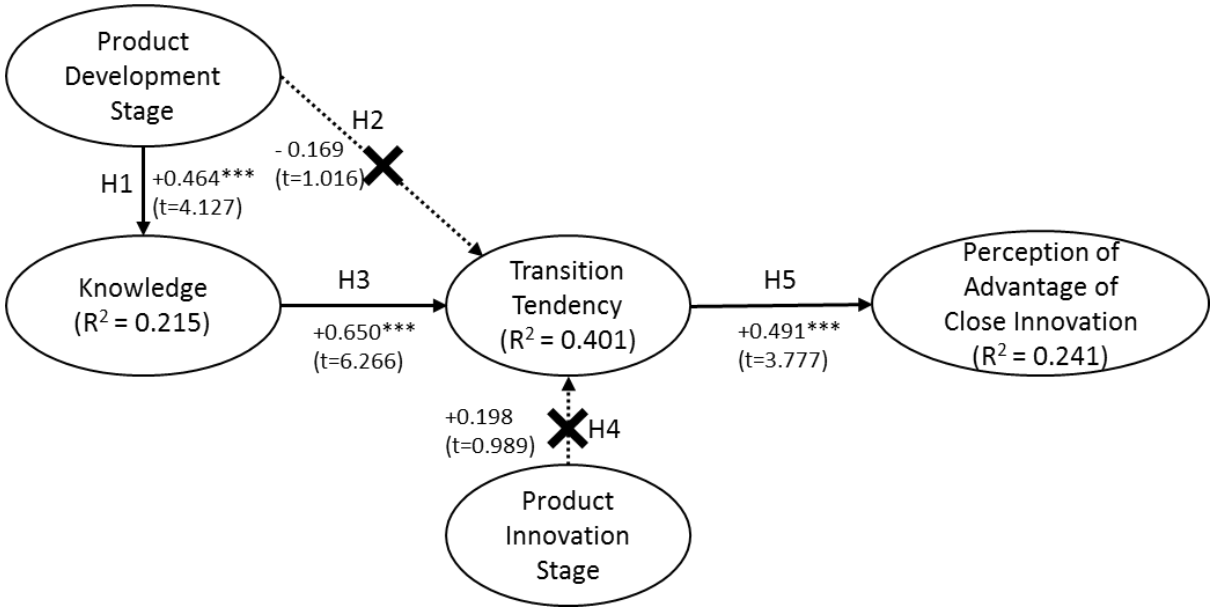

Figure 4.16. Model result for relation between transition tendency and advantage of close innovation

Table 4.11. Path Coefficients

	Original Sample	Sample Mean	Standard Deviation	T Statistics	P Values
KNW → TTC	0.650	0.650	0.104	6.266	0.000***
PDS → KNW	0.464	0.485	0.112	4.127	0.000***
PDS → TTC	-0.169	-0.156	0.166	1.016	0.310
PIS → TTC	0.198	0.172	0.201	0.989	0.323
TTC → ACI	0.491	0.499	0.130	3.777	0.000***

*** p<0.001, ** p<0.01, * p<0.05

The results in Figure 4.3 suggest the following. Since t-value and *p*-value are within an acceptable range, the product development stage is positively related to knowledge, meaning that as product develops more and becomes into commercial status, the degree of knowledge in firm increases. This result indicates that the firm acquires more knowledge accumulation through open innovation activity from the initial stage of product development, since, due to open innovation, new technologies from outside flow into firm to make the product as time goes by. Therefore, Hypothesis 1 is substantiated by our data analysis.

When t-value and *p*-value are considered, the relation between the product development stage and transition tendency to close innovation is not established. When t-value is over 1.96, the hypothesis is significant at 5% level of significance. However, t-value was 1.06 for relation between the product development stage and transition tendency and thus this relation was not confirmed. As the acceptable range of *p*-value is lower than 0.05 and *p*-value of this relation is 0.301, this relation was not confirmed. Therefore, Hypothesis 2 has to be rejected. The results suggest that the product development stage is not directly related to change of innovation type of firm. By evaluating Hypothesis 3, it can be tested that the relation between the product development stage and change of innovation type of firm can be established only with knowledge as a mediator.

Since t-value and *p*-value are within an acceptable range, knowledge is positively related to

transition tendency to close innovation, meaning that the more knowledge, such as patent and know-how, has been accumulated in commercial stage of product, the more a firm may want to change the innovation type from open to close. Since the firm has sufficient knowledge, closing the relationship with its open innovation partners can reduce product development expenses, leading to more profit. The results suggest that, if a firm starts to get more knowledge, like new technology from outside, and the knowledge accumulation increases, the firm may not need more inflow of knowledge from the outside, since the firm has sufficient knowledge to make commercial product and, thus, wants to close the relation with external partners. Thus, Hypothesis 3 is supported by our results.

When path coefficient and t-value are considered, the relation between the product development stage and transition tendency to close innovation is not established. When t-value is over 1.96, the hypothesis is significant at 5% level of significance. However, t-value is 0.989 for the relation between the product development stage and transition tendency and, thus, this relation is not achieved. As the acceptable range of *p*-value is lower than 0.05 and p-value of this relation is 0.198, this relation was not confirmed. The results suggest that, although the emergence of related new product or new application of current product occurs, the transition tendency to close innovation is not affected by the emergence of those in bio-pharmaceutical firms. The results in the bio-pharmaceutical industry are different from those in the biochip industry. The reason might be that the newly emerged product in the pharmaceutical industry is not directly connected from previous products and technology that is not an extended technology of the previous product. Thus, Hypothesis 4 has to be rejected.

The government approval stage could be analyzed, since the number of respondents was only 20 (out of 48). Therefore, Hypothesis 5 was not evaluated.

Since t-value and *p*-value are within an acceptable range, the transition tendency to close innovation is positively related to the perception of advantage of close innovation, meaning that as the tendency to close innovation becomes higher, the perception of advantage of close innovation increases. As firm closes the relation with external partner, i.e. there is a lower degree of open innovation, the expenses regarding collaboration with external partner and outflow of know-how decrease, causing the firm to make more profit. Thus, Hypothesis 6 is supported by our data analysis.

