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Abstract: “Design-driven Innovation” is now widely recognized as one of the most competitive business creation approach. This concept includes cross section of design-oriented innovation and technology-driven innovation (Verganti, 2009). However, these arguments tell littlie about innovators for such a type of innovation. This study tried to examine a potential of industrial designers to technology innovation. Using data of patents applied by Japanese major 16 home electronics companies during 1995-2004, we examined the correlation between technological quality of patents (measured by inventor forward citations and examiner forward citations) and their inventors’ categories (measured by intra-firm rank of aggregated numbers of patent applications and deign registrations). In the categorization, we have set top productivity design right creator as a group of industrial designers, who are belong to the design department or the design center. Our result shows including a top productivity design right creator as an inventor will lead to be significantly higher in technological quality. Especially, creators who represent medium-top level patent productivity and top design productivity, hold a consistently high and significant positive effect on their technological outputs. This result suggests that industrial designers who have certain amount of technical knowledge play a key role in design-driven technology innovation.

Keywords: Design-driven innovation; design inspired innovation; interaction between technology and industrial design; technology innovator.

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1. Introduction

“Design Driven Innovation” (Verganti, 2009) or “Design Inspired Innovation” (Utterback et al., 2006), a concept of design-oriented (or novel meaning oriented) product/service planning, is now widely recognized as one of the competitive business creation approaches. This approach focuses concept oriented product development to bring a novel meaning into the product, as represented by iPod (Apple Inc.), Allesi’s kitchen wares (Allesi S.p.A.) and Wii (Nintendo Corp.). A unique product concept and a consistent strategy overcome various market barriers or technological obstacles. Indeed, iPod established a new virtual market for the music industry, Swatch turned watches into daily dress-up accessories from lifelong adornment and Wii intercalated a novel controller, which provides a completely fresh experience for users and expands game players to senior citizens.

Design driven innovation is not isolated from technology innovation, but includes interactions with technology. For example, Verganti(2009), analysing four cases (Wii of Nintendo Corp., Swatch, iPod of Apple Inc. and ST Micro Electronics), revealed that an industrial design feature unveils substantial value of technology innovation, and even in the high technology firm design is a core driver of technological breakthrough. These cases imply not only industrial design features contribute user’s cognition of the meaning of the technology innovation (see, Rindova and Petkova, 2007), but also designs formulate user needs, translate them into product concept and define a necessary technology innovation (Moody, 1980). To illustrate, an investigation of 44 innovative projects in British SMEs has revealed that commercially successful technological innovation projects involved various aspects of design innovation (Roy and Riedel, 1997).

Our interest is in an innovator: who can drive a design-driven innovation brought by interaction between design and technology? Although Verganti(2009) emphasizes the importance of interpreters of product/service meaning, he did not state any specific characters of such interpreters. In this regard, a global leading design consulting firm, IDEO, provides rich implications to us. Their core value, “design thinking” is based on a typical skill set for industrial designers (Brown, 2009). Design thinking focuses a user observation, a user experience understanding, a brain storming with various actors, and trials and tribulations. Industrial designers, using such methods, have been led a design-driven innovations. However, even they can bring an innovative concept, it still remains unclear whether industrial designer can manage interaction between design and technology.

We can assume that industrial designers potentially contribute to technology innovation. Borja de Mozota(2003) discussed the potential ability of industrial designers to contribute to technological improvement. He mentioned that some designers mediate technologies among organizations.

Nevertheless, design and technology are regarded as “apples and oranges” or “oil in water”(Candi, 2010) in corporate strategy. Especially, among high technology firms, design rarely captures their attention; for example, although positive relations are found between attractive new customers and using educated designers, a limited number of Scandinavian high-tech startups use such designers (Candi, 2010). Under such a condition, it is hard for designers to enroll in a technology development. Also, Moody(1980) found in several UK Design Awarded firms that design stimulate technological innovation, but an industrial designer provides limited affection to the innovation.

Consequently, we do not dissipate the doubt about whether industrial designers can serve as a driver of interaction between designs and technologies. Therefore, this paper focuses on the role of industrial designers in an interaction between design and technology as a part of basis for design-driven innovation.

