An Alternative Resource for Technology Innovation: Do Industrial Designers Create Superior Invention?

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***Abstract*--Recent design studies have advocated how design practices enhance innovation in various fields. Indeed, the latest case study discovered that industrial designers can contribute even in natural science research. On the other hand, the majority of R&D management scholars and practitioners have long overlooked the value of collaboration between R&D engineers and industrial designers. To fill the gap, in this study, we test the link between an enrollment of industrial designers in inventing activities and their impacts on inventing outcomes using patent applications to Japan Patent Office from a Japanese electronics manufacturer. By connecting each inventor's individual affiliation information collected from the design patent, we constructed 75,932 invention-level data points for inventor affiliations to use in our regression analysis. Our analysis reveals a significant contribution by industrial designers to high-impact inventions. Our estimation result shows that an enrollment of industrial designers increases forward citations of a focal patent application by an average of 17%. We can interpret that these contributions of industrial designers come from their latent demand-oriented thinking, which concurs with recent design studies. This study provides the implication for R&D managers that they should not exclude industrial designers when seeking to develop innovative technologies.**

I. INTRODUCTION

During this decade, "design thinking" has captured the attention of innovation scholars. Design thinking, originating from the basic practices of designers, is a series of activities and attitudes aimed at advancing innovation [3][30]. The idea does not imply the necessity to be a designer; however, designers may have a high potential to be innovators in various circumstances.

In fact, recent management studies have discovered that industrial designers contribute to innovative scientific research in the natural sciences [7][34]. These studies clearly illustrate how industrial designers tactfully set a demand-pull goal and facilitate consensus building among research project members.

They are also likely to achieve technological innovation in their respective industry sectors. Reference [32] found their superiority in setting consumer-oriented goals. Indeed, James Dyson, a versatile entrepreneur and industrial designer, invented a novel vacuum technology to resolve a suction problem that had long frustrated consumers [8]. These facts, even though supported by only a limited number of cases in three studies, imply a positive correlation between technology development performance and industrial designer enrollment.

Both R&D managers and management scholars, however, seem to have long overlooked the value of collaboration between R&D engineers and industrial designers; rather, they rarely consider cross-functional collaboration. Most of the literature and practices have focused on cross-technological field partnership. Major keywords, such as transdisciplinary research or industry−university collaboration, essentially premise a synergetic knowledge recombination [10] between different technologies.

In this study, we test the dogma that an R&D activity is an exclusive sanctuary for believers in technocracy. Needless to say, not all R&D managers and scholars accept this dogma. Dyson Ltd., Apple Inc., and the design firm IDEO, for example, conduct R&D and industrial design together. The primary purpose of this study is to empirically examine the capability of industrial designers for technology innovation. We also contribute to organizational R&D and management studies by introducing new evidence.

This article proceeds as follows. In the next section, we derive our theoretical assumptions. Section III describes our data and the framework for empirical analysis. Section IV presents the findings and a discussion. Finally, we conclude with implications, limitations, and future research directions.

II. THEORY AND HYPOTHESES

A. Technology innovation drivers of industrial designers

At first, we explore several characteristics of industrial designers that may contribute to technology innovation. Based on design studies, industrial designers have several unique skills and ways of thinking. In particular, design thinking arguments (e.g., [22]) assist our exploration.

First, industrial designers' user demand-oriented thinking potentially leads to commercially high-impact inventions [32] (Hypothesis 1). One of the most significant activities in the industrial design process is the identification of latent or unexpressed user demands [13]. A convincing argument about the origin of such a characteristic emphasizes the industrial designers' desire to self-express [3]. This desire motivates most of them to create something completely differentiated from others. Of course, they are aware that industrial designing is not an artistic work and that they should create styles that are acceptable to users; thus, they often take the golden route: an exploration of latent demands[1]. However, even their outputs are originated from demand; users do not accept their novel shapes directly. Rather, users need to be "re-educated" [46]. This induces a certain time lag in diffusion between industrial designer-originated products and other products.

Through these design management discussions, we argue that technologies benefiting from this characteristic might require a long-term strategy to fully realize their value (Hypothesis 2). Most consumers and engineers, except innovators or early adopters [38], do not accept such latent demand-based technologies; inevitably, latent demand-oriented technologies show delayed growth in their evaluation.

Second, industrial designers' visualization skills assist in creative idea selection and consensus building in R&D activities [7][34] (Hypothesis 1). They are well trained in sketching, making scale models, and crafting mock-ups. These tools enable R&D teams to examine various ideas by trial and error [3] and to share conceptual directions among members by providing tangible goals [46].

From these arguments, we can introduce the following two hypotheses.

