

Organizational Strategy for Technology Convergence

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Abstract—The purpose of this article is to identify the practical strategies of R&D (research and development) entities for developing converging technology in organizational context. Based on the multi-assignment technological domains of patents derived from entire government-supported R&D projects for 13 years, we find that technology convergence is likely to occur when a university solely develops technology or when university develops technology as one of the collaborators. These results reflect the important role of universities in developing converging technology

Keywords—Interdisciplinary; Research and development strategy; Technology convergence

I. INTRODUCTION

A number of scholars have emphasized the importance of convergence and interdisciplinary research [1]–[3]. Managers and researchers on R&D fields also strongly perceive the importance. For instance, since 1980s, a number of firms' strategic plans have involved considerations regarding technology convergence [4], and more than 80% of surveyed Spanish researchers use knowledge and techniques from other techno-scientific domains [5]. Furthermore, more than half of the knowledge on academic journals is interrelated with other techno-scientific domains [6].

Despite this important background, it has not been fully clarified why R&D entities combine knowledge from different fields and what conditions promote technology convergence. Several scholars speculated the factors of convergence through heuristic approaches [7]–[8] and elucidated the social barrier of mingling with other R&D entities in different techno-scientific domains [9]–[10]. Conspicuously, some empirical research demonstrated the individual propensity of participation in interdisciplinary research through survey [11]–[12]. However, few previous studies empirically demonstrate how the characteristics of R&D entities affect the advent of technology convergence.

Complementing the unrevealed research agenda, the study demonstrates the practical strategies of R&D entities on the entry to technology convergence, mainly to technology convergence between distinct macro techno-scientific domains.

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While programs for encouraging technology convergence are in serious doubts concerning their effects [13]–[14], identifying where, how, and whether convergence occurs and investigating how it could be fostered may widen understanding of convergence, thus giving implications for policy-related and managerial issues on calling technology convergence forth at greatest possible rate.

The remainder of the study is organized as follows. The next section briefly discusses the definition of technology convergence. The article then introduces the way of measuring technology convergence and the heuristic framework of convergence between techno-scientific domains and, in turn, formulates hypotheses. The description of the data and the empirical methodology are followed by a discussion of the results and overall conclusions.

II. THEORETICAL BACKGROUND AND HYPOTHESES

A. The definition of technology convergence

Convergence, in a strict sense, differs from “fusion” coined by [15] and “interdisciplinarity” as commonly used in the field of academic research [16]. The primary difference from fusion is that fusion creates a sub-segment in the same spot as a parts of the original segments whereas convergence dose create a new spot [17]. As for interdisciplinarity, it only characterizes integration at a discipline level [16]. Nevertheless, those terms conceptualize the similar concepts to that of convergence in a wide standpoint of interchangeability. In addition, the terms usually appear to not to be discerned at all [17].

The more important thing is what convergence merges and when it occurs. Along with the sequential process of the development of new products/services, convergence can be categorized into (i) science convergence that merges different scientific disciplines or areas, (ii) technology convergence that combines technologies of different application areas, and (iii) industry convergence that unites sets of companies with different technology bases, different application fields, and different target groups in different markets [17]. Namely, technology convergence occurs between discovery of scientific innovation and activity of commercial entity, but it is not exclusively isolated from those levels since it also evolves when scientific disciplines, technologies and/or markets have converged [17].

B. The measurement of technology convergence

Having the same interests as this study, several studies in science convergence focus on interdisciplinary between macro disciplines. Using citation analysis of journals in the six macro research domains, previous study found that interdisciplinarity between disparate disciplines has grown by 5% over 30 years, a much lower rate than that between neighboring disciplines [18].

By the discovery, they contend that most classifications of science and technology strongly intersect with each other and that the intersection between neighboring research domains leads to overstatement of the degree of interdisciplinary. Similarly, based on the multi-assignment of journals in macro subject categories, previous study found that the propensity of convergence varies by macro research domain and posited the importance of analysis of science convergence on a macro-level [6].