However, our results of structured interviews in the biochip industry show that the product

development stage directly affects the transition tendency to close innovation, product development stage does not directly affect the transition tendency to close innovation. Product development stage is directly related to knowledge in firm and then, consequently, knowledge is directly related with the perception of advantage of close innovation performance in the bio-pharmaceutical industry. Level of product development stage becomes a control factor to manipulate the change of innovation type and even the increase of firm performance in bio-pharmaceutical industry. This is a newly developed relation in open innovation for high-tech products.

4.7. Conclusions and Discussion

The results of structured interviews in the biochip industry based are shown in Figure 4.14. And the summary of the research result in bio-pharmaceutical industry is shown in Figure 4.17.

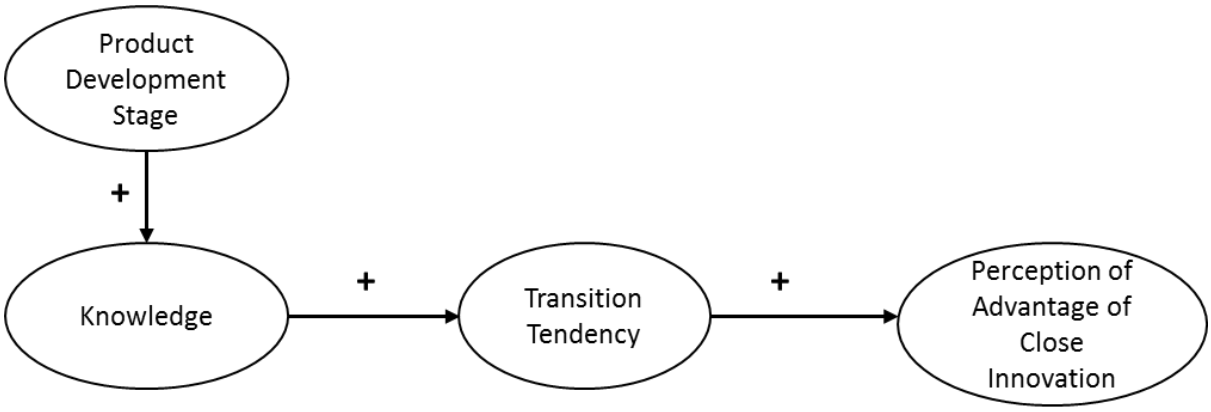

Figure 4.17. Summary of model result for relation between transition tendency and advantage of close innovation in bio-pharmaceutical firms

The purpose of this study was to investigate the factors affecting the transition of innovation type during the final stage of product development. Structured interviews were conducted with 6 firms: 3 large and 3 small. At first, based on structured interviews for the biochip industry, the factors were elucidated for the product development stage, knowledge, product innovation stage, and government approval stage. We found that the transition tendency to close innovation affects the profit of firm as the perception of advantage of close innovation. Based

on the above relations, the model for the transition tendency to close innovation during final stage of product development was proposed for the biochip industry.

To test the generality and extend applications of the proposed model, the model to be used in the biochip industry was first applied to analyze the bio-pharmaceutical industry in Korea. The model was analyzed based on the survey data of 48 bio-pharmaceutical firms. However, the government approval stage in the model could be analyzed, since the number of respondents was only 20 (out of 48).

We found that the level of product innovation stage shows a positive relation with accumulated knowledge related to technology. If the level of product innovation stage is near commercialization, knowledge accumulation for product inside firm increases, meaning that the firm has sufficient knowledge for technology for commercialization of a new product. Our results demonstrate that the knowledge accumulation of technology has a positive relation with transition tendency to close innovation. As level of knowledge in firm becomes high and firm has sufficient knowledge for a new product, the firm wants to move to close innovation, since the firm does not need more external knowledge. Thus, closeness in innovation should be increased, meaning that the firm becomes less open to get external technologies. However, our results also show that, due to the intrinsic nature of bio-pharmaceutical technology products, the product innovation stage is not directly related to transition tendency to open innovation. As making a new drug, which is the main work of a pharmaceutical firm, is not generally an extension of a previous product, a new innovative product is not much related to knowledge accumulation in a previous innovative product.

The factors affecting the perception of advantage of close innovation and transition tendency were then investigated. It was found that the transition tendency to close innovation has a positive relation with the perception of advantage of close innovation. If transition tendency and the perception of advantage are high, the firm starts to close and, consequently, gets less knowledge from external collaborator, meaning that the technology-sharing and -transfer from external partner decreases. This means that, if the close innovation increases and open innovation decreases during the final production stage of a new product, the decrease of operating cost, expense for collaboration, cost for management of open innovation, and royalty payment can be achieved and, thus, various perceptions of advantages of close innovation can be obtained. If transition tendency is too low and, due to this, the perception of advantage of close innovation is low as well, the firm should continue to use the open innovation strategy.

Moreover, the increase of product development stage positively affects the knowledge of technology in firm and then the knowledge in firm has a positive relation with the transition tendency to close innovation. Thus, an increase of the knowledge due to the increase of production development stage causes an increase of the transition tendency, after which an increase of transition tendency causes an increase of the perception of advantage of close innovation (see Figure 4.17).

Since the problem with innovation improvement efforts is rooted in the lack of innovation strategy (Pisano 2015), the innovation strategy to effectively do innovation is urgently needed. Based on the results of this study, a strategy to manage open innovation in the final stage of new product development was suggested. At first, the current stage of product development for new product was carefully examined. If the level of product development stage becomes high, then the knowledge of technology in the firm should increase. The state of knowledge was carefully evaluated as to whether or not there is sufficient knowledge for final product in the firm. Then the firm should decide to decrease the open innovation activity with external research partner. As a second step, the decision to decrease or stop open innovation in the final stage of new product development should be made based on the consideration of status of accumulation knowledge of technology to close innovation and the perception of advantage of close innovation. If the amount of knowledge accumulation in the firm is high when commercial stage is achieved in firm, the firm wants to close the inflow of external knowledge, the transition tendency to close becomes high, and, thus, the firm should stop open innovation. If the transition tendency is within an acceptable range, the firm should decide to start close innovation with new external research partners, but most of collaboration with current external partners should be maintained to improve the current product or to modify the current product for new applications. If the transition tendency is too low, the firm should decide to keep current open innovation with new external partners.