Hypothesis 1. *Inventions developed with at least one industrial designer will likely show greater impact than other inventions.*

Hypothesis 2. *Enrollment of industrial designers in inventing will likely delay evaluation of their invention.*

B. Requisites of technological knowledge

The industrial designer-side arguments above may be too optimistic in regard to novel technology creation. A significant amount of R&D management papers confirm that technology innovation originates from new combinations of disparate knowledge [19][29], especially technological knowledge in different fields [10]. Indeed, even when an industrial designer sets an innovative goal or facilitates team discussion, without sufficient technical knowledge, the goal remains a mere concept and never reaches the stage of a tangible invention. We can argue that technological knowledge is a requisite for invention and industrial designers' characteristics accelerate its positive effects.

In particular, we can expect that the consensus-building enhancement function elicits potential benefits from technological knowledge diversity (Hypothesis 3A). It is well known that even a diversified technological knowledge base potentially increases the possibility of inventing variable novel technologies by occasionally discovering a new "re-combination" of well-known distinct technologies [10], too large a diversity of technological knowledge can hinder its positive effects [11]. Several researchers argue that this leveling out is due to difficulty in selecting a suitable knowledge combination out of exponentially increasing combinations [26] and in understanding unfamiliar technological terms and methodologies used by colleagues [27]. We assume that the visualization skills of industrial designers will aid the selection of appropriate technological combinations and overcome the technological knowledge gaps within the inventing team.

Hypothesis 3A. *The effect of enrollment of industrial designers will likely increase with increased technological knowledge of the team.*

Of course, there might be several counterarguments. At least in regard to latent user demand-oriented thinking, novel technological "recombination" [10] is not always required. Rather, technology transfer from other fields [20] or new applications of clichéd technology may be essential, since people's demand has a certain commonality and in some fields, it may already be fulfilled by some technologies. A classic case is Dyson's cyclone vacuum cleaner technology, which incorporated dust extraction technology from sawmills [8]. If so, a diversified technological knowledge will not be an issue, but it might be useful whether industrial designers know a transferable technology or a person who has one or whether they have the serendipity to discover an applicable technology. These potential key elements are, unfortunately, difficult to measure; but, we can at least argue that technological knowledge diversity has very little or no interaction with industrial designers (Hypothesis 3B).

Hypothesis 3B. *The effect of enrollment of industrial designers will have no interaction with the technological knowledge of the team.*

Our conceptual model is illustrated in Figure 1. We assume that two characteristics of industrial designers influence an invention's impact: user demand-oriented thinking and delayed growth of impact. We also surmise that these positive effects are combined with an amount of technological knowledge.

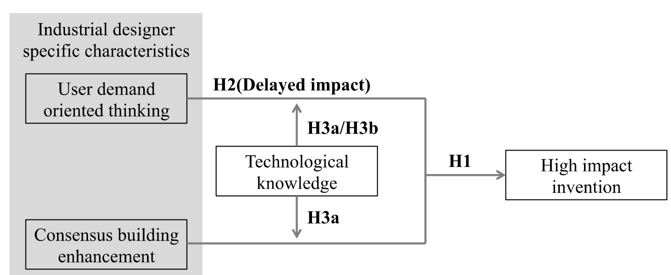

Figure 1 Conceptual framework

[1] Indeed, design thinking debates stress the importance of this and propose ethnographic research as a practical measure [3][30] to follow the tacit process, which industrial designers conduct.

III. METHODOLOGY

A. Research design and data

We examine the link between enrollment of industrial designers and impacts of inventing outcomes using Japan Patent Office patent data. Following [39], we conduct a patent-level regression analysis. Patent data analysis provides an objective work history of engineers and R&D project teams as well as their performances. Thus, numerous R&D management studies and innovation studies have used this rich data source.

For this examination, we need a solid case, in which industrial designers are independent of R&D activities. This paper selected the consumer electronics manufacturing industry in Japan. A vast majority of industrial design education in Japanese higher education is conducted at art colleges or art-related schools. Consumer electronics manufacturers employ industrial designers as a specific profession, in principle. This selection is also beneficial for analysis since both industrial design and technology development are active in this industry; thus, sufficient data are available to acquire statistical robustness. Moreover, Japanese statistics show high patent propensity [16] in the electronics industry [28].

Among several leading manufacturers, we pick up on one multinational company: Hitachi. This company has a certain global market share in the field of general electronics, such as electricity generators and transportation systems; similarly, it held 25% of the domestic home electrical appliance market in 2010. It has a central design department to which industrial designers are generally assigned. A striking benefit of choosing Hitachi is the documentation of its design rights (a patent-like protection system for product shapes, similar to design patents in the United States). The majority of patent or design right applicants do not indicate detailed affiliations of every inventor/creator in their application documents; however, Hitachi meticulously indicates its design creators' affiliations at the departmental level. Thus, by connecting this information with patent data, we can estimate with high accuracy whether or not an inventor is also an industrial designer.

