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Abstract

The anecdotal evidence has indicated that inter-organizational collaboration increases R&D productivity by providing access to outside complimentary assets for firms. Focusing on the length of time from launching R&D project to realizing its R&D outcomes, we call it innovation speed, this paper examines a prize data-set on industrial technology, including 434 award-winning R&D projects, and empirically examines the relationship between inter-organizational collaboration and innovation speed and explores how the relationship varies across different types of collaborations. After controlling time periods, technological areas, prize categories, and collaboration types, the data reveal that inter-organizational collaboration among non-business group firms is associated with shorter innovation speed. The curtailed time periods vary from 19.9% to 32.2% according to the models. However, such accelerated time periods are not observed in other collaboration types such as inter-firm collaboration and firm-academic collaboration.

1. Introduction

Traditionally, in-house R&D has been an important source of innovation and competitive advantage for firms (Chandler et al., 2001; Mowery, 1983). However, with the increasing complexity of technology, it has become impossible for firms to internalize all of the resources needed for in-house R&D (Powell et al., 1996). Thus, the previous literature on business collaboration has indicated that utilizing external information and resources gives firms an important competitive advantage (Chesbrough, 2003; Chesbrough et al., 2006; Freeman, 1991; Gulati, 1999). As the literature suggests, an increasing trend of collaborative inventive activity has been clearly observed in the R&D 100 Awards (Fontana et al., 2009). This trend has been observed in scientific organizations as well (Wagner and Leydesdorff, 2005).

While organizations collaborate with each other for various reasons and in various ways, this paper focuses on exploring the effects of collaboration on innovation speed. One of the reasons behind the collaboration lies in the expectation that a firm can significantly reduce time to market. The length of product life cycle has been decreasing (Qualls et al., 1981). Products are rapidly becoming obsolete in many industries. Supplying new products and marketing them aggressively became important (Gomory, 1989; Rosenaut, 1988). Saving time lowers costs by reducing man-houses and overhead as well.

While anecdotal accounts have indicated that collaboration actually accelerate innovation speed, the relationship between collaboration and innovation speed has not been empirically examined with systematically collected data. Exploring 434 award winning R&D projects from a prize data-set on industrial technology, the Okochi Prize, this paper empirically examines the association between inter-organizational collaboration and the length of time from launching R&D project to realizing its R&D outcomes, we call it innovation speed. It explores how the relationship varies depending of types of collaborations.

The empirical results reveal that inter-organizational collaboration among non-business group firms is associated with shorter innovation speed after controlling time periods, technological areas, prize categories, and collaboration types. The curtailed time periods vary from 19.9% to 32.2% according to the models. However, such accelerated time periods are not observed in other collaboration types such as inter-firm collaboration and firm-academic collaboration.

2. R&D Collaboration and Speed

The utilization of knowledge and resources outside the firm plays an important role in establishing competitive advantages (Chesbrough, 2003, 2006; Chesbrough et al., 2006). R&D collaboration can provide entry to a field in which the relevant knowledge is widely distributed and not easily produced inside a firm or obtained through market transactions (Chesbrough, 2003; Chesbrough et al., 2006; Powell et al., 1996). Inter-organizational collaboration is critical to supplementing the internal resources of an organization (Dodgson, 1993; Hagedoorn, 1993; Teece, 1986)and can provide access to complimentary assets for firms, building technological capability (Teece, 1986). Through the collaboration, an organization can share both knowledge and increasing R&D costs with its partners (Ahuja, 2000).

Inter-organizational collaboration in R&D has been discussed from various angles. For example, one line of discussion in R&D collaboration was conducted within the boundaries of the firm. Firms' choices between in-house and external sources of R&D are dependent on transaction costs, bargaining hazards, and appropriability concerns (Pisano, 1990). Another line of research explored how the increasing trend in inter-organizational collaboration in R&D occurred. This latter line of research necessarily examines the Bayh-Dole Act. The Bayh-Dole Act, which gave universities, small businesses, and non-profit organizations intellectual property control of their inventions, resulted from governmental funding; it is considered a primary stimulus of R&D collaboration in the U.S.(Henderson et al., 1998). However, the effect of the Bayh-Dole Act is debatable. The Bayh-Dole Act is only one of the factors stimulating university patenting and licensing activity, which in turn is only one of the important factors behind the increasing pattern of R&D collaboration; some universities were active in patenting and licensing before passage of the act (Mowery et al., 2001; Mowery and Sampat, 2001).

Many detailed case studies have explored how collaboration is formed, managed, and lead to high performance as well. For example, based on the case studies of the National Cooperative Program for Infertility Research and the TexAQS collaboration, the development of epistemic and organizational domain creates common incentives to collaborate and eliminates barriers via effective planning and management (Corley et al., 2006). The case of collaborations between private firms and Lawrence Livermore National Laboratory revealed that careful selection of projects for collaboration and the development of a good fit between project characteristics and the specific vehicle supporting the collaboration leads to the successful completion of the project objectives (Ham and Mowery, 1998). A longitudinal study of 65 biomedical scientists in a New Zealand university revealed that within-university collaboration and international collaboration are positively related to an article's quality (He et al., 2009). Faems et al. (2005) conducted an empirical study of Belgian manufacturing firms, which showed a positive relationship between inter-organizational collaboration and innovative performance measured by the composition of turnover, which is attributed to both new and improved products. This demonstrates that the impact of innovative performance differs depending on the nature of the partner involved. For instance, collaborations with customers and suppliers are associated positively with higher levels of turnover stemming from improved products, while collaborations with universities are associated positively with turnover levels related to new products.

These studies clearly suggest that collaboration plays an important role in increasing R&D productivity by utilizing external complimentary knowledge. However, how the collaboration influences innovation speed has not been well, even though the speed is one of the central motivations in forming inter-organizational collaboration.

Products are rapidly becoming obsolete in many industries. Supplying new products and marketing them aggressively became important (Gomory, 1989; Rosenaut, 1988). Therefore, Firms may license or buy technology from other organization. Firms may contract R&D organizations to develop new products or form inter-organizational collaboration. Previous literature suggests that time-saving can enhance product quality (Schmenner, 1988). The speed of innovation generally has been positively correlated with a products' quality, or the degree to which it satisfies customers' requirements (Clark and Fujimoto, 1991). Referencing updated knowledge can increase quality of invention (Nagaoka, 2007). Saving time lowers costs by reducing man-houses and overhead. A firm can reduce fixed costs and fully leverage R&D resources by accelerating the pace of R&D and commercialization (McEvily et al., 2004; Page, 1993). Shortening development time can allow a firm to spend extra resources to accelerate an innovation in the long run (Clark and Fujimoto, 1991).