As a third step, the decision to stop open innovation in the final stage of new product development should be made based on the consideration of both transition tendency to close innovation and the perception of advantage of close innovation. The balance between the expense to keep open innovation and profit of firm due to closeness should be considered and then the degree of close innovation can be decided upon based on the balance. To increase transition tendency to close causes the acceleration of reducing the degree of open innovation, as the perception of advantage of close innovation increases due to an increase of firm profit

and a decrease of collaboration expenses. The relations among knowledge, transition tendency, and the perception of advantage of close innovation should be simultaneously evaluated.

Taken together, the results of this study provide the following insights. Product development stage and level of knowledge in firm are key factors affecting transition tendency to close innovation, i.e. the degree of close innovation with external partners. Based on the insights about the relations of closeness with firm performance as the perception of advantage of close innovation, the decision to control the degree of close innovation should be made.

Chapter 5. Conclusions and Recommendations

5.1. Conclusions

This research has sought to establish management strategies for open innovation in new product development of biochip. The open innovation activity was analyzed according to three phases: (1) the switching phase, when open innovation starts in the initial stage of NPD; (2) the implementation phase in the middles stag of NPD; and (3) the transition phase, when open innovation changes into close innovation in the final stage of NPD. The factors affecting open innovation activity in each phase were evaluated and a model (based on the relation between factors) was proposed for each phase. The proposed models were then applied to analyze open innovation activity in the new product development of biochip. The models were evaluated by conducting surveys and analyzing their results in the context of the Korea biochip firms. The models were shown to be well adopted for the open innovation activity in each phase. Other factors affecting openness in each phase were verified based on both the technology and the non-technology points of view. These achievements lay the foundation for further research on open innovation in the bio-pharmaceutical industry, which can help analyze open innovation in other high-tech industries in the future.

5.1.1. Management strategy for the switching phase of open innovation in new product development of biochip

The factors affecting the decision to start open innovation in the initial stage of new product development were investigated in this section. The switching cost refers to the cost for change from close innovation to open innovation. If the switching cost is high, firm is reluctant to enter open innovation. These factors relate to the switching cost (cost to start open innovation with new partner) by considering the perception of advantage of open innovation and how these affect the decision on whether or not to start open innovation. A model as proposed based on the relations of factors and then evaluated by conducting surveys of the Korean biochip firms and analyzing their results. We found that the switching cost has a negative relation with the perception of advantage of open innovation. If the switching cost is low and the perception of

advantage of open innovation is high, the firm starts to open and get knowledge from external collaborators, meaning that technology-sharing and -transfer from the current external partner (not a part of new open innovation for new product development) and internal research team decrease. If the current external partner already exists before NPD, the current external partner relates to production of old existing product and has knowledge for old product. Therefore, it is difficult to think of the current external partner as a partner of NPD in a newly starting open innovation in new precut development. If the switching cost is too high and the perception of advantage of innovation decreases due to the high switching cost, the firm will not want to open the technology flow between inside and outside. The trust to the current external partner, as well as the level of research capacity in the firm, is found to influence the switching cost. Our results demonstrate that the trust to the current external partner and the level of research capacity in the firm have is positively related to the switching cost.

Based on the results of the model, the following strategy to manage open innovation is suggested as following. The decision to start open innovation or not in the initial stage of new product development should be done based on the consideration of the switching cost and the perception of advantage of open innovation. At first, factors such as trust to the current external partner and the internal research capacity to affect the switching cost should be considered. If any of these is high, the switching cost is too high and, thus, the firm should keep the current external partner and internal research team in close innovation.

If the switching cost is within an acceptable value, the firm should decide to start open innovation with new external research partners. The relation with the current external partner should be reduced to reduce the switching cost. The research capacity should be reduced by reducing the number of researchers or Ph.D. level researchers, which causes a decrease of the switching cost. However, the internal research capacity should be kept over the medium level, since the internal research capacity affects the performance of open innovation activity. Internal research team with a good research capacity can efficiently manage the technology transfer from the outside. Due to reducing the switching cost, the perception of advantage of open innovation increases, which leads to an acceleration of implementation of open innovation.

The results of this study suggest the following insights. The current internal research capacity and external partner are important factors that inform the decision to start open innovation by introducing new partners. Based on the insights about the relationship between the current situation (research capacity and presence of external partners) and the switching cost and

between the switching cost and the perception of advantage of open innovation, the decision of the firm to start open innovation should be made. It can be concluded that the switching cost and the perception of advantage of open innovation are used to decide whether or not to start an open innovation activity in the initial stage of NPD.

5.1.2. Management strategy for implementation phase of open Innovation in new product development of biochip

In this section, the factors controlling the degree of openness in the middle stage of new product development were investigated based on the technology characteristics, technology novelty, and technology complexity in this section. The model was proposed based on the relationships of a certain number of factors and then was evaluated by carrying out surveys in the Korean biochip firms. We found that the technology novelty has a positive relation with openness in new product development. If the technology novelty is high and thus new product is a very creative one, the degree of open innovation should be increased, meaning that the firm should become more open in order to get more external technologies. We also established that technology complexity is not directly related to openness due to the intrinsic nature of the biochip, which is a very complex technology-based product.

The factor affecting the change of firm's technology capability was then investigated together with openness affecting the firm's technology capability in new product development. We saw that the openness has a positive relation with firm's technology capability. If openness becomes higher during production of a new product and the degree of open innovation increases, then more external technologies flow in the firm. Consequently, the technology capability related to design and production of new products is increased. More openness and a higher inflow of external technologies cause an increase in the technological capability of the focal firm.