B. Data construction

We restrict our final sample to patents filed with the Japan Patent Office from 1995 to 2007 by Hitachi and its consumer electronics-related major subsidiaries (hereinafter, Hitachi Group). We exclude all joint applications with third parties to control for the positive effects of joint research. The time window is carefully framed in terms of accuracy and sufficient data. Old documents, especially those filed before 1998, when electronic application started, sometimes include inconsistent inventor names and the probability of fluctuations or mistypes. On the contrary, new patents hold truncation bias in their forward citations, a performance indicator of inventions. This paper allocates at least 7 years for forward citation accumulation.[2] In the construction of measures, we use information from all patents and design rights applications filed by the observed company from 1990 to 2009.

The first step in construction is unification (or disambiguation) of the names of inventors to measure the inventing experiences of each inventor correctly. Inventor names are sometimes mistyped or lack consistency. We matched names with similar names that share the same co-inventors/co-creators, technology/design fields, and active terms.[3] We also carefully verified the names of women with different last names to detect a family name change following marriage or divorce.

The second step is detection of industrial designers using design rights applications. Considering the above-mentioned practices of the observed company, we searched those belonging to the design department at his/her first consumer electronics-related design right registration in the Hitachi Group. Taking this step, we focused on the inventor's original background instead of their temporary affiliation and excluded any noise from job rotation or personnel change. To construct a strict dataset, design rights are limited to consumer electronics-related products. Software designers in the graphic user interface and engineering designers in industrial tools are labeled as non-industrial designers even if they are affiliated to the design department since these kinds of designers are more likely to have an engineering background. To prevent misidentification of non-designer inventors as industrial designers who share the same name, we matched a design creator to a patent inventor only when they shared at least one co-worker or when the interspace of active terms between inventing and designing was less than three years.

C. Variables

Dependent Variable. To test our theory, we estimated invention impact using a proxy, EXAMINER FORWARD CITATIONS, which indicates how many times patent examiners cited the focal patent in the examination of subsequent applications. In general, forward citations well reflect the technological and commercial value of inventions [17][25][43]. Examiner citations indicate conflicting or neighboring patents for which focal applicants or their competitors expensed drafting efforts and official fees; thus, they seem to represent commercial value rather than technological impact. Contrary to inventor citations,

[2] Patent data collected during December 2014 from a commercial patent database, PatentSQUARE.

[3] The detailed process is described in the Appendices.

uniformity of the reference process assures relatively high accuracy in such economic values.

Before entering analysis, we confirmed the applicability of US patent arguments to Japanese patents. Japanese literature has already investigated the reliability of forward citations as an impact indicator. By inventor survey, [44] discovered that examiner citations are likely to correspond with essentially referenced patents. Reference [48] conducted empirical analysis using large amounts of patent data and revealed a positive correlation between examiner forward citations and patent maintenance term length.

Independent Variables. A dummy variable, which indicates the involvement of at least one industrial designer in the inventing team (INDUSTRIAL DESIGNER; when an industrial designer was involved, the dummy was set to 1), was prepared for testing Hypothesis 1. We also split the time window into four terms (1995–1998, 1999–2001, 2002–2004, and 2005–2007) and took cross-terms between the INDUSTRIAL DESIGNER dummy and application term dummies (when application year is 1995, the 1995–1998 dummy is 1) for Hypothesis 2. A technological knowledge measure was calculated as the following process for the examination of Hypothesis 3.

As a technological knowledge measure, we adopted the breadth of technological experiences in different technological fields possessed by the members of the inventing team (TECH KNOWLEDGE BREADTH). Based on the widely accepted theory on the origin of technology innovation—which stresses new combinations of disparate knowledge [19][29]—dozens of R&D management papers have proven a direct relation between the impact of inventions and variety of inventors' or inventing team members' technology experience [11][12][14][39]. This study follows those works.

In the operationalization of this model, two questions arise: (1) how do we measure the breadth of technology fields, and (2) how do we state a window term of valid experience? In regard to the former, we count primary subclasses of International Patent Classification (IPC: 633 subclasses total), which attach to the focal patent. The subclass-level classification represents technological fields and types of methods; thus, it almost corresponds to popular perceptions of technological fields. Some research papers also adopted subclass-level classification (e.g.,., [25]), whereas [5] employed loose classification at the IPC-class level. In line with [33] and [41], we only use primary IPC subclasses instead of all subclasses attached to the focal patent, since it is unreasonable to postulate that all co-inventors share all aspects of the focal invention. For the window term, we employ a five-year cutoff based on an estimated annual obsolescence rate of patented knowledge of 20%. This is in accordance with [35], which estimated the rate at 25%, and [47], which calculated the rate as 21%. Using this cutoff, [24] found a significant correlation between an inventor's technological performance and their past five years' inventing experiences.

Control Variables. Our test approach for Hypothesis 1 faces a single counter-argument: the estimated effect may contain a benefit from knowledge diversity due to cross-site or cross-functional collaboration. As [2] proved, the geographical distance between collaborating parties drives the commercial impacts of developed technologies. In Hitachi, collaborations between the Tokyo-based design department and engineering sections, generally located in suburban areas, often benefit from geographical distance. To control for such an effect, we counted how many different sites join the inventing team (SITES) using the inventor address on the patent document. Our concern is knowledge diversity yield from daily communication; therefore, we defined different sites as different cities.