2. Research question: Interaction between technology and industrial design

(1) Definition of "design" in this paper

The word of "design" is ambiguous, even in academic debates; some scholars refer only aesthetic ornamental, others mean planning or synthesizing activities of a certain system. At least, the definition of "industrial design" by International Council of Societies of Industrial Design covers key factors of design driven innovation debates;

> Industrial design is a creative activity whose aims are to determine the formal qualities of objects produced by industry. These formal qualities are not only the external features but are principally those structural and functional relationships which convert a system to a coherent unity both from the point of view of the producer and the user. Industrial design extends to embrace all the aspects of human environment, which are conditioned by industrial production. (ICSID, 1969)

Consequently, we use the term of "design" as industrial design. But considered the suggestions of prior studies (which are descried at the following subsection (2)), this paper mainly focuses on the styles or shapes. Therefore, in this paper, we refer "industrial designers" as the designers who create a shape or an ornamental of the product. Generally speaking, among home electronics companies, those people belong to a design center or a design department and have educated in designing.

(2) Fitness of Industrial designers for technological innovation

Freeman(1974) and Freeman & Soete(1997) stated two requirements for innovation; a coordination of different organizations and a user-needs oriented concept making. In the concept-oriented development process, necessary resources are often scattered over different departments in the focal organization or other organizations, therefore a coordination of multiple departments is the core driver of product/service competitiveness. In fact, in the automobile industry, "heavyweight product development managers," who integrate engineering, marketing, manufacturing and design, significantly contribute to product integrity and commercial success (Clark and Fujimoto, 1990).

To this extent, industrial designers can be a driver of innovation. Firstly, their task relates various departments, like marketing, manufacturing and engineering; consequently, they inevitably acquire communication and coordinating skill (Gregory, 1966). Moreover, their visualization skill, such as drawing images of product concept or arranging mock-ups, assists understanding the product concept among different background members (Walsh, 1992). In this way, whether designers exercise their leadership or not, they contribute integration among different organizational functions. Secondly, industrial designers are well trained in user-needs oriented concept development (Gregory, 1966). Of course we do not stand to all industrial designers hold such skills, however, as these skills might improve productivity, we can assume that many designers who have generated a certain amount of designs are endowed or acquired these capabilities.

In addition to those basic skills for innovation, most of industrial designers, at least who creates shapes of the product, have a fair understanding of technologies. Product designing process requires a fundamental understanding of functions and manufacturing process (Gregory, 1966). Indeed, at some design firm, design consultants act as mediators of technology (Hargadon and Sutton, 1997; Borja de Mozota, 2003). A Japanese case study reveals that under trade-off situation between technology and design, designers brought technological breakthrough (Hasegawa, 2012). We can imagine that industrial designers may not only fit for user-needs oriented technology innovation but also engage in novel invention by integrating technological resources of inter-organizational functions.

As Fujimoto(1991) mentions, this innovation may be observed only in modularized and user-interface-oriented industries. In a non-modularized industry, any technology development processes requires sufficient engineering knowledge, so there is limited contribution of designers to the invention. In those industries where user interface does not add any value, roles of designers are limited.

Based on discussions above, we can introduce the following hypothesis;

Hypothesis 1: In a modularized and user-interface-oriented industry, industrial designers, who create relatively high quantities of industrial designs (especially shapes), will contribute to the technological innovation.

Prior studies only touch the integration capability of designers, but they may also invent by themselves as long as they have some technical knowledge. In some leading design-driven innovation cases, such as Dyson's cyclone vacuum cleaner, core technologies are invented by product designers (in Dyson's case, see James Dyson's autobiography: Dyson, 2000). Consequently, we can also establish a further hypothesis by modifying hypothesis 1 as follows;

Hypothesis 2: In a modularized and user-interface-oriented industry, industrial designers, who create relatively high quantities of industrial designs, will contribute to the technological innovation ***by inventing some core technology for the realization of their product concept by themselves****.*

3. Methodology

(1) Outline of research design

In this study, we investigate Japanese home electronics manufactures. Japanese home electronics makers have brought several design-driven innovative products for these three decades. Numerous design management and design innovation studies covered these cases; such as Sony's Walkman and Nintendo's Wii (Walsh, 1992; Verganti, 2009). The home electronics industry was selected, since industrial designers are assumed to have a relatively high influence on product development process as Fujimoto(1991) mentioned.