The factors affecting firm's performance were also investigated. We found that the firm's technology capability shows a positive relation with firm's performance. If the firm's technology capability due to openness increase is increased during NPD, then a higher increase of revenue, operating margin, competitive production cost, number of newly developed product, and royalty income should be achieved and, consequently, the firm's performance is increased. Thus, an increase of openness causes an increase of technology capability in firm; then an increase of technology capability in firm causes an increase of firm performance.

Based on these results, a model of the strategy to manage open innovation during implementation of open innovation was suggested. At first, the novelty of technology for new product was carefully examined. If the technology novelty is high, the degree of open innovation should be increased. If the technology novelty is very low, the firm should decide to decrease the open innovation activity with external research partner. The results suggest that the technology complexity is not related to the degree of open innovation and openness.

As more open innovation is implemented due to novelty, more technologies flow into the firm. By controlling the degree of open innovation, the technology flow can be controlled, which, in turn, controls the technology capability of firm to produce new products. As a second step, the degree of open innovation is decided upon based on the level to which firm wants to increase its internal research ability. Then, an increase of the research capability of the firm causes an increase of firm's performance, which, in turns, increases profitability. As a third step, the balance between the expense of open innovation and profit of firm due to openness should be considered and then the degree of open innovation should be decided upon based on the balance. The relations among openness, technology capability, and firm performance should be simultaneously evaluated.

Therefore, it can be concluded that technology characteristics and technology capability of the focal firm are key factors to decide on the degree of openness with external partners. Based on the insights of the relations between openness and firm performance (evaluated from the technology point of view), the decision to control the degree of openness should be made.

In this study, which is based only on technological considerations, the technology is the center to the value offering. It determines openness and firm's performance. However, in the real world, to increase firm performance, there are other sources of opportunity, such as organization, environment, market, business model, and expansion to other products. Of note, these factors are interdependent (Henderson et al. 2016). The process for creating a new product starts with technology, from which we create value, but ends with market – the source of need and place where we realize value (Henderson et al. 2016). Therefore, to develop a strategy for open innovation, the variables outlined above should be considered together with technology. Consequently, non-technological factors such as the market, organization, and environment should also be evaluated.

The factors affecting open innovation activity, such as institutional-, environmental-, and firm

characteristics, were investigated to enhance the technological innovation activity. Survey data of Korean biochip firms for open innovation activity were used for empirical verification. The results yielded by the analyses are as follows. First, the market competition and governmental support show a statistical positive relationship with the depth of open innovation activity. This result suggests that the firm enhances the collaboration with external partner due to the reinforcement of competition, in the case of the necessity of strengthening competency. Therefore, a firm under an industry group related to the high intensity of market competition focuses on the collaboration with the favorable external partners when the firm takes the open innovation strategy. Also, the firm focuses on collaboration with current collaborators if the government supports the firm more, meaning that the government supports the firm to enhance open innovation.

Second, the higher the number of doctoral researchers in R&D staff in a firm, the higher the depth of open innovation. This result is consistent with the results reported by Link and Bauer (1987) who suggest that the growth of the capacity of internal research promotes cooperation while maintaining core technologies. Therefore, it is necessary to increase the number of doctoral researchers in order to enhance the depth of open innovation activity while pursuing core competencies. Furthermore, as shown by our results, the quality of the researchers is more important than their number. In addition, there is a statistically significant (+) positive relationship between the amount of R&D investment and the breadth of open innovation. Due to a larger cash flow into the firm, more investment to find new partners and then more R&D investment to collaboration with external partners are needed. In the biochip industry where human resources in R&D are essential, it is necessary to continuously invest and expand human resources to increase the breadth of open innovation activity. Of note, governmental investment in the above environmental characteristic variables is used to increase the depth of open innovation, while the R&D investment is more related to the breadth of open innovation.

Third, the flexibility of organizational culture is found to be positively related to the depth of open innovation activity, and the openness of organizational culture is positively related to the breadth of open innovation. Therefore, it can be suggested that the firm should make an effort to increase the flexibility of its organizational culture. With this flexibility, it should be decided how to act to other external collaborators. In addition, an open organizational culture makes the firm to be more open in open innovation activity. Therefore, in order to establish a relationship with various external entities, at first, it will be necessary to make an effort to have openness in the organizational culture.

Fourth, our results also demonstrate that the presence of a dedicated group for open innovation proves to have a statistically significant impact and has a positive relation with the depth of open innovation activity. Thus, in order to achieve open innovation, the presence of a dedicated group in the focal firm is an important factor. If the research capacity of firm is higher than the level on which the firm can make commercial product by itself, it is strongly recommended to establish a dedicated group for open innovation in the firm to enhance open innovation activity.

The significance of this study and suggestions for further research are as follows. First, a survey for open innovation was conducted for a single industry group—the biochip industry, which was rare in previous research. Therefore, this study provides more detailed and accurate analyses through the research on open innovation activity in just one industry, which is characterized by a relatively small size, but nonetheless requires open innovation activity. Our results provide significant practical implications related to the strategy and implementation of open innovation. From the academic point of view, this study identifies and links influential factors in the model, which are then linked to the investigation of breadth and depth of open innovation activity.

Second, our study provides important implications for the strategy to be followed in open innovation activity. This strategy is based on the analysis of influential factors. From the practical point of view, the question whether or not to establish a relationship with new external collaborators is shown to be an important issue to be solved in a real industrial context. With regard to firm practitioners, our results offer a strategic choice for open innovation, since the effects of factors affecting the breadth and depth of open innovation activity are analyzed.

It can be concluded that the influential factors related with technology point of view and non-technology point of view are evaluated together to affect the degree of openness; furthermore, the management strategy for implementation of open innovation is proposed based on the relations among influential factors.