Previous literature has suggested that greater use of external resources is associated with relatively faster product development (Chesbrough, 2003; Chesbrough et al., 2006; Kessler and Chakrabarti, 1996). It has indicated that relying on outside knowledge and utilizing external sources can shorten the length of the new products development process because a firm can focus more on its internal core capabilities (Gold, 1987; Venkatesan, 1992). Of course, it must be noted that external sourcing does not necessarily reduce innovation speed and development costs since external knowledge is tacit and not easily transferable (Kessler et al., 2000).

The extent to which inter-organizational collaboration can enhance R&D productivity and innovation speed has not been explored well empirically (Faems et al., 2005). Despite several case studies discussing inter-organizational collaboration and its effects, large-scale empirical evidence on the effect of inter-organizational collaboration on R&D is still scarce.

The primal reason for this dearth of evidence lies in the fact that collaboration can take various different forms ranging from one based on informal and personal ties to one based on formal organizational contracts (Katz and Martin, 1997). Patents allow examination of inter-organizational collaboration by exploring co-patenting. Academic papers published also allow investigation of inter-organizational collaboration by examining co-authorship. However, co-patenting and co-authorship do not necessarily cover inter-organizational collaboration because organizations do not always co-patent or co-author, even though they may jointly carry out R&D. Since several problems concerning intellectual property rights arise when a firm makes a cross-licensing contract, a firm tends to decide to patent developed technology in its own individual domain rather than co-patent. Moreover, even if inter-organizational collaboration can be identified by patenting and co-authoring, the time that organization spent for its R&D cannot.

European community innovation survey has changed its trajectory. Many studies have begun to investigate external sourcing motivation and its effects based on the European community innovation survey. For example, Investigating the response to the UK's version of the second European community innovation survey, Tether (2002) has shown that co-operation does not necessarily bring innovation straightforwardly (Tether, 2002). It has indicated that firms attempting to introduce higher level innovations tend to engage in co-operative arrangements for innovation. Exploring the France version of the second European community innovation survey, Miotti and Sachwald (2003) has examined co-operative R&D activities and determinants of the choice of partners (Miotti and Sachwald, 2003). Based on systematically collected data, they examines why co-operate, who does and with whom questions. They have found that R&D co-operation exhibits a significant positive impact on the propensity to innovate. They have indicated that the propensity to co-operate on R&D is higher for firm from sectors with relatively high R&D intensity. Co-operation with public institutions increases the capability of firms to conduct research at the technological frontier and to patent. Their analysis has shown the strategic motivation behind R&D co-operation. And it has examines the effects of co-operative R&D on patenting and product innovation measured by shore of innovative products in turnover. Using the Dutch firms' responses to the Community Innovation Survey, Belderbos, Carree and Lokshin (2004) has examined the impact of R&D co-operation on firm performance (Belderbos et al., 2004b). They have shown that the impacts of co-operation on firm performance varied according to four types of R&D

partners (competitors, suppliers, customers, and universities and research institutes). For example, while competitor and supplier cooperation improves productivity of firms, university cooperation and competitor cooperation promotes the growth performance of firms. Customers and universities are important sources for radical innovations.

All of these studies have indicated that the motivation and impact of R&D cooperation varies across firms, while they have found that the positive impact of cooperation on firm performance overall. However, such positive impacts would be realized in different flow of time. The impact of co-operation on the speed of innovation has been untapped yet. One of the reasons lies in the fact that much of previous literature on strategic practices related to speed has been based on anecdotal evidences not on enough systematic hard data (Crawford, 1992; Kessler and Chakrabarti, 1996). It is not easy to systematically collect data on R&D and commercialization speed.

3. Okochi Prize

Award, prize, and exhibition data are used in the analysis of technological innovation. Patents formally protect intellectual property rights; prizes diffuse technological knowledge. Because the primary aim of prizes is not to provide pecuniary gain, applicants do not heavily consider the costs of research and development when vying for prizes. The certification of new technologies by judges through a prize system confers indirect monetary benefits. The announcement of the prize promotes advertising and generates potential user awareness. Usually firms begin to consider awards after patenting an invention because the award does not provide any exclusive right of technology. Patent and prize are not interchangeable but complementary because inventors can pursue patents and prizes concurrently (Nicholas, 2011).

Various institutions award a prize. The Nobel Foundation is perhaps the most well-known prize-awarding institution. Governmental institutions award citizens for their excellent technological achievements. For instance, the U.S. Patent and Trademark Office awards the National Medal of Technology and Innovation (formerly known as the National Medal of Technology). Academic societies and professional associations also provide awards in areas of expertise. For example, IEEE (the Institute of Electrical and Electronics Engineers) provides different types of award programs in the field of electric and electronics engineering.

In celebration of Masatoshi Okochi's achievements, the Okochi Memorial Foundation was established in 1954. Masatoshi Okochi was a Japanese physicist and entrepreneur. He graduated from Tokyo Imperial University in 1903 and began his career as a scholar. He became a director of Rikagaku Kenkyūjo (currently, the Institute of

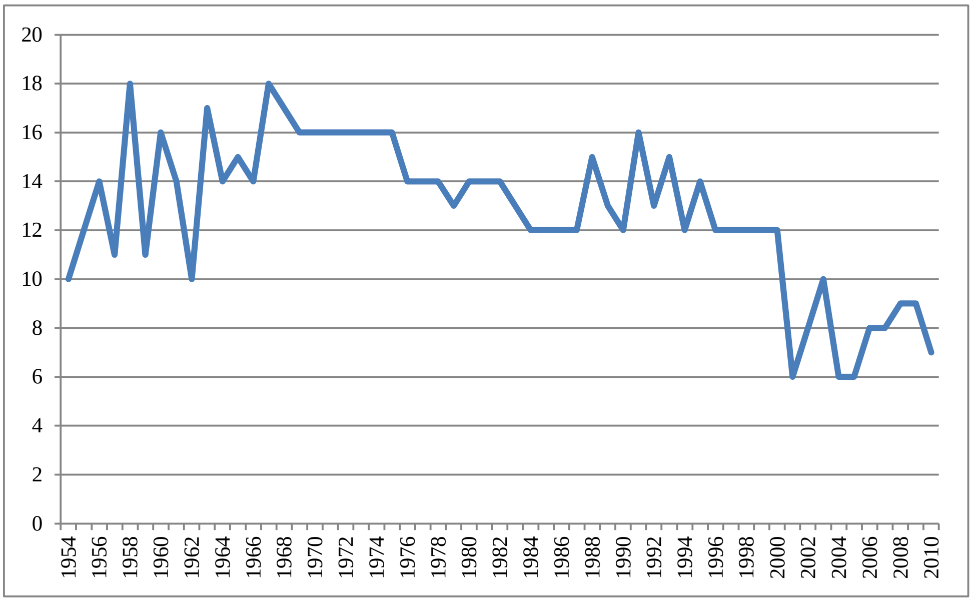
Physical and Chemical Research, known as RIKEN), which is still one of the largest natural sciences research institutes in Japan. Okochi promoted empowerment of research group leaders and tried to commercialize their research outcomes. In 1927, he established spin-off companies that used the institute's research outcomes for commercial applications. The Okochi Memorial Foundation has awarded distinguished achievements every year since 1954.