To test hypotheses, two types of data are required; (i) technology development performance at individual, team or organizational level and (ii) inventor's skills of coordination and user-oriented thinking. While technology development performance can be observed by using public data such as patents (Ernst(2003) provides a conceptual framework of patent data analysis for performance investigation), inventor's skills are basically measurable by a questionnaire survey. However, as we discussed previous section, if we stand on the assumption that quantities of design outputs indirectly shows whether each designer holds such skills, we can estimate by using design right bibliographic data.

We used patent and design right applied to Japan Patent Office[1]. Japanese companies tend to apply these industrial property rights to Japan first and later choose international protection, therefore, patents and design rights in Japan well represent a real output of technology or design without any selection bias by applicants. Japanese data include a further advantage. Contrary to European Community Design, Japanese design right system protects only a shape, so the data are well fitting to our hypotheses, which assume a shape design skill relates to a technology creation. On the other hand, Japanese design right data include certain noise. Contrary to United States Design Patent, Japanese design system does not exclude functional shapes from the subject matter of protection. Some applicants use design right as a complement of patent protection (Japan Patent Office, 2010), hence, creators of design rights includes engineers. The next paragraph will explain the procedure to control this point.

Provided that engineers rarely register too many designs and designers rarely apply too many patents, we distinguished engineers and designers by the total number of patents and design registrations; a large number of design creations and a less number of inventions would indicate that the focal inventor is an industrial designer, while a large number of inventions and a modest number of designs would represent an engineer. This procedure will not specify all affiliations of inventors, however, at least identify a highly possible group of industrial designers. In addition to the identification matter, we can assume that inventors in top design productive categories may hold a designing skill set as we have hypothesized above.

We defined 12 inventor categories by number of patent applications and design rights for 15 years. First, we calculated total numbers of patent applications and design registrations by inventors (we treated primary inventor and other co-inventors equally) and have measured their in-firm ranks (relative productivity in their companies). Next step is s classification of inventors into categories by 3 levels of patent application rank (top/medium/low) and 4 levels of design registration rank (top/medium/low/no design registration).

We used a number of 15 years total patent/design production; we stand on the supposition that a design productivity of the focal creator in long-term window might well represent his/her designing skills. In addition, a distinction between engineers and designers are expected to be more obvious in long-term data. In-firm rank was adapted to control a gap of patent/design right propensities among sample companies. Dividing points are set by an inventory survey of affiliations of inventors at randomly chosen sample companies to identify the highly possible group of industrial designers (details are described below).

Afterwards, we analyzed correlation between technological quality of each patents defined by inventor forward citations and categories of inventors of focal patents.

(2) Data generating process

For an empirical analysis, we used patent applications and design right registrations, which applied from 1995 to 2009 by Japanese 16 major electronic home appliance manufactures to Japan Patent Office. All companies belong to Association for Electric Home Appliances (Japan) in Jun. 2013 and applied more than 1,000 patents for 15 years. In this study, we examined 877,229 patent applications and 52,457 design right registrations (see table A1 at Appendix).

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[1] We used design registrations to Japan Patent Office. Design protection systems are differ among countries; U.S. adapts the design patent (examining the novelty and requiring claims), European countries have the design registration system (registering without any novelty examination and requiring only figures) and Japan prepares the design right system (examining the novelty and requiring only figures).

Our research data generated as follows. To calculate the number of each inventor's patent applications and design right registrations, inventors and creators are combined by name and active period. On the extraction of their names, we aggregated some varieties in names and excluded suspicious inventor/creators who might share same first and last names.

In the category setting, we defined 12% and 25% as a border, since we have found in three sample companies that a large majority of upper 12% creators, who have at least one patent application, are industrial designers[2] (see also, Figure A1 and A2 at Appendix). By this mean, each inventor is classified like "inventor A is top 12% inventor/top 13%-25% creator" and each patent is described like "Patent X includes 3 of top 12% inventor/top 13%-25% creator and 2 of top 26%-inventor/no design registration".