The regression analysis employs several other variables related to characteristics of invention and to patenting activities:[18][39][42][45][48]: INVENTORS (number of co-inventors); LONE INVENTOR (a dummy variable, set to 1 if INVENTORS equals 1 [39]); INVENTOR CITING (number of referenced prior patents by inventors, which is a proxy of quantity of accessed knowledge [18][42]); CLAIMS (number of claims, represents the technological breadth of patented invention [48]); TRI-APPLICATION (a dummy variable, set to 1 only if focal invention is also filed in both the United States and Europe [45]); EXAMINATION REQUEST (a dummy variable, set to 1 if the applicant requested examination of focal invention); FAST TRACK REQUEST(a dummy variable, set to 1 if the applicant requested fast-track examination); REFUSAL OBJECTIONS (number of objections made by the applicant to a refusal to grant a patent); and INSPECTION REQUESTS (number of inspection requests for file wrapper for patent made by third parties). We also control application year fixed effects by dummy variables (APPLICATION YEAR dummies) and technology field effects by primary 3-digit IPC dummies (TECH FIELD dummies).

D. Analysis model

Table 1 summarizes the variables. Table 2 shows their correlation matrix. In our dataset, the 648 applications include industrial designers as co-inventors and only 30 inventions are lone inventions by an industrial designer.

The dependent variable is count data and is over-distributed; thus, we test for the effects of our hypothesized factors using a negative binomial model. Variance inflation factors are less than 2 (not reported).

TABLE 1 SUMMARY OF VARIABLES

Variables	Description	Min	Max	Mean	Std. Dev.
EXAMINER FORWARD CITATIONS	Number of forward citations made by examiners	0	116	2.911	4.476
INDUSTRIAL DESIGNERS	The dummy that takes 1 if focal patent includes at least one industrial designer as a co-inventor.	0	1	0.009	0.092
TECH KNOWLEDGE BREADTH	Number of distinctive 4-digit IPCs, which all inventors have experienced in past five years	0	51	7.141	6.107
SITES	Number of cities which appears at inventor address of all co-inventors	1	11	1.274	0.551
INVENTORS	Number of co-inventors	1	23	3.173	1.778
LONE INVENTOR	The dummy that takes 1 if co-inventors are 1	0	1	0.177	0.381
INVENTOR CITINGS	Number of reference patents in the document	0	66	1.286	1.534
TRI-APPLICATION	The dummy that takes 1 if focal patent applied in the United States and Europe	0	1	0.076	0.265
CLAIMS	Number of claims for patent	1	96	6.602	5.378
EXAMINATION REQUEST	The dummy that takes 1 if applicant requested an examination for focal invention	0	1	0.516	0.500
FAST TRACK REQUEST	The dummy that takes 1 if applicant requested a fast track examination for focal invention	0	1	0.010	0.101
REFUSAL OBJECTIONS	Number of objections from applicant to refusal of patent granting	0	2	0.051	0.219
INSPECTION REQUESTS	Number of inspection requests of patent file wrapper from third parties	0	61	0.071	0.597

TABLE 2 CORRELATION MATRIX

		1)	2)	3)	4)	5)	6)	7)	8)	9)	10)	11)	12)
1)	EXAMINER FORWARD CITATIONS	1.000											
2)	INDUSTRIAL DESIGNERS	0.066	1.000										
3)	TECH KNOWLEDGE BREADTH	0.128	0.066	1.000									
4)	SITES	0.103	0.078	0.318	1.000								
5)	INVENTORS	0.122	0.051	0.567	0.444	1.000							
6)	LONE INVENTOR	-0.081	-0.032	-0.347	-0.230	-0.566	1.000						
7)	INVENTOR CITINGS	0.046	-0.013	0.159	0.077	0.141	-0.091	1.000					
8)	TRI-APPLICATION	0.093	-0.010	0.096	0.079	0.104	-0.067	0.054	1.000				
9)	CLAIMS	0.165	-0.001	0.124	0.084	0.131	-0.103	0.114	0.134	1.000			
10)	EXAMINATION REQUEST	0.142	0.025	0.083	0.105	0.166	-0.135	0.105	0.233	0.068	1.000		
11)	FAST TRACK REQUEST	0.029	0.032	0.029	0.024	0.054	-0.026	0.016	0.089	0.036	0.099	1.000	
12)	REFUSAL OBJECTIONS	0.101	0.003	0.050	0.046	0.074	-0.049	0.032	0.114	-0.016	0.223	0.084	1.000
13)	INSPECTION REQUESTS	0.124	0.053	0.066	0.039	0.072	-0.034	0.022	0.073	0.010	0.107	0.152	0.098