This paper investigates the awards given by the Okochi Memorial Foundation to explore the relationship between inter-organizational collaboration and R&D time reduction effects for two reasons. First, the Okochi Prize is well-known in manufacturing sectors in Japan. The Okochi Prize competition is regarded as a good opportunity for firms, government laboratories, and academic institutions to showcase the outcomes of their R&D. Nominated technology is judged by third party expertise. Therefore, awarded R&D represents a technological breakthrough. Second, the Okochi Memorial Foundation reports detailed descriptions of award-winning R&D projects. The description on award-winning R&D projects reports (1) Background and Target of R&D, (2) R&D process, (3) Description of Technology and its Features (e.g., originality, academic quality, advantages over competing technologies, economic performance, social contribution, and potentials), and (4) Achievements (e.g., production, sales, and market share). The detailed description is provided by the award-winning organization and checked by the Okochi Memorial Foundation. Based on the reports, we can explore the time that an organization spent for the awarded R&D. The information on R&D duration is significantly important for exploring the effect of collaboration on innovation speed, which has not been well documented by other resources.

All of the awarded project is given a certificate and medal/ trophy. Prize money is given only for the most distinguished R&D projects. However, the amount of monetary gift is one million yen for the Okochi Memorial Grand Technology Prize, which is given for the best project. 30 thousand yen is awarded for the maximum of seven projects. Such monetary gifts is not given for the rest of awarded projects. Since the prize money does not necessarily large, it does not serve as direct monetary benefits. This prize plays an important role in providing honorable position and in showcasing the R&D outcomes.

Applicants may nominate themselves. The application and nomination are judged by a committee composed of industry experts and university professors. The committee asks for additional information, interviews candidates, and, in some instances, conducts on-site investigations. Even though the committee does not rule out nomination of foreign R&D projects, Japanese firms dominate the Okochi Prizes; nearly all of the Okochi Memorial award winners are Japanese. The only award-winning foreign organization has been TWI (The Welding Institute of the United Kingdom), which was jointly awarded the prize in 2000 with Hitachi for their Application of Friction Stir Welding to Rolling Stock Body Shell. The Okochi Prizes emphasize production technology. Of course, this does not necessarily mean that product innovation is excluded from the Okochi Prizes; some product innovation certainly originates from process innovation. Moreover, the award-winning process innovation exists in a marketable form such as patent licensing, manufacturing facility, and material. The Okochi Memorial Foundation's report provides us information such as the name of the award-winning organization, technological details of the award-winning R&D project, the number of patents, academic presentation, sales, and other economic and industrial contributions for each individual project. Figure 1 shows the number of Okochi Prizes awarded from 1954 to 2010 and their awarded year.

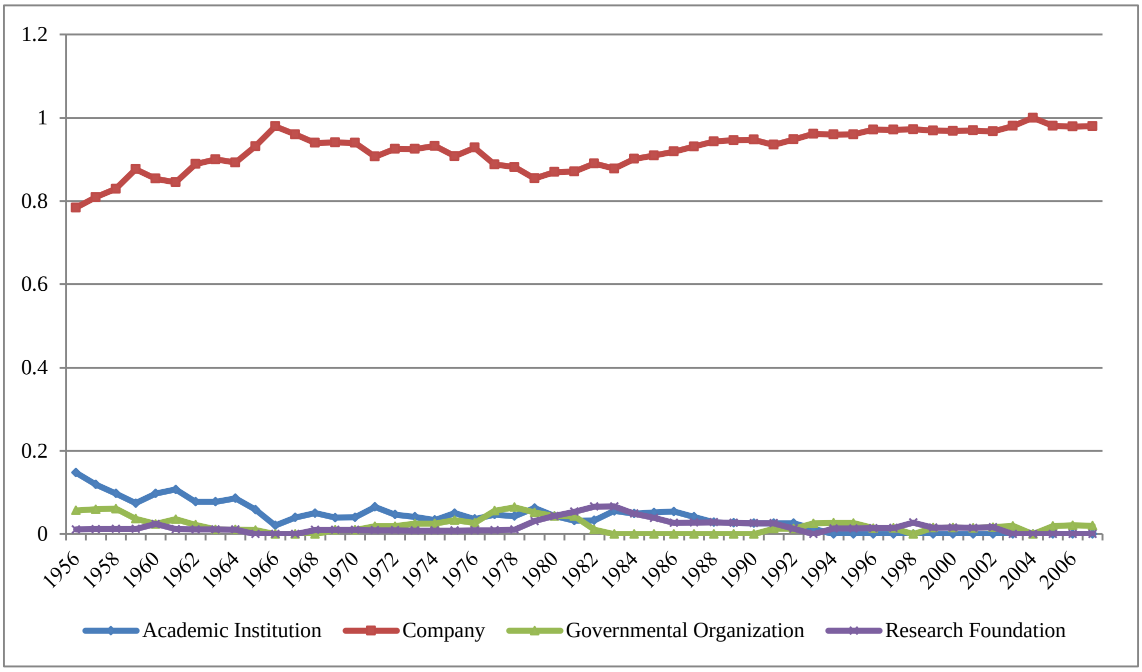
Figure 1: Number of Awarded R&D Projects



Source:(Okouchi Memorial Foundation, 1974-2011; Okouchi Memorial Foundation Tomonokai, 1960-1974) The 1950s includes only from 1954-1959, because the Okochi Prize was established in 1954. The 2000s includes 2010.

Figure 2 displays the time series of award-winning organization categories. Award-winning organization is specified in the report provided by Okochi Memorial Foundation. If an award is given to multiple organizations, this figure gives a full count to the award-winning organization. The figure shows that private companies dominate the awards. This reflects the fact that production or its manufacturing process should exist in a marketable form at the moment of submission of the nomination.

Figure 2: Shares of Okochi Prizes Granted to Different Types of Organizations[1]



Source: (Okouchi Memorial Foundation, 1974-2011; Okouchi Memorial Foundation Tomonokai, 1960-1974)

By classifying award-winning organizations based on Japan's securities identification code, Table 1 shows the decennial number of award-winning projects across industrial classes and their total collaboration ratio. If an award is given to multiple organizations, the figure takes the securities identification code of the principal organization appearing as the first author in the award report. If an organization is not listed and is not assigned a securities identification code, a code is assigned based upon the firm's business description and technological details as explained in the report. Since the award winning projects are quite diverse across industries, it merges them into eight categories. Food, agriculture, constructions, and are included in the Other category. The top three award winning categories are Electronics/Telecommunication/Information, Iron and Steel/Non-Ferrous Metal, and Petrochemical/Chemical/ Petroleum /Gas. The top three industries comprise more than half of each decennial sample throughout all time periods. It is interesting to note that despite Japan's competitive advantage in the

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1 Nippon Telegraph and Telephone (NTT) was privatized in 1985. Therefore, technically, it was a nationally owned public corporation before 1985. However, the figure counts it as a company throughout the periods.

automobile industry, the Okochi Prize has rarely been awarded in the category of transportation equipment. While machinery was one of the dominant industrial areas in the Okochi Prize in the 1950s, that industry has been steadily decreasing in its share.