However, such bibliometric methods cannot be applied to this study without alteration, mainly because academic journals cannot represent technical and commercial knowledge and innovative activity. Instead, patent documents constitute an ample source to describe such knowledge [19] and to understand the linkages between industries, nations, or technologies in terms of technological innovations and knowledge flow [20].

Hence, we suggest an alternative means of measuring technology convergence, the mean that is based on multi-assignment of patent documents. The key issue of the measurement is how we can define the original source of technological knowledge as in the studies of science convergence. One of sensible ways of defining the base level of multi-assignment is to set sourced R&D projects as sources of techno-scientific domains, in the premise that technological knowledge is the result of R&D activities. Regardless of the different paths that eventually comprise technological emergence, an upwelling of technology accompanies a set of linked knowledge [8]. In fact, some scholars argue that convergence can also be gauged in terms of proposals or projects [21].

C. The drivers of convergence

The drivers of convergence have been discussed in the diverse perspectives, because the underlying activity (i.e. R&D) of convergence is performed in the various contexts. For that reason, scholars have paid considerable attentions to technological factors, institutional obstacles, and structural aspect such as assessment and funding problems, believing that those altogether affect the willingness to involve convergence and to determine successful convergence [10], [22]. Incorporating aforementioned factors and concerns, we review the drivers of technology convergence within organizational context and then develop hypotheses based on the context.

D. Organizational context in technology convergence

From an economics viewpoint, the incentive structure is one of the essential keys in influencing the knowledge production behavior of individuals and organizations [8]. As for creation of convergence, organizational context such as the institutional framework and the incentive structure actually can play as a deterrent to convergence research [8].

This rationale on the role of organizational context is primarily based on the assumption that each organization owns heterogeneous intangible and tangible resources [23]. The way of distinguishing organizations by the resources may vary, but scholars generally categorize organization related to R&D activities into university, industry, and government within the understanding of the national innovation system [24].

Similarly, Korean R&D entities tend to be categorized into university, industry, and government research institute; in addition, the characteristics of each sector differ [25]–[26]. In general, universities take a role in discovering new scientific/technological knowledge, and government research institutes focus on the adaptation of advanced technology and development of applied technology in order to introduce to the industry. Contrary to these public research institutes, private firms, i.e. industry, concentrate on developing technology for their own use [26].

When venturing into the development of converging technologies, the ultimate risk that each sector has to take varies largely due to the differentiated purposes and the innate characteristics by sector. Firms have to carry out and pay for commercial activities such as marketing and manufacturing after the development of technology; some developed technologies can be transacted in the market for technology, but the amount of the transaction is at best marginal. In addition, the major outputs for assessment of technology development at universities such as patents and academic papers turn out visible within a short period, whereas the practical outputs for firms such as cost reduction, growth in sales, and market penetration [27] become recognizable not within short period [28]. In this regard, the potential risk in technology development to firms surpasses that to other sectors [29], so firms are more precautionous about R&D activities than other R&D entities are [30]. Furthermore, when participating in government-supported R&D programs, firms tend to be reluctant to develop technology that contains high risk with high potential return, because of bureaucrats' excessive obsession with the R&D outputs and unpredictable policy change [31].

Since converging technologies primarily contain high risk [32]–[33], firms could be relatively reluctant to develop converging technologies, especially through government-supported R&D programs. On the contrary, universities and government research institutes would have less risk in developing converging technologies than firms would, because few significant deterrents to technology convergence for researchers in public research institutes exists.

Accordingly, we can hypothesize the strategic behaviors of firm, university, and government research institute to the development of converging technologies when each solely copes with it, as the follows.

Hypothesis 1-1 Firms are less likely to develop converging technology.

Hypothesis 1-2 Universities are more likely to develop converging technology.

Hypothesis 1-3 Government research institute are more likely to develop converging technology.

On one hand, organizations, especially firms, tend to adopt a collaboration strategy when confronting a risk-involved problem, e.g. R&D activities [34]–[35]. This phenomenon is understood upon the resource-based theory suggesting that an organization is considered a portfolio of own competencies.