IV. FINDINGS AND DISCUSSION

A. Findings

Table 3 lists the estimated results of the four models. Model 1 contains only control variables. Coefficients of control variables are consistent with prior research findings and theoretical predictions; especially, both TECH KNOWLEDGE BREADTH and SITES enhance technological impact at 0.1% significance. To test Hypothesis 1, Model 2 includes the INDUSTRIAL DESIGNERS dummy in addition to control variables. To examine Hypothesis 2, Model 3 resolves the INDUSTRIAL DESIGNER dummy into four dummy variables by application year terms. Finally, Model 4 takes a cross-term between the INDUSTRIAL DESIGNER dummy and TECH KNOWLEDGE BREADTH for evaluation of Hypothesis 3.

Fitness of all four models is sufficient level to several previous patent analyses; but objectively it is not so high. Although major control variables are included, their pseudo R-squared are between 0.27 and 0.31. One possible explanation is that they lack important organizational factors; an R&D investment and organizational knowledge stock, which have been used in a cross-organizational analysis [5]. Our dataset is limited to a single organization; but this limitation also realizes an important control of unobservable organizational factors, such as organizational inventive systems for inventing or organizational cultures of cross-functional collaborations.

Another explanation will be a lack of individual factors, such as educational backgrounds [14][19][35] and social network effects [40]. Apparently, to the extent of our research interest, there may be a close link between educational backgrounds and their affiliations whether they are industrial designers or not. Of course, a distinction between academic degrees among engineers may improve the fitness of our models; but this is not our main argument. In contrast, the social network effect is perhaps an important limitation of our research. Industrial designers often work cross-sectorally, overarching several product categories; thus, they may have a broad engineer network[4] and hold unique network positions, such as "structural hole," which bridges two different groups and brings an opportunity for arbitrage [5]. Yet, as recent longitudinal inventor performance study in Japanese electronics industry revealed, being in the structural hole significantly decreases the inventing productivity of engineers, and the social network effect remains unclear.

Our key independent variable, INDUSTRIAL DESIGNERS, shows a positive effect on EXAMINER FORWARD CITATIONS at 0.1% significance. Compared with Model 1, an inclusion of this independent variable improves Nagelkerke's Pseudo R-squared from .269 to .272. The fitness of Model 2 is better than Model 1. A positive effect of enrollment of industrial designers is substantial and far-reaching; that is, industrial designers improve on EXAMINER FORWARD CITATIONS at 0.5 citations (17.8% increase). This magnitude is the same as for cross-organizational R&D team composition with members from more than eight sites. This result supports Hypothesis 1.

Interestingly, this positive effect is only observed in patent applications from more than a decade ago. In stark contrast, in Model 3, the INDUSTRIAL DESIGNERS dummy from 2005 to 2007 has no significant effect, with a 0.1% level positive and significant effect of these dummies from 1995 to 2001. Among relatively old patents, industrial designer enrollment increases technological impact in general; however, this influence is diminished in more recent patents.

One possible explanation of this phenomenon is the growth in technological complexity. Industrial designers, mostly with an arts-oriented education, have relatively less specific and advanced engineering knowledge; thus, their technological contributions are likely to be small when technological development becomes more complicated and requires leading science knowledge. One might assume that our estimation result simply shows it becomes difficult for industrial designers to contribute to technology development in the 21st century.

Our collateral evidence, however, seems to reject such an interpretation. Figure 2 shows a transition of industrial designer-enrolled patent application share in Hitachi Group. Average share marks 0.8% and a linear approximation of the transition is a decrease of a mere 0.008% per year. This implies that enrollment difficulty remains static. In addition, most of the major technology fields where industrial designers contribute are not changed and even in changed fields, relative technological performance has been not superior. Table 4 lists five major IPC subclasses in which industrial designers were enrolled in inventing: three subclasses (G06F, H04N, G06Q) are for data processing and two are for domestic appliances. Shares of industrial designer-enrolled patent applications in the data processing field remain unchanged before and after 2001; however,

TABLE 3 IMPACT OF INVENTIONS: EXAMINER FORWARD CITATIONS ESTIMATIONS (NEGATIVE BINOMIAL MODEL)