An inter-organizational collaboration occurs when multiple organizations win the prize as co-applicants and recipients. It is safe to hold this assumption because the Okochi Prizes are given based on self-nomination. The collaboration ratios do not show significant difference across industries. They range roughly from 11 to 36 percentages. As previous literature has pointed out that collaboration has played an important role for its R&D, the highest collaborating industrial category is Pharmaceuticals (Cockburn and Henderson, 1998, 2001; Zucker et al., 2002).

Table 1: Award-Winning Industries and Collaboration Ratio

	1950s	1960s	1970s	1980s	1990s	2000s	Total	Collaboration Ratio
Electronics/Telecommunication/ Information	17	42	53	44	50	38	244	29.79
Iron and Steel/Non-Ferrous Metal	14	32	25	33	35	24	163	11.43
Machinery/Precision Machinery	27	18	13	9	6	4	77	24.14
Petrochemical/Chemical/ Petroleum /Electricity/ Gas	7	34	34	19	15	9	118	21.19
Pharmaceuticals	2	2	8	6	6	5	29	36.36
Pulp/Fiber/Glass/Textile	5	10	6	6	4	4	35	17.18
Transportation	2	8	11	12	10	4	47	17.21
Others	2	5	1	2	4	1	15	20

Source: (Okouchi Memorial Foundation, 1974-2011; Okouchi Memorial Foundation Tomonokai, 1960-1974)

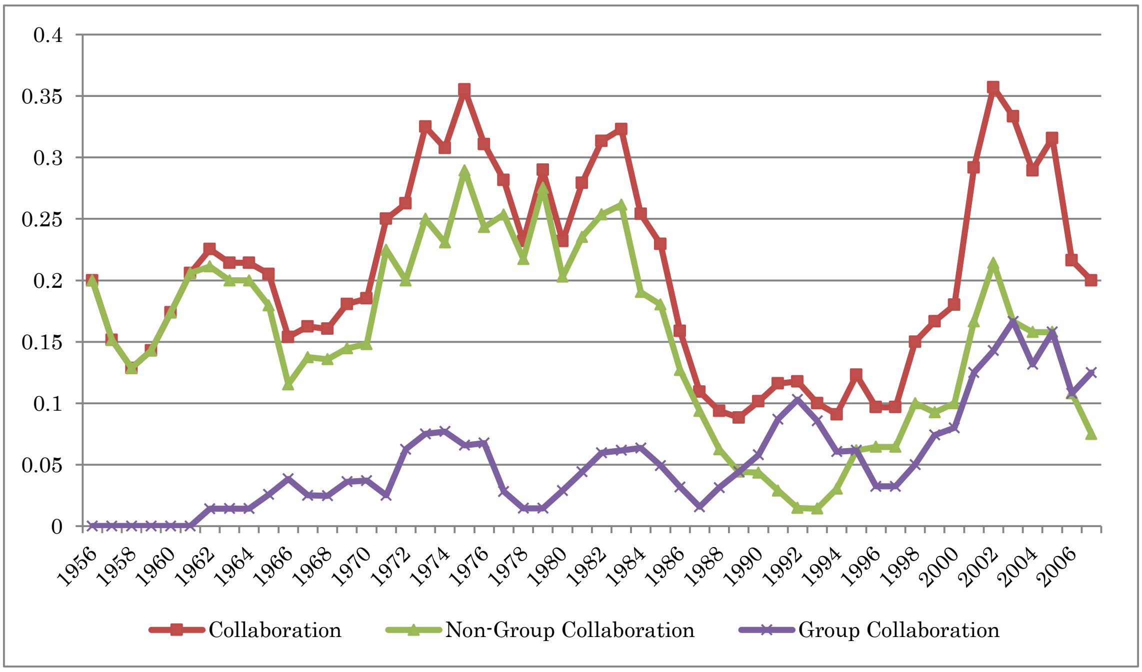
The following figure shows the shares of different types of inter-organizational collaborations receiving an award from the Okochi Prize Committee. Since the number of Okochi Prize winning R&D projects hovers around 10 every year, the figure shows a five-year moving average of percentage of collaborative R&D for the Okochi Prizes. A reasonable assumption is that Japanese firms tend to collaborate with group firms such as "*keiretsu*" firms or "*zaibatsu*" firms.[2] Actually, it is not rare to observe inter-

[2] On "keiretsu" and "zaibatsu," see Miwa, Y., Ramseyer, J.M., 2006. The Fable of the Keiretsu: Urban Legends of the Japanese Economy. University of Chicago Press ; [Bristol : University Presses Marketing, distributor], Chicago, Ill, Morikawa, H., 1992.

organizational collaboration among group firms. For example, Fujitsu won the prizes in 1981 and 1982 with Fujitsu Laboratories, which was separated from Fujitsu and became independent in 1968. Matsushita Electric Industrial Co. won the prizes with Matsushita Electronics in 1986. Hitachi won the prize with Hitachi High-Technologies and Hitachi High-Tech Fielding in 2007. Denso and Toyota Boshoku, both of which are automobile parts manufacturers and Toyota's suppliers, won the prize together in 2001.

However, the number of award-winning group-firm collaborations is not necessarily great compared to the number of inter-organizational collaborations among non-group firms. From 1954 to 2010, a total of 728 R&D projects were awarded. The number of award-winning inter-organizational collaborations was 151 during this period. The inter-organizational collaboration among non-group organizations was 114 out of 151. Thus, inter-organizational collaboration among group-firms is not a dominant pattern among Okochi Prize winners. This patter holds across award-winning industries.

Figure 3: Inter-Organizational Collaborative R&D (Award-Winning Year)



Source: (Okouchi Memorial Foundation, 1974-2011; Okouchi Memorial Foundation Tomonokai, 1960-1974)

Zaibatsu: the Rise and Fall of Family Enterprise Groups in Japan. University of Tokyo Press, Tokyo.

4. Estimation Strategy

This paper examines how different types of inter-organizational collaboration lead to different speed of innovation. In the Okochi Memorial Foundation's reports, the award-winning organization reports when it began its R&D project. Because this information is rarely obtained at the large scale, this is one of the strengths of the Okochi Prize data when estimating the relationship between collaboration and innovation speed.

