The Signal of Post Catch-up in Open Innovation Dynamics

JINHYO JOSEPH YUN, XIAOFEI ZHAO, EUISEUB JEONG, SANGWOO KIM, KYUNGHUN KIM and SUNG DEUK HAHM

The digital transformation can serve as a window of opportunity for those late-comers who are equipped with the capability to create complementary assets for grabbing new opportunities of technological leapfrogging as a way of catch-up while penalising the forerunner. In this context, we want to answer the following research question. Is there any difference in open innovation effect on the firm according to the changing of belonging sectorial innovation system from catch-up to post-catch-up?

We statistically analysed the moderating effects of open innovation between catching-up, and the performance with the patents which were registered in United States Patent and Trademark Office, which were applied from China in telecommunication, from South Korea in Semiconductors, and from Japan in biotechnology on 1995–1999, and 2005–2009. We found three results from this study: first, from this research, as the signal of post catching-up, open innovation effects on the performance of firm, and the moderating effects of open innovation between catching-up, and the performance of the firm were found; second, the appearance of new dominant design after post catching-up was explained through the powerful open innovation and third, open innovation could be a useful new strategy for firms in the post catching-up to use.

Keywords: Catching-up, open innovation, dominant design, telecommunication, semiconductor, biotechnology

Research Question, Research Scope, and Research Method

With the mature of capitalism economy, several sectors of late industrialising counties are moving from catching-up, in other words, just follow-up of industrialised countries, to post-catching-up, so to say, producing new product or process

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innovation which had not appeared before. By the way, the role of open innovation as the trigger of motivating post-catch-up did not examined until now through enough researches. In this research, we want to examine the role of open innovation when a sector of any country moves from catch-up to post-catch-up. In east Asian capitalist economy, Korea, Japan and China had similar experiences of moving from catch-up to post-catch-up in different industries recently. For example, the biotechnology industry of Japan, semiconductor in Korea and telecommunication in China between 1990s and 2000s.

Research Question

With digital transformation, firms easily use open innovation strategy because the information on technology, know-how or new markets which are the key components of the open innovation strategy could be transferred easily, and enough through more diverse channels. As numerous firms use digital technologies to manage their innovation processes, innovation processes have become more open and require greater resources in different implementation phases to capture and transfer knowledge within and outside the firm's boundaries (Urbinati et al., 2020). And, if a firm arrives at post catch-up, it has to recombine diverse knowledge on technology, and markets that are outside the firm including international technology acquisition, market cultivation, product servicng, and so on, to develop creative new business model (Chen & Wen, 2016; Noh et al., 2019). The period of paradigm shift, in other words, digital transformation or the 4th industrial revolution, can serve as a window of opportunity for those late-comers who are equipped with the capability to create complementary assets for grabbing new opportunity of technological leapfrogging as a way of catch-up while penalising the forerunner (Lee et al., 2005).

In this context, we want to answer the following research question.

Is there any difference in open innovation effect on the firm according to the changing of belonging sectorial innovation system from catch-up to post catch-up?

By answering to this research question, this study could find out the relation between the level of catch-up of any sectorial innovation system, and the open innovation effects on the firms. If the open innovation effects on firms are different according to the catch-up situation of the belonging sectorial system, firms could find out different open innovation strategies according to the difference of sectorial innovation system even though in the same national innovation system or regional innovation system. This is because that catching up is a learning process that requires a long time and often differs significantly across economic sectors in the factors leading to success or failure (Malerba & Nelson, 2011). The leapfrogging is being accepted at the way of catching up in the sustainable development because leapfrogging remains highly relevant and promises to bring newly industrialising countries up to the level of advanced countries and propels them to lead in certain sectors, such as greening technologies that are in use today in Africa and elsewhere (Lee, 2019; 203, 04).

Table 1
Research Target Areas (or Fields) and IPC Codes.

Area, Field	*IPC Code*	*Country and Registration Year*
I Electrical engineering 3. Telecommunications	G08C, Ho1P, H01Q, H04B, H04H, H04J, H04K, H04M, H04N-001, H04N-007, H04N-011, H04Q	Applying from China Registration Year (1995–1999) + (2005–2009)
I Electrical engineering 8. Semiconductors	H01L	Applying from South Korea Registration Year (1995–1999) + (2005–2009)
III Chemistry 15. Biotechnology	(C07G, C07K, C12M, C12N, C12P, C12Q, C12R, C12S) not A61K	Applying from Japan Registration Year (1995–1999) + (2005–2009)

Research Scope and Research Method

Research team used 'new concept of technology classification' which had been updated on May, 2008 as the report of the world intellectual property organisation (WIPO) to connect the research area or field and international patent classification (IPC) code as follows, as shown in Table 1 (Schmoch, 2008). Our research team searched all the united States Patent and Trademark Office (USPTO) registered patents that meet the category and registration time by the "Gpass" database which belong to Korea Institute of Science and Technology Information (KISTI), a kind of public database (www.Gpass.kisti.re.kr) on November 2, 2021, which include patent database of United States Patent and Trademark Office.

This study used the regression-based statistical moderation analysis with patents data (Hayes & Rockwood, 2017). Moderation plays an important role in many social science theories such as the elaboration likelihood model of persuasion, cultivation theory, or the potential causes of knowledge gaps (Hayes, 2017, pp. 209, 210).