According to this theory, an organization attempts to collaborate with the partners whose resources are mutually complementary [36]. This is because diverse technological competencies are required for the firms' success, but the accumulation of technological competencies accompanies risk: the uncertainty of commercial success and the high potential cost [37]–[38]. Therefore, firms implement a strategy of collaboration in order to reduce their risk by sharing it with their partners, and such a strategy has widespread by the name of R&D network [29]–[30], [38], since it improves the outcome of technological innovation [39]–[41].

In this context, firms tend to collaborate with public research institutes (e.g. university and government research institute) when undertaking explorative R&D activities, such as R&D activities for the radical product innovation [25] and for the penetration to another market [42]. It is because such collaboration provides firms with the newest scientific and technological knowledge as well as relevant labor at a low cost from public sector [42]. Furthermore, it provides the opportunities of seeking new technological paths as well [43] and eventually improves the sourcing firms' outcome [44].

Likewise, opting against sole R&D activities, firms can be motivated enough to collaborate with public research institutes in developing converging technologies, since converging technologies highly contribute to the forming of cross-market entry incentives [45] and entail high risk for firms in the development process [33]. Moreover, on the side of public research institutes, no significant deterrent factors for such strategic collaboration would exist, since such collaboration also benefits the researchers of public research institutes in terms of acquisition of potential licensees: that is, the researchers can lessen the concerns of seeking licensee [33], and the licensing incomes will financially benefit them afterwards.

In addition, it is sensible that government research institutes would desire to collaborate with universities in developing converging technologies, in that the resources of universities are worth even for that government research institutes. For the adaptation of advanced technology, government research institutes would need a source that provides new scientific/technological knowledge, and universities play the role of source in general. Such new scientific/technological knowledge may give more unique and novel possibility of merging another technology to government research institutes. Universities can also find fruitful opportunities for exploring potential applications of own technologies; thus, collaboration with government research institutes would be beneficial for them as well.

Hence, in summarizing the aforementioned proposition, we can surmise as the follows.

Hypothesis 2-1 Firms are more likely to develop converging technology in collaboration with universities.

Hypothesis 2-2 Firms are more likely to develop converging technology in collaboration with government research institutes.

Hypothesis 2-3 Government research institutes are more likely to develop converging technology in collaboration with universities.

III. DATA AND METHODOLOGY

A. Data sources

In order to demonstrate the strategies of developing converging technologies in practice, we employ data from the National Science and Technology Information Service (NTIS) that contain the information about the features of wholly government-supported R&D programs and their outputs. Researchers who undertake any government-supported R&D project ought to register the R&D output such as patents as an output from R&D activities.

This novel database with vast time span and technological domains makes it possible for us to reveal the generalized strategies of R&D entities for technology convergence, especially the R&D entities using public R&D resource. As of 2010, the total number of patents that resulted from government-supported R&D projects was 66,244, and the time span of patent application extends from 1997 to 2010.

In Korean case, the OSTI (Office of Science and Technology Innovation) also proclaimed Promising New Future Technologies (a.k.a. 6T) that consist of the six major technological domains for convergence: NT (nano-technology), BT (bio-technology), IT (info-technology), ET (energy-technology), ST (space-technology) and CT (culture-technology),¹ and entire R&D projects were classified into those domains [46].²

Among all the patents, some do not include proper information such as the macro technological domain (6T) and the identification code of associated project. In order to demonstrate the factors in the contexts suggested in our study, we exclude those patents; thus, the patents we employ in this study numbers 53,847 after all. Some patents have not yet been approved for registration by the Korean Intellectual Property Office (KIPO), but it is sensible that those can be understood as respective inventions from R&D activities and that some of those were still under review in the registration process; therefore, we do not exclude patents that do not have the registration number.

B. Variables and Method

The multi-assignment of sourced R&D projects for patents gives evidence of whether the produced technologies are convergent. At the time of planning R&D projects, researchers mark the macro-technology domain on which R&D projects are based and then submit the proposal to funding agencies.

¹ Unlike other technological domains, CT is of uncommon definition to other nations. CT denotes technology for cultural contents such as virtual reality, cyber-communication, and multimedia content.