From 1954 to 2010, the Okochi Memorial Foundation awarded 728 R&D projects. We identify the R&D start year for 434 award-winning R&D projects out of a total 728 projects. The reports do not necessarily always indicate precise R&D start year because the details are not firmly established. For many cases, the R&D start year is precisely indicated in the report; for others, the date is merely given as a time span. The R&D start year is not stated at all for some cases. Thus, this paper uses other source of information in addition to that provided in the Okochi Memorial Foundation's report. The Institute of Innovation Research at Hitotsubashi University has conducted detailed case studies on Okochi award-winning R&D projects by interviewing the concerned managers, scientists and engineers. The Institute has amassed more than 50 case studies since it began the Okochi Prizes case study project in 2008. This paper employs the R&D start year precisely articulated by the Okochi Memorial Foundation's reports or by the case studies. If the R&D start year was reported in an ambiguous way such as "the beginning of 1970s," this paper does not include that data in the sample. The number of observations for this dataset on the innovation speed is 434. The average innovation speed is 10.862 years.

This paper set the award-winning year to calculate innovation speed as the end year for two reasons. The first is that many of the reports do not provide the specific year in which the R&D project was completed. It is difficult to determine when the R&D project was completely finished because R&D is a long consecutive process in which technology is usually incrementally and sometimes radically being developed. The second is the fact that the award is given to the project whose results exist in a marketable form such as patent licensing, manufacturing facility, and material. An organization usually sends its application to the Okochi Memorial Foundation just after the industrial and commercial impacts are released. This paper regards innovation not as just development of new technology but as new technological development bringing significant industrial and economic impact. Therefore, this paper measures the period between the beginning of the R&D project and the year of the award in order to investigate the innovation speed from R&D to industrial and commercial success.

This paper estimates the correlation between collaboration and the logtransformed *Speed* using the regression model and controlling award type, industrial area, and time period. Collaboration variables are classified into six types. One is *Collaboration* that simply takes the value one if the award is given to multiple organizations. This variable is set to examine how the general inter-organizational collaboration is associated with the innovation speed. The second type is *Inter-firm collaboration*, which takes on the value one if the all co-recipients of the prize are private firm. Third, *User-customer collaboration* examines if the inter-firm collaboration is conducted in the relation between supplier and assembler for example. It explores assumption that user-customer collaboration tends to narrowly focus on industrial application and takes less time, compared to horizontal collaboration, which tends to develop more basic technology, takes longer innovation speed. Fourth, if the collaboration among firms and academic/governmental research institutions is awarded, the variable *Industry-academic collaboration* takes the value one. It examines an assumption that industry-academic collaboration takes longer time compared to inter-firm collaboration because a firm tends to collaboration with academic in the area where research is basic and still not close to market.

The fifth type is *Non-group firm collaboration*, which takes on the value one if the co-recipients of the prize are firms and not from the same business group organization. Business group has been defined in a variety of ways (Colpan et al., 2010). Japanese firms traditionally form a business group called *keiretsu* and *zaibatsu* in which firms develop tight interlocking relationships and shareholdings (Gilson and Roe, 1993; Miwa and Ramseyer, 2006; Morikawa, 1992). The nature of collaboration varied among prize recipients; in some instances, collaboration occurred within the business group, but in other instances, it occurred outside of the business group. Therefore, following the definition of business group, which is a group of independently managed firms with intertwined activities reinforced by governance mechanisms such as presidents' councils, partial cross-ownership, and personnel exchanges (Lincoln and Shimotani, 2010), this paper explores how collaboration within the same business group and the collaboration among the non-group organizations are each associated with the innovation speed. The last variable for collaboration is the *Number of organizations* involved in the award-winning R&D projects.

Collaboration is not the single determinant of the innovation speed. Various factors such as the amount of R&D investment, the nature of R&D, the level of competition, technological areas, and the technological capabilities influence the speed of innovation. The amount of R&D investment is one of the critical factors determining the innovation speed. However, it is certainly difficult to collect R&D investment for individual R&D projects for a large sample size. This paper includes four control variables for the investigation of collaboration and innovation speed.

First, introducing a variable, *Paper*, it controls to what extent the R&D project was basic rather than close to industrial application by exploring whether the project published academic paper or not. If an academic paper was published from the R&D project, we assume that the project had begun from basic research or the project had been science-based, both of which tend to take longer time period.

Second, it controls award classifications by introducing *Okochi Memorial Grand Technology Prize*. The Okochi Memorial Grand Technology Prize is awarded for the best R&D projects among the applicants each year. It is reasonable to assume that a project bringing distinguished R&D outcome takes longer time period.

Third, it controls R&D start year in a decennial manner. It is reasonable to assume that the macroeconomic conditions a firm confronts have influenced its R&D project setting. For instance, if a firm confronts favorable economic condition for long-term R&D investment, it may launch challenging R&D project. Furthermore, the product life cycle of the industry may have influenced a firm's R&D project choice.

Fourth, it controls industrial areas of the award-winning R&D project. As it is explained above, this study identifies the award-winning R&D project's industrial category based on its securities code category. It uses the lead organization's industrial category when multiple organizations share the prize. If the lead organization is an academic/governmental organization, this paper employs the second lead organization's securities code. If all of the co-recipients are academic/governmental institutions, it examines the description about the award-winning technology. The categories are merged into eight categories as Table 1 indicates. Table 2 and 3 provide descriptive statistics and correlations for all variables

Table 2 : Descriptive Statistics of Variables

Variable	Obs	Mean	Std. Dev.	Min	Max
lnSpeed	434	2.226	0.584	0	3.807
Collaboration	434	0.207	0.406	0	1
Inter-firm collaboration	434	0.141	0.348	0	1
User-customer collaboration	434	0.124	0.330	0	1
Non-group firm collaboration	434	0.071	0.258	0	1
Number of organizations	434	1.272	0.592	1	4
Industry-academic collaboration	434	0.069	0.254	0	1
Paper	434	0.578	0.494	0	1
Okochi Memorial Grand Technology Prize	434	0.101	0.302	0	1
Before 1960	434	0.242	0.423	0	1
1960s	434	0.224	0.417	0	1
1970s	434	0.253	0.435	0	1
1980s	434	0.194	0.396	0	1
1990s	434	0.078	0.269	0	1
2000s	434	0.009	0.096	0	1
Transportation	434	0.069	0.254	0	1
Pulp/Fiber/Glass/Textile	434	0.046	0.210	0	1
Pharmaceuticals	434	0.041	0.200	0	1
Petrochemical/Chemical/ Petroleum /Gas	434	0.177	0.382	0	1
Machinery/Precision Machinery	434	0.083	0.276	0	1
Iron and Steel/Non-Ferrous Metal	434	0.235	0.425	0	1
Electronics/Telecommunication/ Information	434	0.323	0.468	0	1
Others	434	0.007	0.083	0	1