5.1.3. Management strategy for the transition phase of open innovation in new product development of biochip

The factors controlling the transition to close innovation in the final stage of new product development were investigated in this section. Structured interviews were carried out with 6

firms, 3 large firms, and 3 small firms. At first, based on structured interviews, the factors for innovation transition were elucidated as the product development stage, knowledge, the product innovation stage, and the government approval stage. Our results demonstrate that the transition tendency to close innovation affects the profit of firm as the perception of advantage of close innovation. Repetition of transition of innovation is therefore proposed based on the emergence of new innovative product. Based on the above relations, the model for the transition tendency to close innovation during the final stage of product development is proposed in the biochip industry.

To test the generality and to extend applications of the proposed model, the model constructed in the biochip industry was first applied to analyze the bio-pharmaceutical industry in Korea. The model was analyzed based on survey data of 48 bio-pharmaceutical firms. However, the government approval stage in the model could be analyzed, since only 20 out of 48 expected responses were obtained in the government approval stage.

Our results show that the level of product innovation stage shows a positive relation with accumulated knowledge of technology know-how and patents. If the level of product innovation stage is near commercialization, knowledge accumulation for product inside the firm increases, meaning that the firm has sufficient knowledge for commercialization of a new product. We also observe that the knowledge for technology for commercialization of new product has a positive relation with transition tendency to close innovation. As level of knowledge in firm becomes high and firm has sufficient knowledge for a new product, the firm wants to move to close innovation, since it does not need more external knowledge. Thus, closeness in innovation should be increased, meaning that the firm becomes less open to get external technologies. However, according to our results, due to the intrinsic nature of bio-pharmaceutical technology products, the product innovation stage is not directly related to the transition tendency to open innovation. Since making a new drug, which is the main work of a pharmaceutical firm, is not generally an extension of a previous product, the new innovative product is not much related to knowledge accumulation in the production of previous innovative products.

The factors affecting the perception of advantage of close innovation were then investigated and transition tendency to close innovation was found to affect the perception of advantage of close innovation in new product development. Our results show that the transition tendency to close innovation has a positive relation with the perception of advantage of close innovation.

If both transition tendency and the perception of advantage of close innovation are high, the firm starts to close and, consequently, gets less knowledge from external collaborators, meaning that the technology-sharing and -transfer from external partner decreases. Therefore, if the close innovation increases and open innovation decreases during the final production stage of a new product, the decrease of operating cost, expense for collaboration, cost for management of open innovation, and royalty payment can be achieved; as a result, various perceptions of advantages of close innovation can be obtained. By contrast, if both the transition tendency and the perception of advantage of close innovation are low due to low tendency, the firm should continue to keep the open innovation strategy. Moreover, an increase of product development stage positively affects the knowledge of technology and then the knowledge in firm has a positive relation with the transition tendency to close innovation. Thus, as times goes by, an increase of knowledge due to an increase of production development stage causes an increase of the transition tendency which, in turn, causes an increase of the perception of advantage of close innovation.

Based on the results of this study, we propose a strategy to manage open innovation in the final stage of new product development. At first, the current stage of product development for a new product should be carefully examined. If the level of product development stage becomes high, then the knowledge of technology in the firm should increase. The state of knowledge is carefully evaluated as to whether or not there is sufficient knowledge for final product in the firm. Then the firm should decide to decrease the open innovation activity with external research partners. As a second step, the decision whether or not to decrease or stop open innovation in the final stage of new product development should be made based on the consideration of the status of accumulation knowledge of technology to close innovation and the perception of advantage of close innovation. If the amount of knowledge accumulation in the firm is high in the commercial stage, the firm wants to close the inflow of external knowledge, the transition tendency to close becomes high, and, thus, the firm should stop open innovation. If the transition tendency is within an acceptable range, the firm should decide to start close innovation with new external research partners, but most of collaboration with external partner is kept to improve the current product to have a better performance or to modify the current product for new applications. If the transition tendency is too low, the firm should decide to keep current open innovation with new external partners. The product innovation stage related to the emergence of new innovative products by extension of the current new product should not be considered to decide on the transition tendency to close innovation, the

reverse of the degree of open innovation.

As a third step, the decision to stop open innovation in the final stage of new product development should be taken based on both the consideration of transition tendency to close innovation and the perception of advantage of close innovation. The balance between the expense to keep open innovation due to high transient tendency to close innovation and profit of firm due to closeness should be considered; thereafter, the degree of close innovation can be decided based on the balance. To increase the transition tendency to close causes an acceleration to reduce the degree of open innovation, because the perception of advantage of close innovation increases due to an increase of firm profit and a decrease of expense for collaboration. The relations among knowledge, transition tendency, and perception of advantage of close innovation should be simultaneously evaluated.

Taken together, our results demonstrate that product development stage and level of knowledge in firm are key factors to decide on the transition tendency to close innovation, i.e. the degree of close innovation with external partners. Accordingly, the decision to control degree of close should be accounted for based on the insights about the relations of closeness with firm performance as the perception of advantage of close innovation.

5.2. Perspectives and Recommendation for Further Research

In this study, three phases of open innovation were examined. In addition, the phases of open innovation were analyzed based on influential factors related mainly to the technology-point of view, though influential factors based on the non-technology point of view were found to be also very important in open innovation activities. Thus, in future research, other phases of open innovation (e.g. recruiting, evaluating, marketing, and so on), as well as an analysis focused on the non-technology point of view (e.g. marketing, environment, organization, firm culture, institutional characteristics, and so on) should be considered to better understand open innovation activities and to suggest appropriate management strategies for open innovation.

A new model to explain product development in the biochip industry is needed to increase our understanding of NPD. In addition, a new model for organization behavior on the macro level related to open innovation is needed to better understand open innovation activity on the

whole bio-pharmaceutical industry level. Concepts of such models are proposed in the following sections. In the future, if the analyses are performed based on these models and the models are validated, open innovation in high tech industry will het more comprehensively verified and, consequently, more effective strategies will be developed.

5.2.1. Recombinant technology model for new product development

If teach segment of technology characteristics for fusion technology are clearly understood by decomposition and the model to describe this action is made, the NPD for fusion product can be clearly clarified. When a new NPD product is made, if product technology for a product is very complex (see Table 3.4), it is difficult to predict which direction the research will go in.