We used the most recent data, which could compare three sectors in different countries in the same two periods like Telecommunication of China in 1995–1999 and 2005–2009; semiconductor industry of South Korea in 1995–1999 and 2005–2009; and biotechnology industry of Japan in 1995–1999 and 2005–2009.

Literature Review, Research Framework, and Hypothesis

Literature Review

Patent Citation

Technology could be diffused from developed countries such as United States and Japan to less-developed countries such as Korea and Taiwan through patent (Hu & Jaffe, 2003). Patents citation as a technique for measuring the Knowle flow of information and innovation contains valuable data and if analysed well, may sometimes reveal concealed mysteries of the information flow between countries, laboratories, companies, and universities (Sharma & Tripathi, 2017). Patent citation counts have long been used to evaluate research performance or economic value even though it is also used as a way of prediction of emerging technologies based on analysis of the patent citation network, all of which are areas of bibliometrics (Érdi et al., 2013; Nicolaisen, 2007). Though the citations that appear in a patent (its 'backward' citations) inform us about the technological antecedents of the patented invention, conversely, the citations received by a patent from subsequent patents ('forward' citation) inform us about the technological descendants of the patented invention (Jaffe & de Rassenfosse, 2019). Because patent citations serve as an important legal function, since they delimit the scope of the property rights awarded by the patent, the applicant has a legal duty to disclose any knowledge of the 'prior art,' but the decision regarding which patents to cite ultimately rests with the patent examiner, who is supposed to be an expert in the area and hence able to identify relevant prior art that the applicant misses or conceals (Hall et al., 2001). Patent citations could also be used as the geographical localisation of knowledge spillovers in addition to measure of the value of innovations, or international knowledge flows (Jaffe et al., 1993; Jaffe & Trajtenberg, 1999).

Open Innovation at the Context of Catch-up

Firms can achieve better positions, depth, and scope of catch-up with higher efficiency in the open innovation era by succeeding in the capability reconfiguration with the efficient control of the cost of open innovation, in other words, complexity or transaction cost (Guo & Zheng, 2019; Yun et al., 2020). According to open innovation among industry laggards in the hybrid automotive Industry, partners in a horizontal open innovation coalition enter into formal cooperative agreements while retaining their focus on their individual payoffs even the open innovation alliance became the 'road not taken' (Cano-Kollmann et al., 2018). During the catch-up process in a developing economy, firms rely on open innovation in many industries because firms in a developing economy must collaborate with local, national, and international research institutes and companies to obtain knowledge and technologies that are necessary to improve their competitiveness (Ren & Su, 2015). For Korean medium-sized firms which are in post-catch-up, though, all three open innovation processes such as outside-in, inside-out, and coupled are useful for the developing technological capabilities, R&D intensity is negatively moderating the effects of open innovation of technological capabilities (Paik & Chang, 2015). According to 184 publicly listed firms in the Chinese telecommunication-equipment industry from 2009 to 2014, the positive association between recombinant reuse and innovation is strengthened by the high degree of R&D collaboration, which is a kind of open innovation method (Guo & Zheng, 2021). In the open innovation paradigm, intellectual property, specially patent could be new business model for the leaders such as IBM, Intel, Millennium Pharmaceuticals even though it could be useful open innovation channels for firms in catch-up (Chesbrough, 2003). By the complex interplay between technology entrepreneurs and incumbents, open innovation sometimes have to be conducted under conditions of high transaction costs (Christensen et al., 2005). Understanding the full benefits and possible limits of open innovation still remains a challenge to us (Bogers et al., 2019).

The Logic Catch-up

There could be three different patterns of catching-ups, path-creating catching-up like CDMA mobile phone in South Korea, path-skipping catching-up like D-RAM and automobile in South Korea, and path-following catching-up like consumer electronics, personal computers, and machine tools in South Korea (Lee & Lim, 2001). Catching-up economies are defined as those economies generating more rapid technological innovation than advanced countries such as those countries called the G7, the United States, Japan, Germany, the United Kingdom, France, Italy, and Canada (Park & Lee, 2006). Catch-up cycles which mean the changes in industrial leadership are based on three dimensions of windows of opportunity such as (1) changes in knowledge and technology, (2) changes in demand, in other words, demand-led catch-up such as China's green industries, and (3) changes in institutions and public policy, for example, appearing of private enterprises and favourable institutional conditions as determinants of well-functioning innovation system as a way of the transition from middle to high-income country in China (Landini et al., 2020; Lee & Malerba, 2017; Liu et al., 2017). International technology acquisition activities are diversified in post catch-up countries, relative to catch-up countries, with improvements of their internal capability among foreign direct investment, strategic alliances, research and development (R&D) cooperation, patent licensing, and so on specially from global production networks, knowledge diffusion and local capability formation (Ernst & Kim, 2002; Noh et al., 2019). For example, Multinational enterprise leaders, especially from china, have been aggressively catching up with global leaders, often by acquiring companies in advanced economies (Meyer, 2018). In fact, technological catch-up is not necessarily a prelude to post catch-up, depending on the nature of new innovation trajectory and entry modes of the emerging industry in the context of the importance of product servicing as a means of post catch-up, especially from the perspective of market cultivation (Chen & Wen, 2016). Catching-up is more likely to happen in technological classes with shorter technological cycle time and more initial stock of knowledge and that among those candidate classes the speed of catch-up varies depending on appropriability and knowledge accessibility (Park & Lee, 2006). Proactively constructed internal crises in catching-up in the case of Hyundai motor presented a clear performance gap shift learning orientation from imitation to innovation and increase the intensity of effort in organisational learning (Kim, 1998a).