² Projects that do not belong to any of the six domains are categorized as ETC.

Then, if accepted, they undertake the R&D projects. During or after the R&D activities, they register the produced patents with the information about what projects contributed to resulting in the patents.

Due to legal issues related to the ownership of patents and the distribution of profits such as licensing fee that results from the patents, researchers carefully refer to the contributing R&D projects to the patents with the ratio of the contribution. While some patents have multi-assignments of sourced R&D projects with homogeneous macro technological domain or only single-assignment, some other patents have multi-assignment of the sourced R&D projects with heterogeneous macro technological domains. The latter type of multi-assignment represents technology convergence since such type reveals that the researchers refer to and blend technological knowledge from heterogeneous technological domains; hereafter, we define such patent as a converging patent. We construct a dependent variable *Convergence* that is 1 if the patent is a converging patent and is 0 if not. The variables for indicating involved organizations in the development of technology are exclusively designated as the following dummy variables. For example, *Indu* indicates that industrial sector solely develops the technology without any collaboration with university or government research institute. Accordingly, only if industrial sector is solely involved in developing the technology, *Indu* is 1; otherwise, *Indu* is 0. In the same way, we set *Univ* for universities and *Gov* for government research institutes. For the collaboration modes, combination of the three sectors, i.e. *Indu-Univ*, *Univ-Gov*, *Indu-Gov*, and *Indu-Univ-Gov*, are composed with the same rule applied as in *Indu*.

One can argue that there could be difference between a single firm and an alliance of firms in terms of developing technology; surely, those are identically not same (Miotti and Sachwald 2003). However, we consider that the verge of organizational boundaries would better be the boundaries of sector for the analysis. While firms take the collaboration strategy to lower the costs and the risk in R&D activities, they tend to collaborate with public sector especially when high technological risk accompanies. Since developing converging technologies is perceived to contain high risk, we primarily distinguish the sectors (i.e. industry, university, government research institute) and focus on inter-sector collaboration.

In addition, some miscellaneous organizations that cannot be categorized as industry, university, or government research institute are observed; however, the number of patent invented by the organizations is very minimal (less than 3.3%), so that we do not construct a variable for such organizations.

The definitions of variables are summarized in Table I.

TABLE I
DEFINITION OF DEPENDENT AND INDEPENDENT VARIABLES

Variable	Description
Dependent variable	
<i>Convergence</i>	Dummy equal to 1 if the patent is attributed to the R&D projects that are assigned to heterogeneous macro technological domains; if not, 0
Independent variable	
<i>Indu</i>	Dummy equal to 1 if industrial sector is solely involved in developing the technology; if not, 0
<i>Univ</i>	Dummy equal to 1 if university sector is solely involved in developing the technology; if not, 0
<i>Gov</i>	Dummy equal to 1 if government research institute sector is solely involved in developing the technology
<i>Indu-Univ</i>	Dummy equal to 1 if industrial sector and university sector exclusively collaborate in developing the technology; if not, 0
<i>Univ-Gov</i>	Dummy equal to 1 if university sector and government research institute sector exclusively collaborate in developing the technology; if not, 0
<i>Indu-Gov</i>	Dummy equal to 1 if industrial sector and government research institute sector exclusively collaborate in developing the technology; if not, 0
<i>Indu-Univ-Gov</i>	Dummy equal to 1 if industrial sector, university sector, and government research institute sector collaborate in developing the technology; if not, 0

Table II reports the means, standard deviations, and minimum and maximum values of the independent and control variables, and Table III shows that there is no critical correlation between independent variables; thus, a serious multicollinearity problem would not occur.