	Model 1	Model 2	Model 3	Model 4
INDUSTRIAL DESIGNERS		0.479***(0.045)		0.497***(0.093)
INDUSTRIAL DESIGNERS('95-'98)			0.477***(0.072)	
INDUSTRIAL DESIGNERS('99-'01)			0.508***(0.073)	
INDUSTRIAL DESIGNERS('02-'04)			0.206*(0.103)	
INDUSTRIAL DESIGNERS('05-'07)			0.101(0.134)	
*INDUSTRIAL DESIGNERS * TECH KNOWLEDGE BREADTH*				-0.002(0.007)
TECH KNOWLEDGE BREADTH	0.016***(0.001)	0.016***(0.001)	0.016***(0.001)	0.016***(0.001)
SITES	0.070***(0.009)	0.067***(0.009)	0.067***(0.009)	0.067***(0.009)
INVENTORS	0.003(0.004)	0.004(0.004)	0.003(0.004)	0.004(0.004)
LONE INVENTOR	-0.063***(0.014)	-0.061***(0.014)	-0.061***(0.014)	-0.061***(0.014)
INVENTOR CITINGS	0.034***(0.003)	0.035***(0.003)	0.035***(0.003)	0.035***(0.003)
TRI-APPLICATION	0.150***(0.017)	0.154***(0.017)	0.153***(0.017)	0.154***(0.017)
CLAIMS	0.038***(0.001)	0.038***(0.001)	0.038***(0.001)	0.038***(0.001)
EXAMINATION REQUEST	0.436***(0.010)	0.433***(0.010)	0.433***(0.010)	0.433***(0.010)
FAST TRACK REQUEST	-0.037(0.043)	-0.048(0.043)	-0.051(0.043)	-0.048(0.043)
REFUSAL OBJECTIONS	0.235***(0.019)	0.238***(0.019)	0.239***(0.019)	0.238***(0.019)
INSPECTION REQUESTS	0.120***(0.007)	0.118***(0.007)	0.118***(0.007)	0.118***(0.007)
(Intercept)	0.192***(0.027)	0.202***(0.027)	0.201***(0.027)	0.202***(0.027)
(APPLICATION YEAR Dummies)	Yes	Yes	Yes	Yes
(TECH FIELD Dummies)	Yes	Yes	Yes	Yes
Observations	75,932	75,932	75,932	75,932
Log-Likelihood	-320,873	-320,744	-320,738	-320,744
Nagelkerke R-squared	.269	.272	.272	.272

Standard errors in parentheses. ***: p < 0.001, **: p < 0.01, *: p < 0.05

[4] In our dataset, this assumption is not proved. In the inventor network, which is calculated by co-inventing relations at our observations, an industrial designer's average direct network nodes (unique co-inventors) are 9.061, slightly smaller than non-industrial designer's average (9.365). Their gap is not statistically significant (t value = -0.316, p = 0.752).

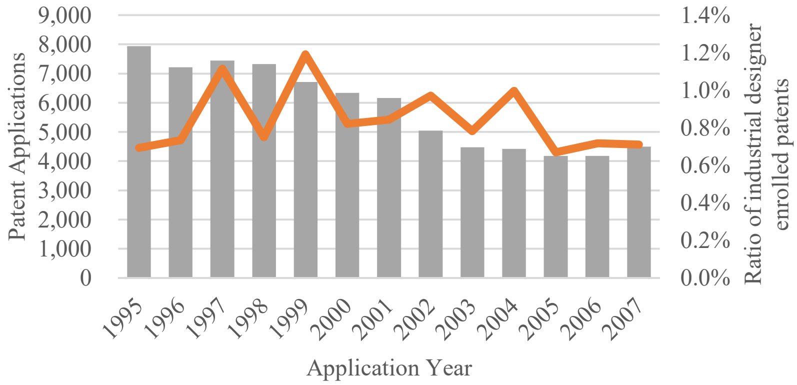

Figure 2 Transitions of Ratio of Industrial Designer-Enrolled Patent Applications

Table 4 MAJOR CONTRIBUTION TECHNOLOGY FIELDS FROM INDUSTRIAL DESIGNERS

IPC	Description	ID Patent Share		Index of Forward Citations of ID Patents		ID Patents
		'95-'01	'02-'07	'95-'01	'02-'07	Total
G06F	Electrical digital data processing	1.1%	1.2%	2.58	1.54	137
H04N	Pictorial communication	2.0%	2.3%	3.32	1.63	75
A47L	Domestic washing or cleaning	14.0%	5.3%	1.49	1.33	72
G06Q	Data processing systems or methods	2.1%	1.0%	2.49	1.30	37
F25D	Refrigerators	7.7%	1.6%	1.48	1.54	33

Note: **ID patent**: Industrial designer-enrolled patents; **ID patent share**: ID patent share in all Hitachi Group patents in same primary IPC subclasses; **Index of forward citations of ID patents**: Index value of forward citations of ID patents divided by those of other Hitachi Group patents.

relative impact (calculated by forward citations of industrial designer-enrolled inventions divided by those of other Hitachi Group inventions) changed to become significantly smaller after 2001. On the other hand, in the domestic appliance field, patent application share decreased dramatically; however, their qualitative impacts were stable (just 1.5 times higher on average than other inventions, whereas industrial designer-enrolled inventions in data processing technologies had forward citations 2.5 times higher before 2001). Considering the situation in digital technology in the 1990s, when the field was mainly populated by "geeks," industrial designers may have felt at ease joining digital data processing technology development throughout the 2000s. Our supplemental analysis implies technological complexity growth is not a vital factor of the Model 3 result.