Cases of Catch-up; Telecommunication of China, Semiconductor of South Korea, Biotechnology of Japan

In the telecommunication switch market in China during 2000, Direct import arrived at nearly zero share, but joint ventures, indigenous suppliers, and local suppliers had increased dramatically because the catching-up in the telecommunication industry occurred in China which was motivated by the trading market for technology, the knowledge diffusion from Shanghai Bell both to the R&D consortium and to Huawei, and industrial promotion by the government (Mu & Lee, 2005). Huawei which is the representative of the catching-up of China telecommunication industry, built its overall innovation capability ahead of core innovation capability in the catch-up process from latecomer to its transition towards global technological frontiers (Guo et al., 2019). In the process of technological learning and catch-up in the Chinese telecommunication industry, knowledge was gained by leveraging China's huge market to 'trade market access for technology'. And that indigenous firms must enhance the intensity of their efforts to assimilate acquired technologies so as to improve their technological capabilities (He & Mu, 2012). Specially, an uniqueness in the catch-up pattern of China can be attributed to its large size leading, for example, by Huawei, to bargaining power in technology transfer (Lee et al., 2017).

The semiconductor sectorial system is characterised by a variety of activities conducted by a variety of factors, including merchant semiconductor manufacturers, silicon foundries, vertically integrated producers, and fabless and design firms. Semiconductor (Macher et al., 2007) which is one of successful catch up of South Korea, requires factors affecting learning and catching as follows:

1. factor which is special for semiconductor such as policies supporting targeted R&D, and
2. factors that are similar across sectoral systems such as
   a. learning and capability building by domestic firms,
   b. access to foreign knowledge,
   c. education and human capital, and
   d. active government policy (Malerba & Nelson, 2011).

Korea semiconductor industry, specially the case of D-RAM of Korea can be considered as a stage-skipping catching-up that relied upon access to the external knowledge base in the form of licensing and overseas R&D outposts and took advantage of the mass production and investment capability of conglomerate firms (Kim, 1997; Lee & Lim, 2001). The 'selection and concentration' strategy in Korean semiconductor industry has contributed to Korean companies such as Samsung and SK-Hynix becoming global primary suppliers in semiconductor memory products in a short period of time, but has also resulted in limited product portfolios and an industrial structure concentrated on a handful of large firms (Hwang & Choung, 2014). According to the Korean experience including semiconductor, catching-up process as accumulative process of technology learning with three steps acquisition, assimilation, and improvement, moves opposite to the process of technology trajectory, like specific maturity, transition consolidation, and fluid emergence (Kim, 1998b). Through the dynamic process of acquiring a technological capability by technological leaning, Samsung Electronics has in only a decade leapfrogged from a mere producer of dynamic random access memory (DRAM) chips such as the heavy reliance on foreign suppliers for the 64K DRAM, and moved through dual approach for the 256K DRAM to internal competition and collaboration for the 1M DRAM before 2000 already (Kim, 1997).

Even though biotechnology may be distinguished by its high dependence on basic research in molecular biology, Japan has emerged as a significant competitor to the United States in biotechnology innovation nearly until 1990s by the turning to the United States as a principal source of basic research in biotechnology (Bartholomew, 1997). Because biotechnology was more dependent on basic scientific research than prior strategic technologies (e.g., semiconductors), and biotechnology catch-up policies required fairly broad reform in the national R&D system, Japan established 'Basic Policy Towards Creation of a Biotechnology Industry' on 1999, and set a target of 1,000 biotechnology start-ups by 2010; and The Japanese government installed a national biotechnology panel in July 2002 (Lehrer & Asakawa, 2004). But the positive attitudes to biotechnology in Japan after arriving in 1993–1997, had been declined in 2000 even though the support for biotechnology in Japan remained higher than United States or Europe (Macer & Ng, 2000). The identifiable collaborations between particular university star scientists and firms in Japan from 1989 to 1999 have a large positive impact on firms' research productivity, including the average firm's biotech patents by 34%, products in development by 27% and products on the market by 8% (Zucker & Darby, 2001). In 1995, Japan already arrived at one of three global regions of biotechnology activity with the United States, and western Europe (Greis et al., 1995).

Research Framework

The research framework of this study is given in Figure 1 based on the literature review. With the moving from the catch-up to post catch-up at the target sectorial innovation system, open innovation will appear because firms in the sectorial innovation system should search inside-out, outside-in or coupled ways to build up new creative business models which will be the engine of catch-up cycle.

We used the definitions of catch-up and post catch-up in the literature reviews such as catch-up means the following-up of the product or process innovation strategy of industrialised countries in the target sector. Post catch-up means the producing of new product or process innovation in the sector, which had not been appeared before by other industrialised countries.