TABLE II
DESCRIPTIVE STATISTICS

Variable	Obs.	Mean	Std. D.	Min	Max
<i>Indu</i>	53847	0.101	0.302	0	1
<i>Univ</i>	53847	0.167	0.373	0	1
<i>Gov</i>	53847	0.138	0.345	0	1
<i>Indu-Univ</i>	53847	0.229	0.420	0	1
<i>Univ-Gov</i>	53847	0.063	0.243	0	1
<i>Indu-Gov</i>	53847	0.137	0.344	0	1
<i>Indu-Univ-Gov</i>	53847	0.128	0.334	0	1

TABLE III
CORRELATIONS OF VARIABLES

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(1) <i>Indu</i>	1						
(2) <i>Univ</i>	-0.15*	1					
(3) <i>Gov</i>	-0.13*	-0.17*	1				
(4) <i>Indu-Univ</i>	-0.18*	-0.24*	-0.21*	1			
(5) <i>Univ-Gov</i>	-0.08*	-0.11*	-0.10*	-0.14*	1		
(6) <i>Indu-Gov</i>	-0.13*	-0.17*	-0.15*	-0.21*	-0.10*	1	
(7) <i>Indu-Univ-Gov</i>	-0.12*	-0.17*	-0.15*	-0.20*	-0.09*	-0.15*	1

* indicates significance at the 5% level.

In the empirical analysis reported below, we begin by estimating the probability of developing converging technology as a function of the variables featured in our hypotheses, along with the technological controls described above. Since Convergence is a dichotomous variable, we use probit analysis for this estimation [47]. The underlying algorithm for probit estimation is examined using the probit option on STATA 10. We also conduct additional models that vary in the variable set of the context and controls in order to explore for possible individual effects in the estimations.

IV. EMPIRICAL RESULTS

Table IV shows the empirical results. The coefficients of each variable are arranged in four individual models that have different set of the hypothesized contexts. The standard deviations of each coefficient are displayed in parentheses below each coefficient.

Overall, the results present the strong consistency in the estimated signs and significance, thus suggesting the robustness of our theoretical model for technology convergence

Hypotheses 1-1 and 1-2 are supported by the estimations, but Hypothesis 1-3 turns out to be opposed to the estimated results. Like private firms, government research institutes are unlikely to develop converging technology independently, whereas universities are likely to do so. One can simply surmise that government research institutes and universities shares a large portion of their characteristics in the name of public institute, however the results show that there is significant difference in the tendency toward the development of converging technologies between two representative public sectors. Similar mismatch is found regarding Hypothesis 2-2, while the results support Hypotheses 2-1 and 2-3 as expected; accordingly, Hypothesis 2-2 is rejected. That is, firms tend to collaborate with universities to develop converging technologies but not with government research institutes.

These results regarding organizational context show the important role of university in technology convergence while suggesting weak preference for government research institute as a partner for technology convergence or unremarkable influence of government research institute on technology convergence. Interestingly, the positive impact of university does not manifest in the collaboration mode that incorporates university, firm, and government research institute altogether (i.e. *Indu-Univ-Gov*); instead, the negative impact of firm and government research institute, which we find by the results related to Hypotheses 1-1 and 1-3 seems to dominate the collaboration mode.

TABLE IV
DEFINITION OF DEPENDENT AND INDEPENDENT VARIABLES

	Coefficient	Standard deviation.
<i>Indu</i>	-0.548 ***	0.054
<i>Univ</i>	0.279 ***	0.044
<i>Gov</i>	-0.212 ***	0.047
<i>Indu-Univ</i>	0.187 ***	0.043
<i>Univ-Gov</i>	0.347 ***	0.048

<i>Indu-Gov</i>	-0.579 ***	0.051
<i>Indu-Univ-Gov</i>	-0.233 ***	0.048
_cons	-1.376 ***	0.041
Number of obs	53847	
LR chi2(4)	1960.28	
Prob > chi2	0	

* p < .1, ** p < .05, *** p < .01,

Note: In each p significance level, (1-p) × 100 percent posterior probability interval excludes zero.