Table 3 : Correlation Matrix of Variables

		1	2	3	4	5	6	7	8	9	10	11
1	lnSpeed	1										
2	Collaboration	-0.0402	1									
3	Inter-firm collaboration	-0.0434	0.7906	1								
4	User-customer collaboration	-0.0645	0.737	0.9121	1							
5	Non-group firm collaboration	-0.1141	0.5422	0.6858	0.7357	1						
6	Number of Organizations	-0.0531	0.8984	0.6882	0.6645	0.4472	1					
7	Industry-academic collaboration	-0.0115	0.5328	-0.0841	-0.0477	-0.0756	0.5196	1				
8	Paper	0.2613	0.0109	0.0231	-0.0033	-0.0531	-0.0414	-0.0064	1			
9	Okochi Memorial Grand Technology Prize	0.0377	0.0541	0.0179	0.0353	0.0254	0.0392	0.0589	0.0858	1		
10	Before 1960	0.0046	0.0561	-0.0117	0.0152	0.0313	0.086	0.1006	-0.5745	0.0598	1	
11	1960s	-0.0836	0.053	0.0536	0.0659	0.1089	0.0526	0.0064	-0.2139	-0.0703	-0.3031	1
12	1970s	0.0375	-0.0367	-0.0527	-0.0431	-0.0999	-0.0439	0.0292	0.3474	0.0149	-0.3292	-0.3126
13	1980s	0.0692	-0.1067	-0.0303	-0.061	-0.0679	-0.097	-0.1335	0.3238	0.0287	-0.2768	-0.2628
14	1990s	-0.0329	0.0201	0.0301	-0.006	-0.0143	-0.018	-0.0118	0.1795	-0.0695	-0.1647	-0.1564
15	2000s	-0.0204	0.0696	0.0997	0.1097	0.1605	0.0372	-0.0263	0.0824	0.0475	-0.0545	-0.0517
16	Electronics/Telecommunication/ Information	-0.1228	-0.049	0.0046	-0.0361	-0.0766	-0.0838	-0.0909	0.15	-0.0522	-0.1827	-0.0271
17	Iron and Steel/Non-Ferrous Metal	0.0205	-0.0557	0.026	0.038	0.0784	-0.0343	-0.1082	0.0771	0.0839	-0.034	0.0157
18	Machinery/Precision Machinery	-0.0748	0.1553	-0.0495	-0.0374	-0.0185	0.1724	0.3133	-0.1831	-0.018	0.2202	-0.0811
19	Petrochemical/Chemical/ Petroleum /Electricity/ Gas	0.1523	0.0451	0.0551	0.0625	0.0117	0.0618	-0.0077	-0.1164	0.0039	0.0897	0.0983
20	Pharmaceuticals	0.0631	-0.004	-0.0256	-0.0163	0.0244	-0.0267	0.0268	-0.0571	0.0354	0.0555	0.0667
21	Pulp/Fiber/Glass/Textile	0.1898	-0.0209	-0.0841	-0.0784	-0.0577	-0.0175	0.08	0.084	0.0067	-0.0096	-0.0284
22	Transportation	-0.1531	-0.0274	0.0205	0.0349	0.0655	-0.0331	-0.0743	-0.0248	-0.0614	-0.0691	-0.0372
23	Others	-0.0067	-0.0102	-0.023	-0.0164	-0.0447	0.0002	0.0138	-0.0404	-0.0056		

Table 3 : Correlation Matrix of Variables (Continued)

		12	13	14	15	16	17	18	19	20	21	22	23
12	1970s	1											
13	1980s	-0.2854	1										
14	1990s	-0.1699	-0.1428	1									
15	2000s	-0.0562	-0.0472	-0.0281	1								
16	Electronics/Telecommunication/ Information	0.0285	0.1111	0.129	-0.015	1							
17	Iron and Steel/Non-Ferrous Metal	0.0268	-0.0377	0.0002	0.1171	-0.3825	1						
18	Machinery/Precision Machinery	-0.0216	-0.0839	-0.0566	-0.029	-0.2075	-0.1667	1					
19	Petrochemical/Chemical/ Petroleum /Electricity/ Gas	-0.021	-0.0901	-0.113	-0.0448	-0.3205	-0.2574	-0.1397	1				
20	Pharmaceuticals	-0.0523	-0.0242	-0.0641	-0.0212	-0.1517	-0.1218	-0.0661	-0.1021	1			
21	Pulp/Fiber/Glass/Textile	0.0913	-0.0434	-0.0176	-0.0201	-0.1435	-0.1153	-0.0626	-0.0966	-0.0457	1		
22	Transportation	-0.0335	0.0964	0.0896	-0.0263	-0.188	-0.151	-0.082	-0.1266	-0.0599	-0.0567	1	
23	Others	-0.0603	0.0694	-0.047	-0.0156	-0.1113	-0.0894	-0.0485	-0.0749	-0.0354	-0.0335	-0.0439	1

5. Estimation Results

Table 4 shows the estimation results on the association between inter-organizational collaboration and innovation speed. The coefficients of control variables show consistent with the basic assumptions. First, the estimation results generally match those described by qualitative case studies on R&D industrial specificity. As the estimated results show, the awarded R&D projects in the pharmaceutical industry take longer to achieve industrial and economic success than the projects in other industries. The study by DiMasi et al. (2003) estimated that it takes 142 months (11.8 years) for new drug R&D in the U.S. This figure is clearly close to the average period of our sample, which is 10.862 years. However, 11.8 years, estimated by Dimasi et al. (2003), includes only R&D period; it is necessary to include the period of achieving industrial and economic success in the Okochi Prize context. Furthermore, it takes longer to come through all of the governmental safety tests and permit approval processes in the pharmaceutical industry of Japan, compared to the other developed economies (Shiaw, 2010). Second, the estimation results show that it takes longer time period if the R&D project publishes an academic paper. It suggests that science-based R&D project takes longer innovation speed.

The key point of this paper is to empirically examine the association between collaboration and the innovation speed. First of all, *Collaboration* does not any significant association with innovation speed at statistically significant level. Both *Inter-firm collaboration* and *User-customer collaboration* do not show any association neither, even though their coefficient is negative as our assumptions expect. However, *Non-group firm collaboration* shows negative association with innovation speed at statistically significant level for all models. The coefficients of the variable *Non-group inter-firm collaboration* are -0.225, -0.198, -0.322, -0.235, -0.253, -0.253 in each model. These estimations clearly indicates that the collaboration among non-group firms are negatively and significantly associated from 19.8% in model 6 up to 32.2% in model 7 with innovation speed reduction, after controlling for other factors. Since the average innovation speed in the sample is 10.862 years, the actual time reduction is from 2.15 up to 3.5years.