In this study, the independent variable, which is defined as the level of catch-up, is measured by the total number of citations of the firm during the period. In patent, the citation means the learning and catch-up of the firm which is advanced in technology.

The number of family patents is used as the independent variable because the number of family patent is showing the prospect of the near future market growth of the technology.

As the open innovation, this study uses two variables, such as open innovation breadth of firm, and open innovation depth of firm. Open innovation breadth of

FIGURE 1

Research Framework.

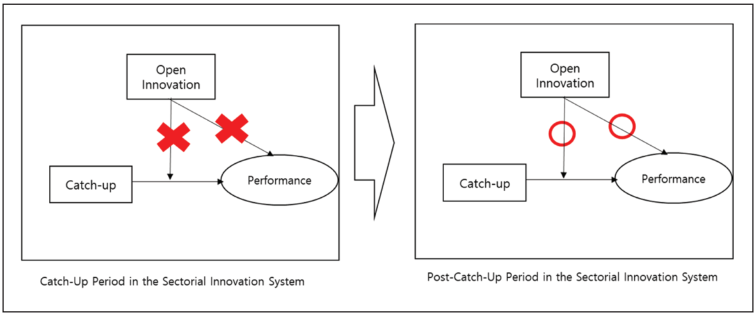
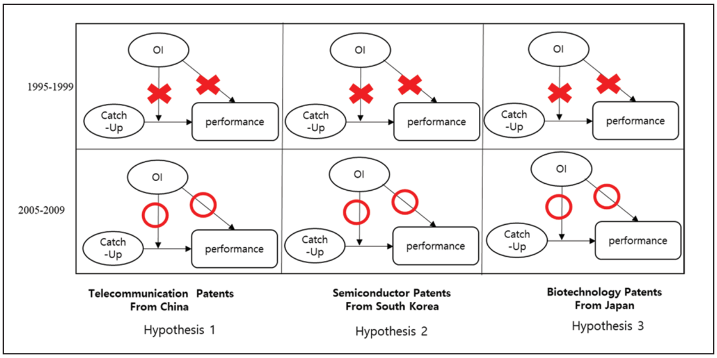


FIGURE 2

Hypothesis.



firm is measured by the ratio of co-applied patent among all applied patents by the firm during the period. Open innovation depth of firm is measured by the average number of co-applicants per patent by the firm during the period.

Hypothesis

Research team selected three sectors, such as telecommunication sector in China, semiconductor sector in South Korea, and the biotechnology sector in Japan, which are the example sectors of moving from catch-up in 1995–1999, to post catch-up in 2005–2009. And, from the research frame work, three hypotheses were built up as given in Figure 2.

H_1: In the telecommunication industry of China, even though the open innovation will not moderate the effects of catch-up on the performance in 1995–1999, it will moderate the effects of catch-up on the performance in 2005–2009.

H_2: In the semiconductor industry of South Korea, even though the open innovation will not moderate the effects of catch-up on the performance in 1995–1999, it will moderate the effects of catch-up on the performance in 2005–2009.

H_3: In the biotechnology industry of Japan, even the open innovation will not moderate the effects of catch-up on the performance in 1995–1999, it will moderate the effects of catch-up on the performance in 2005–2009.

In this study, if three hypotheses were proven, enough open innovation such as together in open innovation breadth, and open innovation depth could be used at the signal of post catch-up of any sector because in 2000s telecommunication of China, semiconductor of South Korea, and biotechnology of Japan were in post catch-up according to all related literature reviews.

Analysis

Open Innovation Effect in Telecommunication of China in 1990s and 2000s

Telecommunication patent of China in the United States increased dramatically from 33 in 1995–1999 to 5,988 in 2005–2009 as given in Table 2. In addition, the ROI, the open innovation breadth increased from 45.679% in 1995–1995 to 90.475% in 2005–2009. This means that nearly more than 90% of China telecommunication patents which were registered at USPTO during 2005–2009 are co-applied patents. This statistic meets the policy of China government in this period according to the literature review.

In addition, the IOI, the open innovation depth increased from 1.679 to 3.978, which means nearly four firms together applied patent in telecommunication of China when they apply at USPTO before 2005–2009.

According to regression analysis, in 1995–1999, there is no statistical acceptance in model (1), model (2) and model (3) all. This means that there is not any

Table 2
Patents in Telecommunications Which had been Enrolled in US Patent Office from China.

Year	*1995–1999*	*2005–2009*
Total number of patent(A)	33	5,988
Co applied (OI) Patent Number (B)	13	5,058
Number of Total Assignee (C)	52	21,327
Number of Total agents (D)	27	3,262
IOI = C/A = Open innovation Depth	1.679	3.978
ROI = B/A*100 = Open Innovation Breadth	45.679%	90.475%
Number of Total Citations	2,132	51,085
Number of Total Families	109	50,868

Notes: OI, open innovation; IOI, intensity of open innovation; ROI, ratio of open innovation.

Table 3

Analysis of the Changing of Open Innovation Effect in Telecommunication Patent from China between 1990s and 2000s.