In contrast, Hypothesis 2 fits well with the empirical result as well as with some cases. Let us pick up some frequently cited patent applications by industrial designers in our dataset. One such application is JP Patent Application Publication No. H10-63682, applied for in 1996 with the title: "Method and System for Providing Guidance Information of Products" and that had received 45 forward citations by the end of 2014. This invention established an idea about an online database of user guide manuals and troubleshooting information. This database was designed to introduce appropriate repairers by connecting the user's address information with repairers' locations and specialties. From a 2010 point of view, it is not so surprising; however, in 1996, when Internet Explorer and Netscape Navigator had just started their "browser war," it was a novel idea. Another case is JP Patent Application Publication No. H9-305259, titled "Information Processing Equipment and Its Operation." Filed in 1996, this invention received 39 forward citations. It is about a tablet personal computer, like Microsoft's Surface Pro. Two slim connected touch screens were disclosed: one to display documents and another for input by handwriting recognition or virtual keyboard. Interestingly, both inventions were designed by industrial designers, without engineers, and were rejected by examiners due to their failure to demonstrate distinctive inventive steps. These ideas look too early to be born; thus, engineers and intellectual property managers may not attempt to refine the applications. These cases constitute evidence for Hypothesis 2.

Lastly, the cross-term between INDUSTRIAL DESIGNER and TECH KNOWLEDGE BREADTH is not significant (Model 4). This result rejects Hypothesis 3a and is consistent with Hypothesis 3b. We will discuss how to interpret the result in the following section.

B. Roles of industrial designers in technology developments

These results let us extend to a further question: what kinds of capabilities do industrial designers contribute to improving the impact of technological outputs?

First, empirical evidence finds that latent demand-based goal setting from user demand-oriented thinking is a unique characteristic of industrial designers. Delays in impact growth support the supposition that industrial designers are likely to provide novel concepts of technology; however, the lag time in acceptance by engineers and the market is nearly 10 years. Besides, no interaction with technological knowledge variety suggests that technological steps for the concept seem to be far from the general inventing process; instead, it may involve deceptively difficult technology brokering or a novel application of a known technology, as previously discussed in the formulation of Hypothesis 3b (Section II.B).

On the other hand, we failed to prove any contribution from another unique characteristic of industrial designers, consensus-building enhancement. In Hypothesis 3a, we expected a positive interaction between technological knowledge and enrollment of industrial designers. Especially, we assumed that industrial designers might mediate the technological knowledge gap between inventing members; however, no mediation is found in our estimation.

There are two potential explanations. One explanation is that industrial designers do not assist the general inventing process (involving technological knowledge recombination) because they are not technological specialists. Another explanation is that their assistance is not observable in our method. The consensus-building enhancement does not look directly at the inventing activity; thus, R&D managers and persons in charge of intellectual property management might not regard them as one of the co-inventors. This is regarded as natural in patent documents because all co-inventors acquire compensation for an assignment of patent rights. We cannot state the applicability of these interpretations and they are open to future research.

V. CONCLUSION

A. Summary

This study examined whether industrial designers can contribute to technology development. Based on recent design arguments, we can expect that industrial designers, although not technological experts, are likely to stimulate technology innovation by taking advantage of their two unique characteristics: user demand-oriented thinking and consensus-building enhancement. To test these assumptions, we conducted a regression analysis on the relationship between industrial designer enrollment and impacts of inventions using information from 75,932 patent applications by Hitachi, a Japanese electronics manufacturer. In the analysis, we adopted the examiner forward citation as a proxy for the impact and defined industrial designers using design right bibliographies.

Our estimation confirms the significant contribution of industrial designers to high-impact inventions. The estimation result shows that an enrollment of industrial designers increases forward citations by an average of 17%. This magnitude is larger than that for inter-site collaborations. Our estimation also shows that emergence of this impact is delayed by almost 10 years. We can interpret that these contributions of industrial designers stem from their latent demand-oriented thinking in line with findings from previous studies [7][32][34]. On the one hand, this paper not only provides empirical evidence for those case study-based works, but also expands their theory by confirming superiority in the impact of industrial designer-enrolled inventions. On the other hand, consensus-building enhancement, which is argued in recent design studies [7][34], seems not to contribute to high-impact inventions. However, this could be due to our methodological limitations.

B. Limitations

Although we achieved a novel finding using a unique dataset, our analysis includes several limitations due to its dataset, operationalization, and analytics. First, our definition of industrial designers is narrow: we only consider industrial designers involved in consumer electronics products. Based on our discussion, all kinds of industrial designers might contribute to technological innovation; however, this generalization is not directly supported by our data. Second, individual creativities are ignored in our analysis. There is a possibility that industrial designers who join inventing teams are exceptionally creative. Third, the fitness of our regression results remains not strikingly high. Several important factors may be dropped. Especially, we neglected social network effects. Our intuition is that industrial designers benefit from their unique network positions to achieve valuable inventions. This may be a counterargument to our theoretical discussion, although practical implications are exactly the same. Finally, voluntary enrollment is likely to drive the relatively large magnitude of industrial designer enrollment. A majority of inventors have a duty to invent, in contrast to industrial designers. In such a case, engineers join research work based on an extrinsic motivation, while industrial designers voluntarily enter according to an intrinsic motivation. Intrinsic motivation drives creativity [1]; thus, industrial designers might perform creatively. The latter two limitations do not constitute a counterargument to our discussion, but urge us to take precautions that not all industrial designers contribute to technology development.