While non-group inter-firm collaboration is negatively associated the innovation speed, other collaboration types do not reveal such time reduction at a statistically significant level. It suggests since utilization of outside resources and knowledge can take various forms, ranging from offering general advice and insights to active participation in a specific piece of research or formal research consortium (Katz and Martin, 1997), performance of collaboration varies a good deal according to nature of collaboration, collaborators' aim, and partners (competitors, suppliers, customers, and universities and research institutes) (Belderbos et al., 2004a). The estimated results might reflect the fact that the nature of industry-academic collaboration is different from inter-firm collaboration, as we expected. The primal aim of an academic institution does not lie in industrializing findings. Moreover, industry-academic collaboration tends to target more fundamental R&D and is less commercially oriented than firm-firm collaboration.

One of the key findings of this paper is the only collaboration type that is associated with shorter innovation speed is non-group inter-firm collaboration. It implies that inter-organizational collaborations among the same business group firms do not have a statistically significant association with the innovation speed.

The estimation raises the question of which form of non-group firm collaboration reduces the time period from R&D to the award year. Since this paper examines the time reduction effect of inter-organizational collaboration on the overall period from the R&D start year to the awarded year, we cannot empirically discern in which process time reduction plays a role. One might argue that the time reduction effect can arise in the process of marketing and distribution, as well as in the process of R&D. If a manufacturing firm collaborates with a retail industry, the time to reach the product market may lessen. However, there is no instance of inter-organizational collaboration between a manufacturing firm and a marketing or retail firm in the sample. All of the award-winning firms have been in the manufacturing sectors in the Okochi Prize. Moreover, since the Okochi Prize aims to award the development of significant manufacturing technology, it is quite reasonable to suppose that the time period reduction effect takes place in the research and development of process innovation in particular.

Then, how is non-group inter-firm collaboration associated with high innovation speed? There can be several interpretations on this finding. One is that because Japanese business group firms are as well-coordinated and closely-tied as a single individual firm, there is no significant difference between the innovation speeds. Another is that complimentary knowledge between collaborating organizations, which is considered a means of increasing R&D productivity, is not greater in the same business group firms of Japan. One can suppose that if a firm requires innovating in the very short period of time, it needs to explore outside resources beyond its business group. These points require more detailed study in the areas of business group studies. However, the estimations are quite consistent with the previous literature on collaboration indicating that collaborations provide mutual access to complimentary resources, if we look the individual cases in the Okochi Prize data-set carefully (Rothaermel and Deeds, 2004; Rothaermel and Hill, 2005). Furthermore, the R&D tends to target to develop clearly well-defined industrial application in non-group inter-firm collaboration, while group firm collaborations tend to target to develop basic technology.

For example, in 2003, Tokyo Electric Power Company and NGK Insulators jointly won the Special Production Award for the development and commercial viability of the sodium-sulfur battery for electric energy storage. The award report indicates that Tokyo Electric Power Company and NGK Insulators jointly carried out R&D and industrialized the technology based on NGK Insulators mass production technology, which Tokyo Electric Power Company did not have. In 2000, Toyota Motor and KOGI Corporation, a company operating in steel roll casting, machinery, and environmental equipment businesses, won the Special Production Award for the development of high toughness alloy cast iron shortening manufacturing time and reducing cost of stamping die for automotive body. KOGI developed the high toughness alloy cast by jointly collaborating with its potential user and borrowing knowledge of automobile manufacturing.

These non-group inter-firm collaboration cases show that the industrial applications and their mutual access to complimentary resources are well-defined, while group-firm collaborations tends to be a collaboration between a parental firm and its subsidiary firm, many of which used to be a part of the parental firm. The one good example of the group-firm collaborations is collaboration between Fujitsu and Fujitsu Laboratories Ltd. Fujitsu Laboratories Ltd was spun off from Fujitsu in 1968. Based on the joint R&D, they won the prizes in 1981, 1982, 1990, 2005, and 2010. Even though they exist as an independent firm, it is reasonable to assume that their decision making is generally based on organizational hierarchy serving as a single firm. Toyota Motors and Toyota Motor Kyushu is another good example of group-firm collaborations. Toyota Motor jointly developed a new vehicle assembly system with Toyota Motor Kyushu, which spun off from Toyota Motor in 1991 and manufactured high-priced product line, and won the production award in 1993. Since they virtually functions as a single firm, it is possible to assume that access to complimentary assets is virtually limited in the boundary of the single firm.

One might argue against the finding that the innovation speed reported by the joint prize winners tends to be shorter than the actual R&D time period. There is no formal definition of the R&D start in the Okochi Memorial Foundation reports; determination is completely subjective and left to the discretion of the applicants. It is not always easy for an award-winning organization to identify when the R&D project was launched. This is particularly true when the R&D is quite evolutionary and based on incremental technological change. On the other hand, it is possible to suppose that the reported R&D start year tends to be when organizations agreed to or began R&D collaboration if the award is shared by multiple organizations. However, when organizations agree to R&D collaboration, it is rare for them to start R&D and develop technology from scratch. It would appear that organizations have already begun R&D and developed technological knowledge before they agree to the collaboration. Thus, one might suppose that the innovation speed reduction effect observed by the estimation results reflects not the actual negative association between collaboration and innovation speed but the possibility that the inter-organizational R&D project tends to report its innovation speed as shorter. However, such innovation speed reduction is observed only in the collaboration among non-group firms. Thus, it can plausibly be argued that the inter-organizational collaboration among non-group firms is negatively associated with the innovation speed.

Table 4: Estimation Results

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Collaboration	-0.0874						0.0928		
	(0.0650)						(0.104)		
Inter-firm collaboration,		-0.0709			0.0780				
		(0.0747)			(0.102)				
User-customer collaboration			-0.111						
			(0.0787)						
Group firm collaboration									
Non-group firm collaboration				-0.225**	-0.299**	-0.198*	-0.322**	-0.235**	-0.253**
				(0.102)	(0.140)	(0.115)	(0.141)	(0.102)	(0.124)
Number of organizations						-0.0263			0.0161
						(0.0497)			(0.0618)
Industry-academic collaboration							-0.221	-0.135	-0.156
							(0.145)	(0.109)	(0.135)
Paper	0.502***	0.494***	0.496***	0.494***	0.491***	0.497***	0.501***	0.505***	0.505***
	(0.0753)	(0.0750)	(0.0749)	(0.0746)	(0.0747)	(0.0748)	(0.0752)	(0.0751)	(0.0751)
Okochi Memorial Grand Technology Prize	-0.0453	-0.0500	-0.0476	-0.0474	-0.0474	-0.0460	-0.0417	-0.0410	-0.0408
	(0.0864)	(0.0864)	(0.0863)	(0.0860)	(0.0861)	(0.0861)	(0.0862)	(0.0861)	(0.0862)
1960s	-0.244***	-0.243***	-0.243***	-0.237***	-0.236***	-0.238***	-0.238***	-0.239***	-0.239***
	(0.0801)	(0.0802)	(0.0801)	(0.0799)	(0.0800)	(0.0800)	(0.0799)	(0.0799)	(0.0800)
1970s	-0.349***	-0.342***	-0.345***	-0.353***	-0.353***	-0.356***	-0.360***	-0.361***	-0.361***
	(0.0952)	(0.0950)	(0.0949)	(0.0947)	(0.0948)	(0.0949)	(0.0949)	(0.0949)	(0.0950)
1980s	-0.264**	-0.252**	-0.258**	-0.262**	-0.262**	-0.267***	-0.279***	-0.280***	-0.280***
	(0.103)	(0.102)	(0.102)	(0.102)	(0.102)	(0.102)	(0.103)	(0.103)	(0.103)