			Technical Statistics			*Correlation Analysis*				*Model 1*		*Model 2*		*Model 3*	
Category			*N*	*Mean*	*SD*	*1*	*2*	*3*	*4*	*Std. Beta*	*p*	*Std. Beta*	*p*	*Std. Beta*	*p*
1995–1999	(IOI)	1. Performance (No. of Family)	27	4.037	5.118	1.000	–.274	–.173	.089						
		2. Catch-up (Citation)	27	78.963	119.549		1.000	.001	.432*	–.274	.166	–.274	.169	–.371	.119
		3. Open Innovation (IOI)	27	1.679	.824			1.000	–.569**			–.173	.379	–.045	.858
		4. Z Catch-up × Z Open Innovation	27	.001	.624				1.000					.224	.430
		R^2								***.075***		***.105***		***.130***	
		F								2.035		1.410		1.142	
	(ROI)	1. Performance (No. of Family)	27	4.037	5.118	1.000	–.274	–.012	–.168						
		2. Catch-up (Citation)	27	78.963	119.549		1.000	.244	.738**	–.274	.166	–.289	.166	–.365	.254
		3. Open Innovation (ROI)	27	45.679	49.913			1.000	.042			.059	.775	.073	.732
		4. Z Catch-up × Z Open Innovation	27	.235	1.035				1.000					.099	.746
		R^2								***.075***		***.078***		***.083***	
		F								2.035		1.022		.692	
2005–2009	(IOI)	1. Performance (No. of Family)	3262	15.594	59.949	1.000	.477**	–.024	–.590**						
		2. Catch-up (Citation)	3262	15.661	34.281		1.000	.062**	–.354**	.477	**.000**	.480	**.000**	.302	**.000**
		3. Open Innovation (IOI)	3262	3.978	2.270			1.000	.150**			–.053	**.001**	.031	**.023**
		4. Z Catch-up × Z Open Innovation	3262	.062	.820				1.000					–.487	**.000**
		R^2								***.227***		***.230***		***.431***	
		F								959.258**		487.207**		821.970**	
	(ROI)	1. Performance (No. of Family)	3262	15.594	59.949	1.000	.477**	–.058**	–.785**						
		2. Catch-up (Citation)	3262	15.661	34.281		1.000	.044*	–.257**	.477	**.000**	.480	**.000**	.297	**.000**
		3. Open Innovation (ROI)	3262	90.475	28.277			1.000	–.107**			–.079	**.000**	–.149	**.000**
		4. Z Catch-up × Z Open Innovation	3262	.044	1.422				1.000					–.725	**.000**
		R^2								***.227***		***.234***		***.720***	
		F								959.258**		496.824**		2787.955**	

Note: $*p < .05$; $**p < .01$.

moderating effect of open innovation in depth and breadth together between catch-up and performance. But in 2005–2009, model (1), model (2) and model (3) all have statistical acceptance value (Table 3).

So, to say, hypothesis 1 is accepted. In other words, at the telecommunication industry of China, even though the open innovation did not moderate the effects of catch-up on the performance in 1995–1999 in addition to the non-existence of the citation effect itself, the open innovation moderated the effects of catch-up on the performance in 2005–2009.

Open Innovation Effect in Semiconductor of South Korea in 1990s and 2000s

The semiconductor patents of South Korea registered at USPTO increased nearly seven times from 1995–1999 to 2005–2009 according to Table 4.

In open innovation breadth of semiconductor industry, co-applied patents which had been registered at USPTO in 1995–1999, and 2005–2009 by South Korea firms or agents increased from 33.359% to 87.453%. This means that nearly 88% of semiconductor patents which was registered in USPTO by South Korea firms and agents were applied together with other firms or agents in 2005–2009.

In the open innovation depth of semiconductor industry of South Korea, the number of co-applied firms or agents per patent increased from 1.492 in 1995–1999 to 4.286 in 2005–2009. Nearly 88% patents which were registered by South Korea semiconductor firms or agents at USPTO in 2005–2009, were applied by nearly five firms together.

Open Innovation breadth, or open innovation depth of South Korea semiconductor industry did not moderate the useful effects of catch-up on the performance in 1995–1999 according to Table 5. But the open innovation breadth and open innovation depth of South Korea semiconductor industry did moderate the useful effects of catch-up on the performance in 2005–2009 with statistically enough meaning like models (1), (2) and (3).

In other words, hypothesis 2 is accepted. In the semiconductor industry of South Korea, even though the open innovation did not moderate the useful effects

Table 4

Patents in Semiconductor Which had been Enrolled in US Patent Office from South Korea.

Year	*1995–1999*	*2005–2009*
Total number of patent(A)	3,844	26,321
Co applied (OI) patent number (B)	214	21,496
Number of total agents (C)	4,082	106,990
Number of total company (D)	148	7671
IOI = C/A = Open innovation depth	1.492	4.286
ROI = B/A*100 = Open innovation breadth	33.359%	87.453%
Number of total citations	87,264	258,121
Number of total families	24,846	210,147

TABLE 5

Analysis of the Changing of Open Innovation Effect in Semiconductor Patent from South Korea between 1990s and 2000s.