To better understand the characteristics of fusion technology, an NPD process of biochip by decomposition is needed to develop relevant strategies that would enable the import of external knowledge in open innovation. Biochip, an innovative product in the biotechnology area, is made by the integration of various technologies. In new product development of biochip, a new model for technology generation can be developed by mimicking recombinant DNA technology. Such model can be called the recombinant technology model. The aim of this model is to develop a systematic combination of the techniques in the fusion technology area. The key technologies needed to develop products are decomposed into segments and are described as genes. The product development stages in the model can be related to influential factors, which can then be applied to develop the management strategy based on the characteristics of fusion technology.

5.2.1.1. Model formulation

The innovative product of fusion technology, like the biochip area, can be made by the combination of various technologies (see Table 3.4). The new model for technology generation based on recombinant DNA technology, called the recombinant technology model, was proposed here to develop systematical combination of the techniques in the fusion technology area. Assume that each technology to make biochip (see Table 3.4) is decomposed and then more than 30 kinds of technology characteristics are obtained. Let us define each technology as a gene, like a human gene to make the human body through gene translation and transcription.

Similarly to this process, key technologies needed to develop a product are decomposed into segments and are described as genes. The fusion of technology can be described as a recombination of each technique, called gene (see Figure 5.1). The original technology in biotechnology can be described as a full gene map. To make a product in nanobiotechology, the genes, i.e. techniques of biotechnology, should be changed by the foreign genes, i.e. the technique of nanotechnology. For example, protein has its reaction characteristics, but cannot be immobilized on a solid surface. That is original biotechnology character, called an original gene. If the nanoparticle is introduced into protein and the protein/nanoparticle hybrid is made, in which nanoparticle is introduced, it is called a foreign gene. By combing two technologies, a protein/nanoparticle hybrid is made and can be immobilized on solid surface, chip; therefore, we can make protein chip. Do a recombination of technologies is similar to making a protein chip.

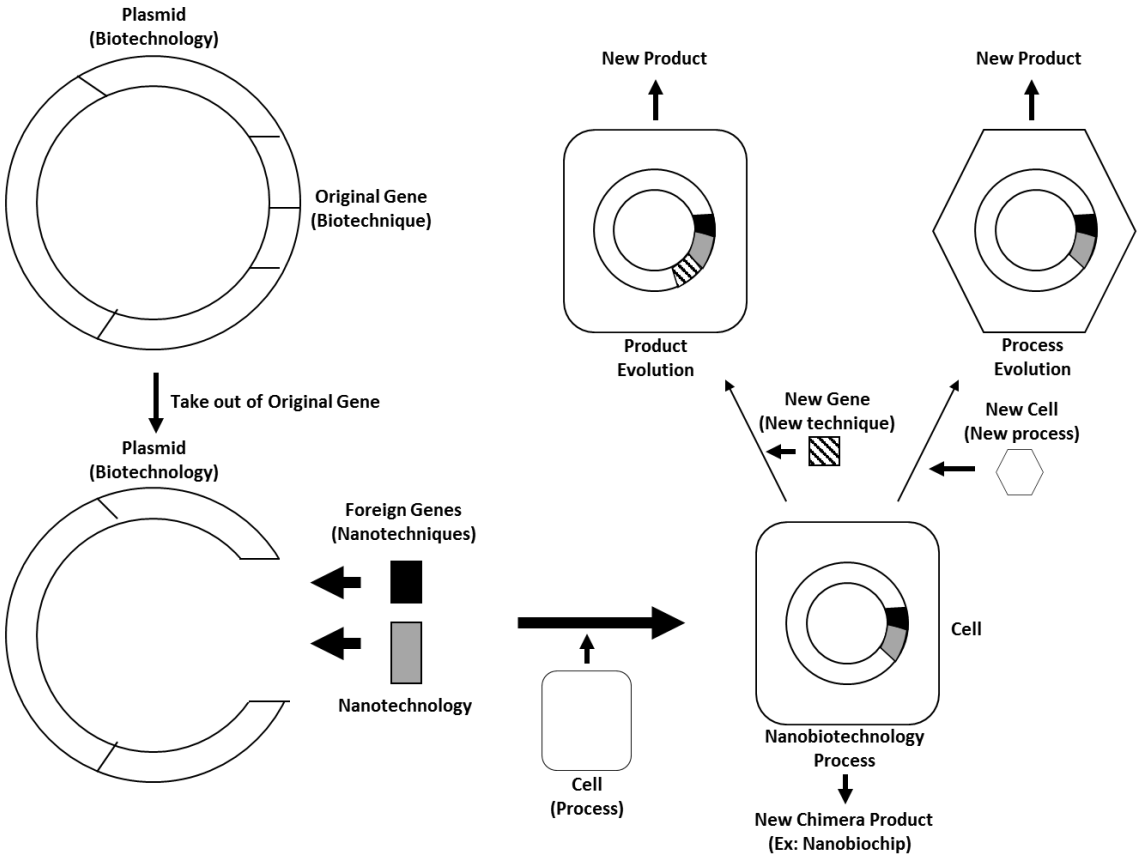

Figure 5.1. Recombinant technology model for NPD of biochip

After the new recombinant gene map for product is achieved, it should be processed in a manufacturing factory to produce products. In this case, the manufacturing factory can be thought of as a cell. For technology evolution as compared to other products, there will be two ways: a totally new product based on the new fundamental principle and a new slightly modified product through changing of the product manufacturing process. First, to design a totally new product, the gene map should be changed by the insertion of a new gene, i.e. a new technique. Second, by a slight change of the manufacturing system (called new cell), the modification of the product can be done, meaning process innovation. By these process evolutions, a new product can evolve from a slightly modified product or improved product.