1990s	-0.356***	-0.351***	-0.357***	-0.361***	-0.363***	-0.363***	-0.371***	-0.368***	-0.368***
	(0.126)	(0.126)	(0.126)	(0.125)	(0.125)	(0.125)	(0.125)	(0.125)	(0.125)
2000s	-0.497*	-0.493*	-0.481*	-0.429	-0.425	-0.437	-0.435	-0.440	-0.438
	(0.282)	(0.282)	(0.282)	(0.283)	(0.283)	(0.283)	(0.283)	(0.283)	(0.283)
Electronics/Telecommunication/ Information	-0.0840	-0.0790	-0.0806	-0.0719	-0.0719	-0.0751	-0.0802	-0.0805	-0.0798
	(0.168)	(0.169)	(0.168)	(0.168)	(0.168)	(0.168)	(0.168)	(0.168)	(0.168)
Iron and Steel/Non-Ferrous Metal	0.0401	0.0484	0.0490	0.0660	0.0694	0.0616	0.0595	0.0541	0.0550
	(0.171)	(0.171)	(0.171)	(0.170)	(0.170)	(0.171)	(0.171)	(0.170)	(0.171)
Machinery/Precision Machinery	-0.0254	-0.0455	-0.0466	-0.0337	-0.0294	-0.0266	0.00126	-0.00213	-0.00156
	(0.185)	(0.184)	(0.184)	(0.184)	(0.184)	(0.184)	(0.185)	(0.185)	(0.185)
Petrochemical/Chemical/ Petroleum /Electricity/ Gas	0.265	0.268	0.269	0.277	0.275	0.276	0.270	0.271	0.271
	(0.173)	(0.173)	(0.173)	(0.172)	(0.172)	(0.172)	(0.172)	(0.172)	(0.172)
Pulp/Fiber/Glass/Textile	0.226	0.227	0.226	0.246	-0.425	0.240	0.252	0.245	0.248
	(0.201)	(0.201)	(0.201)	(0.200)	0.252	(0.201)	(0.200)	(0.200)	(0.201)
Pharmaceuticals	0.489**	0.487**	0.482**	0.495**	0.503**	0.492**	0.509**	0.500**	0.502**
	(0.206)	(0.206)	(0.206)	(0.205)	(0.205)	(0.205)	(0.205)	(0.205)	(0.205)
Transportation	-0.239	-0.233	-0.229	-0.207	-0.202	-0.212	-0.211	-0.216	-0.215
	(0.189)	(0.190)	(0.189)	(0.189)	(0.189)	(0.190)	(0.189)	(0.189)	(0.190)
Constant	2.143***	2.132***	2.137***	2.130***	2.124***	2.164***	2.136***	2.144***	2.125***
	(0.165)	(0.165)	(0.165)	(0.164)	(0.165)	(0.177)	(0.165)	(0.165)	(0.180)
Observations	434	434	434	434	434	434	434	434	434
R-squared	0.201	0.199	0.201	0.207	0.208	0.207	0.211	0.210	0.210

Standard errors in parentheses

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

6. Conclusions

This paper examines the impact of inter-organizational collaboration on the innovation speed by exploring the prize data on significant manufacturing technology. By investigating the Okochi Prizes data-set, it empirically examines the relationship between inter-organizational collaboration and its innovation speed.

If we do not introduce the types of collaboration, the estimated results do not show any significant relation between collaboration and innovation speed. However, after controlling for technological areas, prize categories, and collaboration types, the estimated results show that non-group inter-firm collaboration have association with from 19.8% up to 32.2% faster innovation speed. However, such accelerated innovation speeds are not observed in other collaboration types such as user-customer collaboration and firm-academic collaborations. The collaboration can influence not only the innovation speed but also other things such as costs, nature of technology, and economic and industrial impact. However, since the timing of market entry plays an important role in establishing competitive advantages, and the reduction of the innovation speed can cut R&D costs, faster innovation can be of significance for a firm.

In conclusion, we mention some limitations of this paper that future research should address more explicitly. First, as the previous literature often points out, inter-organizational collaboration would reduce R&D time by facilitating the use of complimentary knowledge. However, it must be noted that the association between non-group inter-firm collaboration and shorter innovation speed this paper has observed is not necessarily causal relationship. It is highly possible to assume that a firm select R&D projects whose target is well-defined and outcome can be realized in a relatively shorter period for non-group inter-firm collaboration rather than such collaboration has innovation speed reduction effects, even though the time reduction effects are often in the anecdotal evidence. Further empirical research aimed at discerning the time reduction effects from this endogeneity bias will surely advance our understanding of collaboration and innovation speed.

Second, we do not control for the amount of R&D investment. It is obviously assumed that the increase in the R&D investment can reduce the innovation speed. One might suppose that if multiple organizations worked together, the total investment in the R&D project would be bigger. If so, one can argue that inter-organizational collaboration can be regarded as the proxy of R&D investment. Other things being equal, bigger R&D investment can bring faster innovation speed. However, if inter-organizational collaboration is positively associated with the amount of R&D investment, and if the increase in the amount of R&D investment results in shorter innovation speed, we should observe shorter innovation speed in all types of inter-organizational collaborations. However, such association is seen only in non-group inter-firm collaboration. Of course, since the joint effort between industry and academia tends to target fundamental and basic research themes, it is reasonable to suppose that this type of collaboration tends to be lengthier in nature. However, if the inter-organizational collaboration is positively associated with the amount of R&D investment, we should observe the negative coefficient not only in the collaboration among non-group firms, but also in collaboration among the same business group firms. If we could, however, control the R&D investment in the award-winning projects, we could control the effect of collaboration more precisely. All of these limitations are immanent to the prize data that this paper has explored. However while these limitations exist, the prize data has provide detailed information on the R&D process that allows empirically investigating the relationship between inter-organizational collaboration and innovation speed.

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