Category			*Technical Statistics*			*Correlation Analysis*				*Model 1*		*Model 2*		*Model 3*	
			N	*Mean*	*SD*	*1*	*2*	*3*	*4*	*Std. Beta*	*p*	*Std. Beta*	*p*	*Std. Beta*	*p*
1995–1999	(IOI)	1. Performance (No. of Family)	148	167.885	999.721	1.000	.955**	–.096	–.917**						
		2. Catch-up (Citation)	148	589.622	3241.003		1.000	–.075	–.941**	.955	**.000**	.953	**.000**	.575	**.000**
		3. Open Innovation (IOI)	148	1.492	.786			1.000	–.160			–.025	.319	–.116	**.000**
		4. Z Catch-up × Z Open Innovation	148	–.075	.634				1.000					–.395	**.000**
		R^2								***.912***		***.912***		***.922***	
		F								1508.008**		754.511**		567.122**	
	(ROI)	1. Performance (No. of Family)	148	167.885	999.721	1.000	.955**	–.106	–.911**						
		2. Catch-up (Citation)	148	589.622	3241.003		1.000	–.070	–.925**	.955	**.000**	.952	**.000**	.706	**.000**
		3. Open Innovation (ROI)	148	33.359	46.604			1.000	–.069			–.039	.111	–.075	**.003**
		4. Z Catch-up × Z Open Innovation	148	–.070	.728				1.000					–.263	**.000**
		R2								***.912***		***.913***		***.922***	
		F								1508.008**		763.411**		567.506**	
2005–2009	(IOI)	1. Performance (No. of Family)	7671	27.395	89.380	1.000	.469**	.004	–.242**						
		2. Catch-up (Citation)	7671	33.649	102.109		1.000	.090**	.428**	.469	**.000**	.473	**.000**	.705	**.000**
		3. Open Innovation (IOI)	7671	4.281	2.255			1.000	.038**			–.038	**.000**	–.038	**.000**
		4. Z Catch-up × Z Open Innovation	7671	.090	1.348				1.000					–.542	**.000**
		R^2								***.220***		***.222***		***.462***	
		F								2166.092**		1091.972**		2191.688**	
	(ROI)	1. Performance (No. of Family)	7671	27.395	89.380	1.000	.469**	–.040**	–.674**						
		2. Catch-up (Citation)	7671	33.649	102.109		1.000	.048**	.037**	.469	**.000**	.472	**.000**	.504	**.000**
		3. Open Innovation (ROI)	7671	87.453	30.598			1.000	–.147**			–.063	**.000**	–.170	**.000**
		4. Z Catch-up × Z Open Innovation	7671	.048	.973				1.000					–.718	**.000**
		R^2								***.220***		***.224***		***.728***	
		F								2166.092**		1107.695**		6832.242**	

Note: $*p < .05$; $**p < .01$.

of catch-up on the performance in 1995–1999, the open innovation has moderated the effects of catch-up on the performance in 2005–2009.

In addition to the increase of open innovation breadth, and open innovation depth between 1995–1999, and 2005–2009, there were effects of open innovation which moderate between catch-up and performance occurred in 2005–2009. This means that there was the qualitative change of the semiconductor sectorial innovation system of South Korea between 1995–1999 and 2005–2009 (Table 5).

Open Innovation Effect in Biotechnology of Japan in 1990s and 2000s

The biotechnology patents of Japan which were registered in USPTO dramatically increased from 3,518 in 1995–1999 to 9,776 in 2005–2009 as given in Table 6. In addition, the number of co-applied patent number and ratio between 1995–1999 and 2005–2009 also highly increased from 1,068 and 30.36% in 1995–1999 to 8,427 and 86.20% in 2005–2009.

Open innovation breadth or open innovation depth of Japan biotechnology industry did not moderate the useful effects of catch-up on the performance in 1995–1999 according to Table 6. But the open innovation breadth and open innovation depth of Japan semiconductor industry did moderate useful effects of catch-up on the performance in 2005–2009 with statistically enough meaning like models (1), (2) and (3).

In other words, hypothesis 3 was accepted. In the biotechnology industry of Japan, even though the open innovation did not moderate the useful effects of catch-up on the performance in 1995–1999, the open innovation has moderated the effects of catch-up on the performance in 2005–2009.

With the increase of open innovation breadth, and open innovation depth between 1995–1999 and 2005–2009, the occurring of effects of open innovation which moderate between catch-up and performance in 2005–2009, give us something new perspective (Table 7). There was the qualitative change of the biotechnology sectorial innovation system of Japan between 1995–1999 and 2005–2009.

Table 6

Patents in Biotechnology Which had been Enrolled in US Patent Office from Japan.

Year	*1995–1999*	*2005–2009*
Total number of patent(A)	3,518	9,776
Co applied (OI) patent vumber (B)	1,068	8,427
Number of total assignee (C)	6,150	43,180
Number of total company (D)	2,206	26,144
IOI = C/A = Open innovation depth	1.75	4.42
ROI = B/A*100 = Open innovation breadth	30.36	86.20
Number of total citations	77,812	55,217
Number of total families	48,478	176,445

Table 7

Analysis of the Changing of Open Innovation Effect in Biotechnology Patent from Japan between 1990s and 2000s.