The differences between the proposed model and previous concepts for technology development are as follows. Previously, the recombination of technologies has been thought of as an assembly of previous technologies (Hargadon 2003). In addition, the technology fusion was considered to be an equal combination of current technologies (Gassmann 2006). In recombinant technology, to achieve an innovative product, the insertion of outside technology to the fundamental core technology should be accomplished, in which the backbone technology concept is used.

For example, the technology for biochip can be divided into bioinformatics, biomarker development and production, surface immobilization of biomarker, reaction and detection technique, and microscale chip fabrication. For the production of biochip, the surface immobilization technique and the chip fabrication technique should be changed by the nanoscale immobilization and nanoscale chip fabrication, respectively. Insertion of a gene, i.e. two kinds of nanotechniques, into the original gene (i.e. biotechnology techniques) should enable for the production of biochip. Since biotechnology companies generally have only techniques for biochip, nanotechniques should be supplied from external resources so that open innovation could be applied to supply the nanotechniques to the biotechnology companies. To make more advanced products as the next stage, the new chip process technology, such as nanoimprinting, can be applied, which can be called the evolution of process innovation. Alternatively, making new products using the new detection- and fabrication- technology, such as the electrical detection in application of scanning tunneling microscope and nanogap electrode, should be applied for a lower detection range, which can be called as evolution of product.

5.2.1.2. Chimera open innovation process in nanobiotechnology

To achieve the distributed innovative product development, the strategy for the managing open innovation is needed in nanobiotechnology. Since the innovative product of fusion technology can be achieved through the recombinant technology method proposed in the previous section, the initiative work, such as design of fusion technology and decision of technology to be imported from external resource, should be done at first by internal source. Since the only use of external source from design of technique to accomplish the final commercial product can cause s loss of the core competency technique of company, the design of the fusion technique and assembly of collected techniques should be done by internal source, and thus the internal execution of part of core technique in original technology (see Figure 5.1) is recommended. We call this kind of the hybridization of internal source and external resources in technology development structure based on company initiative the chimera open innovation process. This process requires a change of organization, such as a structural change of R&D group and a cultural change to adapt a new idea from the outside is needed.

For a successful adaptation of innovative product development by the chimera strategy of open innovation in fusion technology, such as nanobiotechnology, the following structure is can be suggested.

(1) Idea of new product: The idea of a new product can be obtained from an internal or an external source.
(2) Design of technology: The core techniques should be segmented and analyzed based on the recombinant technology method.
(3) New organization: an Open Innovation Initiative R&D group (hereafter called OII) should be made that would design the product technology, collect the internal information in all R&D departments, distribute the ideas to the rest of the firm, and collect the technologies from external resources. OII would consist of members to be educated or trained in fusion technology, such as in different fields of engineering and science. All members should have knowledge for a business and market
(4) Formation of technology supply chain: OII should play the key role in designing the fusion technology, contact external resources such as lead users, customers, and other scientists for open innovation. To open innovation, the following strategies should be used. First, the OII meets lead users and technology developers, and then collects their ideas for a product. Second, a website for open innovation should be created. The

website would consist of two categories, the fully open system to receive the ideas and products of customer and external researchers, on the one hand, and the controlled open system to receive the response of the lead users and friendly experts by suggesting problems of firm and receiving the solution, as well as giving internal knowledge and information, on the other hand Third, OII would make national non-profit society for the firm's research field, creating open collaboration between external expert and other firms. For example, the national nanobiotechnology society should be made and the experts in that society would join open innovation to propose future technology breakthroughs with R&D groups of related firms. Fourth, the appropriate reward should be offered to external contributors. Fourth, OII should do the design of product technology based on the recombinant technology concept and decide which technique should be imported from external resources. Fifth, the collection of information and techniques from the technology supply chain should be done by push and pull. The continuous and stable technology supply would be needed to accomplish the development of innovative product.

(5) Product production: OII would control the recombinant technology in internal R&D groups. If the R&D of firm depends too much on external resources, the firm's own R&D capability may be weakened. Thus, OII should encourage the recombinant technology by giving other internal department's information and external information to internal members of new product development department. The manufacturing of product should be done based on the application of the recombinant technology to the manufacturing process.

(6) Future trend: The leading-edge technology for future should be encouraged and be evaluated for future asset by OII. The spin-off of false negative technology should be done by OII for the future unexpected success and collaboration. OII should regularly report to senior management group, including CEO, and the strategy change by CEO should be prepared based on the dynamic changes of the market and product due to open innovation.

Since the nanobiotechnology field is a fusion of biotechnology and nanotechnology; therefore, here, knowledge distribution should be recognized and the importance of knowledge integration should be considered. The interactive innovation between internal and external experts should become important, since the sources of knowledge are wide-spread and, unlike specialists in kits one technology, experts in fusion technology are rare. Thus, the innovation

in nanobiotechnology should be done based on the recombinant technology concept, network learning, technology supply chain, and combination of internal and external resources in the chimera open innovation circumstances. The innovative product development with hybridization of internal and external resources in technology development structure should play the key role in innovation in nanobiotechnology and other fusion technology markets.

In the future, the proposed recombinant technology model should be evaluated with structure interviews and surveys in bio-pharmaceutical industry so that to analyze open innovation in product development stage. The expected analysis results would yield relevant management strategies of open innovation in biochip, a product of nanobiotechnology.

5.2.2. Macroscopic organization evolution in bio-pharmaceutical industry by open innovation

As reported in section 1.5.1., the alliances between intra-biotechnology companies or biotechnology company-to-pharmaceutical firms are among the major factors to be considered for organization evolution in the biotechnology industry. Alliance is a major activity of open innovation. In the future, to construct the strategies for open innovation for a firm, the organization evolution related to alliances should be considered. In this section, a model for organization evolution is proposed based on the alliances among pharmaceutical firms and biotechnology firms.

The alliance including mergers and acquisitions (M&A) greatly affects the evolution and competitiveness of organization in the biotechnology industry. The alliance becomes just another cooperate reorganization strategy, since biotechnology companies continue to look for ways to accelerate growth and to gain access to sales and marketing talent and market, and large pharmaceutical companies are looking forward to ways to increase revenue, to expand their pipelines of products, and to obtain critical mass in R&D. In this study, the organization evolution in the bio-pharmaceutical industry, including pharmaceutical-and biotechnology-industry due to alliance, are examined.