C. Practical implications

This paper provides an important implication for R&D managers and top managers: R&D teams should not exclude industrial designers. Our analysis clearly confirmed the benefit to technological output of including industrial designers in the R&D activity. Considering recent new product development theories, the benefits of enrollment are not limited to R&D output but also include product success. Industrial design is now considered the most important communication measure for consumers to recognize the functional values of a product [9][21][37]. The enrollment of industrial designers in the R&D process enhances their clear understanding of novel technology and promotes a suitable industrial design for appealing technological values. Of course, we can expect industrial designers to plan a novel concept of a product as well as a technology with user latent demand-oriented thinking.

Intriguingly, one of the innovating companies, Dyson Ltd., manages R&D and industrial design integrally, in line with our findings. They train "design engineers" who conduct both R&D and industrial design development. This paper gives an essential explanation as to why Dyson continues with its serial technological and commercial innovations.

Although our findings confirm the value of including industrial designers, it remains unclear whether or not organizations should intentionally formulate R&D teams to include industrial designers. Our dataset does not distinguish enrollment from voluntary participation. If the positive effect derives only from their intrinsic motivation, then organizations should not force industrial designers to join in with technology development. Our practical implication rests at a passive term: an exclusion of industrial designers is a loss of technological innovation opportunity. This implication clearly gives opposition to the dogma that R&D activities are the exclusive domain of scientists and engineers.

D. Future research

As discussed above, our study omitted a couple of research issues. First, we do not confirm the positive value of consensus-building enhancement functions. This characteristic might assist the novel recombination of different technological knowledge; however, our dataset seems not to match to test the value. This value is one of the components of design thinking. If the value exists, then design thinking as a whole might contribute to technological innovation. Such an investigation would enrich design thinking arguments. Second, we do not state whether or not R&D managers should intentionally enroll industrial designers into their R&D teams. Further micro-level investigations are required. These future studies will extract full capability for innovation from industrial designers. Finally, social network effects should also be investigated. Industrial designers may bring technology innovation by arbitrage, utilizing their unique social network positions. While existing inventor social network literatures (e.g. [22][40]) have focused on co-inventor network, it may be an issue whether the social network should involve co-designer network.

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APPENDICES

Procedures of inventor name unification (disambiguation):

1. Chinese character variations included in the standard character set are defined by the Japan Industry Standard and are modified to the common characters defined by Japan's Ministry of Education, Culture, Sports, Science and Technology as a regular use Chinese character. When two certain modified names are equal, in accordance with the two criteria below, we judged that the names were of the same inventor/creator.
   - The interspace of active terms for the two inventors is less than 3 years.
   - They share more than 50% of experienced technology fields (defined by primary International Patent Classification subclass (4-digit in number and alphabet) of applied patents invented by focal inventor) or share more than 25% of fields and co-inventor.
2. Typically misused (listed by authors) single or combined Chinese characters are also consolidated as an expedient. The same consolidated names are judged as the same inventor using the following three criteria:
   - The interspace of active terms for the two inventors is less than 3 years.
   - They share more than 50% of experienced technology fields or share more than 25% of fields and co-inventor.
   - The number of applications of one inventor is 3 times as many as for another.
3. Some distinctive and not ordinary women's first names are specially checked to detect a family name change by marriage or divorce under the following three criteria. We also searched personal information on Facebook and LinkedIn where possible to check the reliability of these criteria.
   - The interspace of active terms for the two inventors is less than 3 years, and the overlap of active terms is less than 2 years.
   - They share more than 50% of experienced technology fields or share more than 25% of fields and co-inventor.
4. In addition, we conducted a visual inspection to detect inconsistent names of apparently the same inventor, such as;
   - similar names holding unique first name, and their fields and interspaces fulfill the above criteria but were possibly mistyped, and
   - names of foreign inventor with various spellings, such as different spellings of long vowel or peculiar sounds or an abbreviation of the middle name.

Observed Companies

Attribution	*Company Name*
Parent	Hitachi Ltd.
Subsidiary	Hitachi Appliance Inc. (2006-)
	Hitachi Home & Life Solutions, Inc. (2002-2006)
	Hitachi Air Conditioning Systems Co.,Ltd. (1998-2006)
	Hitachi Home Tech K.K. (-2004)
	Hitachi Lighting Ltd. (2003-2010)