			Technical Statistics			*Correlation analysis*				*Model 1*		*Model 2*		*Model 3*	
Category			*N*	*Mean*	*SD*	*1*	*2*	*3*	*4*	*Std. Beta*	*p*	*Std. Beta*	*p*	*Std. Beta*	*p*
1995–1999	(IOI)	1. Performance(No. of Family)	1061	45.691	143.717	1.000	.566**	–.090**	–.516**						
		2. Catch-up (Citation)	1061	73.338	300.208		1.000	–.113**	–.942**	.566	**.000**	.563	**.000**	.868	**.000**
		3. Open Innovation (IOI)	1061	2.771	2.625			1.000	–.180**			–.027	.295	.064	.194
		4. Z Catch-up × Z Open Innovation	1061	–.112	.643				1.000					.313	.032
		R^2								***.320***		***.321***		***.324***	
		F								499.225**		250.185**		168.907**	
	(ROI)	1. Performance (No. of Family)	1061	45.691	143.717	1.000	.566**	–.155**	–.494**						
		2. Catch-up (Citation)	1061	73.338	300.208		1.000	–.156**	–.895**	.566	**.000**	.555	**.000**	.572	**.000**
		3. Open Innovation (ROI)	1061	56.579	47.333			1.000	.001			–.069	.007	–.066	.014
		4. Z Catch-up × Z Open Innovation	1061	–.157	1.046				1.000					.019	.754
		R^2								.320		.325		.325	
		F								499.225**		254.707**		169.693**	
2005–2009	(IOI)	1. Performance (No. of Family)	5853	30.146	84.687	1.000	.802**	.076**	.765**						
		2. Catch-up (Citation)	5853	9.434	39.745		1.000	.061**	.665**	.802	**.000**	.801	**.000**	.524	**.000**
		3. Open Innovation (IOI)	5853	4.658	2.882			1.000	.021			.027	**.000**	.036	**.000**
		4. Z Catch-up × Z Open Innovation	5853	.061	1.405				1.000					.416	**.000**
		R^2								***.644***		***.645***		***.741***	
		F								10582.114**		5037.449**		5580.363**	
	(ROI)	1. Performance (No. of Family)	5853	30.146	84.687	1.000	.802**	–.024	.362**						
		2. Catch-up (Citation)	5853	9.434	39.745		1.000	.030*	.537**	.802	**.000**	.804	**.000**	.872	**.000**
		3. Open Innovation (ROI)	5853	92.192	25.653			1.000	–.235**			–.048	**.000**	–.080	**.000**
		4. Z Catch-up × Z Open Innovation	5853	.030	.470				1.000					–.125	**.000**
		R^2								**.644**		**.646**		**.656**	
		F								10582.114**		5344.021**		3724.016**	

Note: $*p < .05$; $**p < .01$.

Discussion

Summary of Analysis

According to this study, hypothesis 1, hypothesis 2 and hypothesis 3 are accepted as given in Table 8.

The Signal of Post Catch-up with Open Innovation Effect

According to the research result, the manifest signals of post catch-up are two: (1) the occurring of open innovation effect at the performance of firm and 2) the moderating effects of open innovation between catching-up and the performance of firm.

If we merge three effects: (1) the occurring of open innovation effects at the performance of firm; (2) the moderating effects of open innovation between catching-up, and the performance of firm and; (3) the effect of catching-up on the performance of firm, new dominant design could occur as shown in Figure 3. A (new) dominant design is more likely to emerge with 'weak network effects' in other words, high open innovation effects, and high research-and-development intensity in addition to weak appropriability, low product radicalness and so on (Srinivasan et al., 2006). Weak networks will be opposite to strong network effects with strong centrality, density or number of partners at repeated ties which are the base of existing dominant design (Soh, 2010).

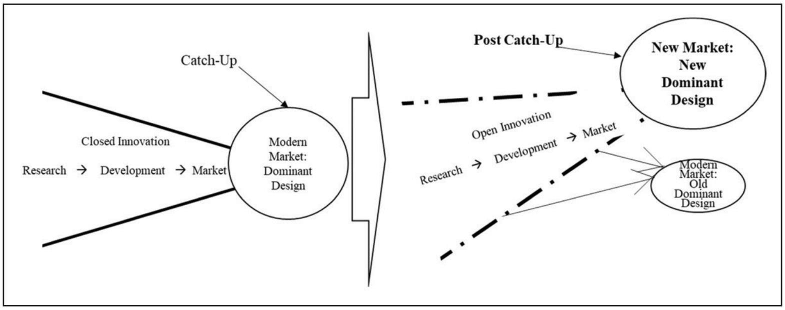
If any sectorial innovation system arrives at the post catch-up, open innovation effects motivate the emergence of new markets that are different from existing dominant design-based market as shown in Figure 3. And it could grow up as a new dominant design based major market with the effects of catching-up, and moderating effects of open innovation between catching-up effects and the permeance of the firm.

TABLE 8

Hypothesis	*Contents*	*Result*
Hypothesis 1	In the telecommunication industry of China, even though the open innovation will not moderate the effects of catch-up on the performance in 1995–1999, the open innovation will moderate the effects of catch-up on the performance in 2005–2009.	Accepted
Hypothesis 2	In the semiconductor industry of South Korea, even though the open innovation will not moderate the effects of catch-up on the performance in 1995–1999, the open innovation will moderate the effects of catch-up on the performance in 2005–2009.	Accepted
Hypothesis 3	In the biotechnology industry of Japan, even the open innovation will not moderate the effects of catch-up on the performance in 1995–1999, the open innovation will moderate the effects of catch-up on the performance in 2005–2009.	Accepted

Figure 3

The Signal of Post Catch-up with Open Innovation Effect.