The competition among major big pharmaceutical companies and biotechnology continues to exist. In addition, alliance in terms of licensing between major big pharmaceutical companies and biotechnology companies has been done. Thus, the organization evolution and competitiveness by the alliance among intra-pharmaceutical companies, among

pharmaceutical companies and biotechnology companies, and among intra-biotechnology companies should be analyzed together. The competition and collaboration among intra-pharmaceutical companies and intra-biotechnology companies are described in Figure 5.2.

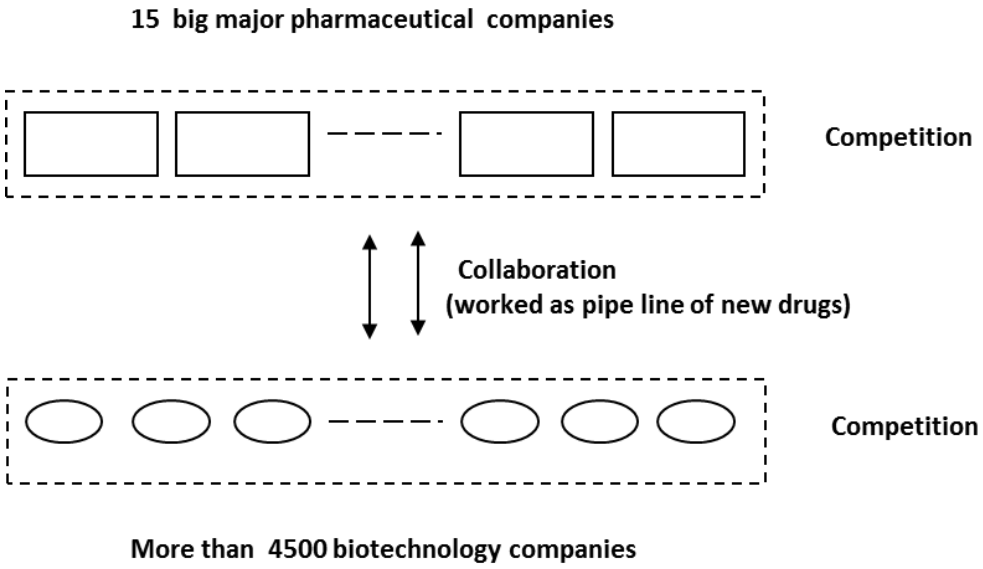

Figure 5.2. Competition and collaboration among major big pharmaceutical firms and biotechnology firms.

In this section, the macro-level relation in the entire big pharmaceutical companies and biotechnology is proposed (see (see Figure 5.3). Also, the organization revolution of biotechnology companies due to the reorganization by M&A among biotechnology companies should be elucidated based on alliance as mesoscopic relation. The microscopic relation the organization evolution of single biotechnology company should be explained based on technology-adoption cycle and entrepreneur-associated factors. Each macroscopic-, mesoscopic-, and microscopic relation affecting organization ecology has been analyzed by the proposition of various models.

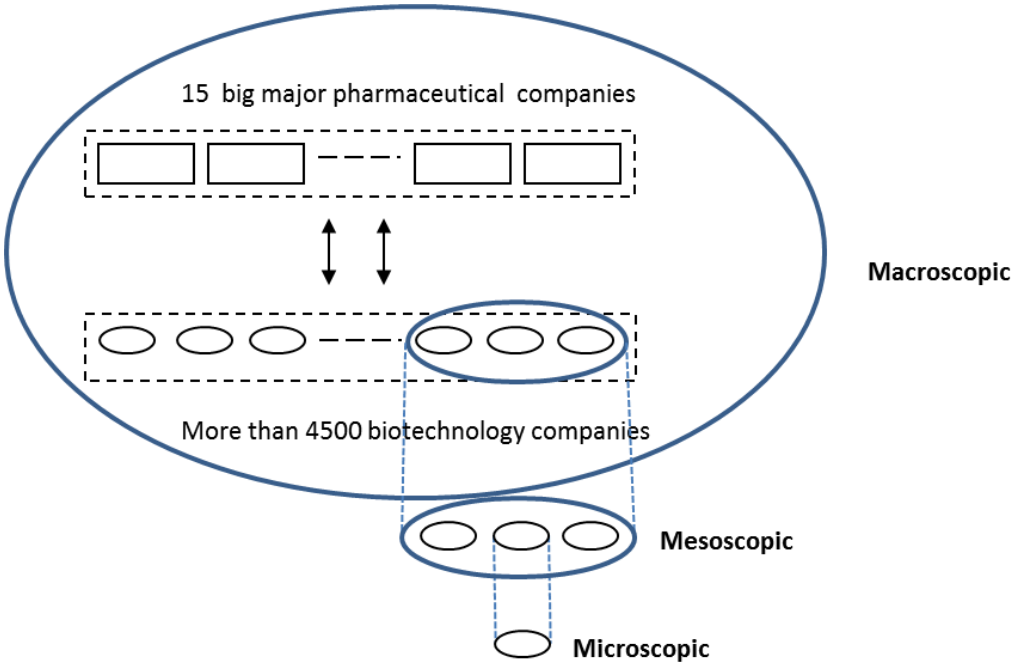

Figure 5.3. Relations among major big pharmaceutical companies and biotechnology companies.

In the future, the relationships in Figures 5.2 and 5.3 should be evaluated with structure interviews and surveys in bio-pharmaceutical firms so that to analyze open innovation on macroscopic level. The analysis results on the macroscopic level can yield relevant management strategies in open innovation for the entire bio-pharmaceutical level.

Bibliography

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International patent: 22, Domestic patent: 36

International book: 16, Domestic book: 8

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Award

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Korean Prime Minister Award for Nanotechnology (2016)

Korean Minister of Health and Welfare Award for Health & Medical Technology (2011)

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