V. DISCUSSION AND CONCLUSIONS

A. Discussion and policy implications

In our framework based on the organizational context, this study answers the question: how does technology convergence occur? Based on the multi-assignment analysis of technological domains, we employed a novel and rich dataset, nearly complete enumeration survey on the technologies from government-supported R&D programs in Korea from 1997 to 2009. Overall, the empirical results above strongly support our framework with the exception of the explanations related to government research institute. To conclude, a useful way of summarizing our findings is to discuss their implications for increasing the opportunities for causing technology convergence and the extent to which policy actions can help this process. In this respect, our analysis produced the following main finding. Our major finding is the important role of university in technology convergence. While firm and government research institute tend to be reluctant or incapable for independently developing converging technologies, they are likely to collaborate with university for developing converging technologies. The empirical results show that firms' collaboration strategy for radical innovation [25], [30], can extend to the strategy of technology convergence for firms, thus strengthening the explanation about the important role of R&D entities' organizational context in leading technology convergence. This extended view suggests that policymakers better design proper incentive system for challenging attempt for technology convergence (e.g. financial support) and supportive system for further processes after R&D (e.g. aid in marketing and seeking consumers) in order to alleviate the risk from developing convergence technologies, especially for firms. An interesting question in this point is why government research institutes do not play a role like universities in technology convergence, whereas the boundaries of public research institute generally incorporate university and government-research institute (e.g. national lab in the US) in the belief of the homogeneity between two [30].

We can reason that the distinct pattern of Korean government research institutes in technology convergence is probably attributed to their local characteristics such as unstable funding structure and weak competitiveness, and inflexible research perspective. Korean government does not guarantee full funding for government-research institutes, so that for survival they have to compete with other R&D entities to gain R&D funding. A similar system exists in EU as well (e.g. Fraunhofer in Germany, VTT in Finland, and TNO in Holland).

However, while such European institutes obtain considerable funding from industry, Korean government-research institutes receive very little amount of funding from industry because of lack of industrial competency.

In fact, a survey of firms shows that they are much less likely to choose government research institutes than other firms or universities as partners for technology innovation, untrusting the competency of government research institutes [48]. Consistence with the survey, previous also suggests that researchers of government research institutes perceive lack of capability of and creativity for adopting new technologies due to the hierarchical organization system and the excessively inflexible research assessment [49]. Hence, in the extended understanding from the strategy for technology innovation, we can speculate that such insufficient capability could lead firm to choose university rather than government research institute as a partner of technology convergence as firm does for technology innovation. A remaining question is probably why the alliance of entire R&D actors (i.e. university-industry-government research institute) has a negative relationship with the occurrence of technology convergence. We can surmise that the organizational diversity increased by adding a different organization for collaborative research can also exacerbate creativity in the R&D process. The cultural and structural difference among sectors (i.e. university, industry, and government research institute) is enormous, and thus it diversifies each actor' goals as well [50]. Due to these differences, R&D entities in R&D collaboration with other sectors carefully and explicitly establish the aim of the R&D in order to minimize clashes caused by the differences [51]. This rigid approach could enhance the efficiency of R&D but could lower the potential creativity that leads to technology convergence.

The explanations from the case of government research institutes and multilateral collaboration give a hint for policymakers: stable funding, strong organizational competency, and appropriate diversity of research collaboration can help in leading to technology convergence; however, to support the hint may require additional extensive review and demonstration.

B. Limitations and further research

Our study has certain limitations. First, our novel and unique data set, which enables this study, presents a restricted view by dealing only with technology convergence between R&D projects. Presumably, technology convergence can occur within a scope that a single project covers, although it is often believed that technological knowledge evolves in the way that existing relevant technologies are put together from pieces.

This study can suggest certain directions for future research. First, the actual benefit from technology convergence at monetary level can be studied. A number of the studies on science convergence have already attempted to measure actual advantage of science collaboration by using citation analysis [52]. In this same way, citation analysis or assessment of patent quality can widen our understanding of the nature of technology convergence and the strategies of R&D entities.

Second, empirical and thorough demonstration of complementarity between technologies can follow our study. Previous research often observes the field-specific growth due to the complementarity between technologies through qualitative interpretation, thus empathizing the role of each technology in technology convergence [53]. Lastly, as mentioned in the limitations of this research, a study with more generic data in terms of regions and different approaches to technology convergence should follow to fortify the generality of our argument.

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