To the firms in the post catch-up at the belonging sectorial innovation system as a early entrant, switching to the new dominant design could be associated with increased chances of survival and market share (Tegarden et al., 1999).

In other words, one of the best planning to catch the dominant design at the early stage of the sectorial innovation system could be to select powerful open innovation between dominant category and dominant design on time (Lee et al., 1995; Suarez et al., 2015).

The Relation Between Catch-up, and Open Innovation

According to the statistical analysis of this study given in Table 7, Biotechnology of Japan statically has the negative correlation in 1995–1995, and the positive correlation in 2005–2009 between open innovation and catch-up as shown in Figure 4.

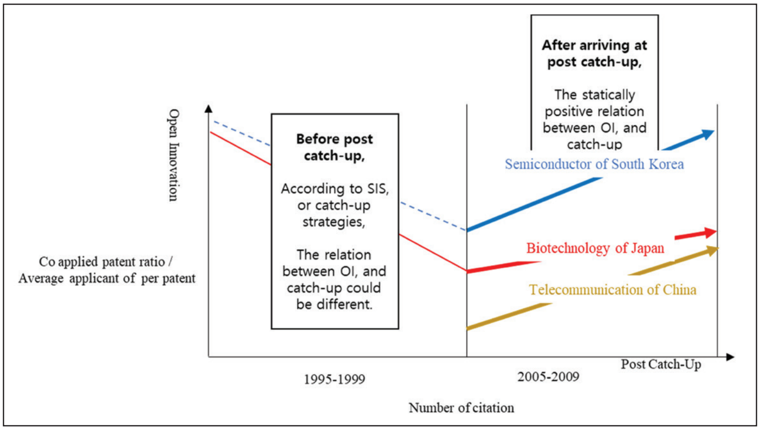
By the way, semiconductor of South Korea does not have any statistical correlation between open innovation and catch-up in 1995–1999 even though it has negative correlation according to Table 5 and Figure 4.

China did not have enough innovation activities which was measured by the registration of patents at the USPTO until 1995–1999 according to Tables 2 and 3, because during this period, just 27 agents including firms, universities, or national labs registered only 33 patents in USPTO. But during 2005–2009 telecommunication of China statically has the positive correlation between open innovation and catch-up like figure according to Table 3.

After arriving at post catch-up which is measured by the number of citations in the firm patent, the statistically positive correlation between open innovation and catch-up could occur according to our study results shown in Figure 4. From this result, if a firm is located at the post catching-up stage, 'active catching-up with active open innovation' could be the best strategy for firm in the post catching-up stage. But when any firm located in before post catch-up, the relation between open innovation and catch-up could be different along with the belonging sectorial innovation system or catch-up strategies of the firm as shown in Figure 4.

FIGURE 4

The Relation between Open Innovation and Catch-up.



Conclusion

Implication

Theoretically, this study tried to explain the relation between catching-up and open innovation. According to the research result, in the post catch-up stage, open innovation gives positive effects of firm performance in all three cases in 2005–2009 such as telecommunication of China, semiconductor of South Korea, and biotechnology of Japan. Most of all, open innovation gave positively moderated effects of catch-up which was measured by the number of citations on the performance which was measured by the number of family patent. In other words, open innovation could give positive effects of firm performance in the post catch-up.

Practically, this study shows the required strategy after catching-up of firms at the belonging sectorial innovation system, regional innovation system, or national innovation system. If any firm is in the post catch-up, it could find out new markets with new dominant design products by high investment in open innovation. In addition, enough open innovation will motivate the synergy effects between catching-up and open innovation as the early entrance of new dominant design. For example, Hyundai motors after arriving at the post catch-up, it is taking strong open innovation strategies such as buying Boston robotics, or investing in software company for autonomous driving nearly 5,000 million dollars to take the new dominant design in the new market of autonomous car market.

Limits and Future Research Target

Even though this study produced several valuable implications, there are several limits and future research goals. First, just two periods such as 1995–1999 and

2005–2009 are used to analyse the post catching-up effects of the telecommunication of China, the semiconductor of South Korea and the biotechnology of Japan in 2005–2009. So, as the next research targets, the serial analysis of three industries will show us the dynamic relation between catch-up, and open innovation. The panel data analysis of three sectorial innovation system will give us the chance to prove the finding of this results and give additional implication.

Second, this study just analysed the statistical relation between catching-up and open innovation. The real and concrete relation between catching-up and open innovation should be examined by case studies. Not just the statistical relation between catching-up and open innovation, but the dynamic relation in the market between catching-up, an open innovation at the firm level which is analysed by a case study with deep interview, and participatory will produce several new findings that have high value in theorical and practical together.

Third, according to the catch-up circle, the correlation curve could be changed. In addition to the U-curve, the change of relation between open innovation and catch-up should be analysed. In other words, the open innovation circling with the dynamics of catch-up should be studied as one of the next research targets.

DECLARATION OF CONFLICTING INTERESTS

The authors declared no potential conflicts of interest with respect to the research, authorship and/or publication of this article.

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