Afterwards, we derived an attribution of each patent's inventor. All inventors are classified into 12 categories by the rank of a number of patent applications (as top 12%/13-25%/26%-) and the rank of a number of design rights (as 12%/13-25%/26%-/no design registration). In this procedure, we used15 years total number for the following two reasons. First, in regard to design rights, as previously discussed, we focus on long-term design output as an alternative indicator of basic skills for innovation. Second, in regard to patents, we used a total number of patent application as a branching point of an industrial designer and an engineer.

Interestingly, inventors at the "top 12% inventor/top 12% creator" are both engineers and industrial designers. On the other hand, a large part of inventors at "top 13-25% inventor/top 12% creator" and "top 13-25% inventor/top 13-25% creator" are approximately industrial designers. Likewise, "top 12% inventor/top 13-25% creator", "top 12% inventor/top 26-100% creator", "top 12% inventor/no design registration" are virtually engineers[3] and not industrial designers.

Meanwhile, in this paper, we regarded inventor's in-firm rank of an aggregated number of patent applications/design registrations as proxies of inventor's patent/design productivity. Especially, as discussed above, we stood on the assumption that high design productivity represents their designing skills.

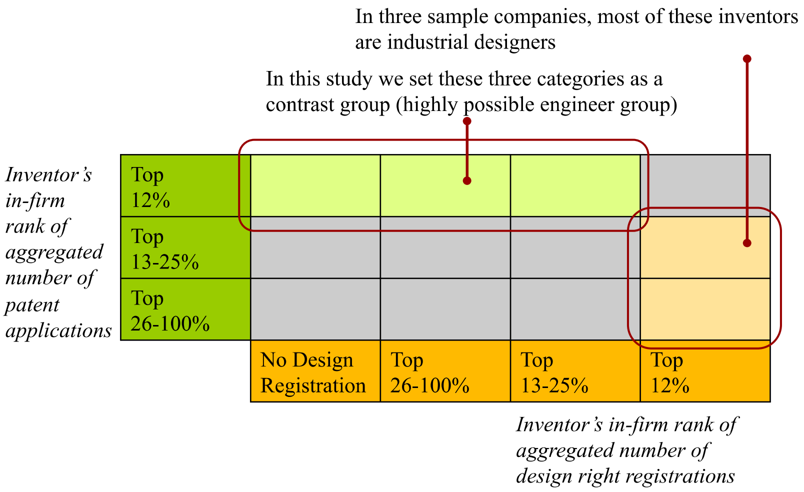

Figure 1 Definition of inventor's category

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[2] We have searched individual name on the Internet and checked whether those inventors are belong to design department or design center.

[3] Including researchers or scientists.

(3) Variables

Dependent variables

As dependent variables, which represent technological quality of patents, we have chosen two bibliographic data; a number of cited by inventors of subsiding patents or by examiners in examination processes of subsiding patents. Regarding US patents, plenty of prior studies considered that forward citations reflect technological qualities of the invention (for example; Trajtenberg, 1990). This idea is almost applicable into Japanese patents. Suzuki & Goto (2006) found inventor forward citations are correlated with technological quality[4]. Yamada (2010) revealed examiner forward citations are stable indicators of patent quality[5].

Although both indicators are representing similar aspects of patents, these two are substantially different. Inventor forward citations are made when inventors emphasize their progress on prior inventions or indicate their technological genealogy, while examiner forward citations are made when subsidiary patents are questioned in their patentability due to the close relationship with a cited patent. In other words, inventor forward citations reflect thr importance of subject matter, while examiner forward citations indicate technology density. In fact, in our sample, these two indicators are not highly correlated; a coefficient between these two variables remains at 0.3685. Thus, we adapted both indicators as dependent variables.

These two variables were standardized by application years and technology fields defined by primary International Patent Classification(IPC) subclasses (IPC 4 digit)[6]; we used *standardized inventor forward citations* and *standardized examiner forward citations* as dependent variables. In this way, we controlled a patent age bias and a technology field bias. Forward citations increase as time past. Also, they differ among fields due to the prosperities of research activities or the convention of documentation. We have diminished their biases accordingly, however, truncation biases are still remains, as we used recent patents. Suzuki & Goto(2006) shows these citations reach the ceil about 10 years after applications. We must aware that about a half of our samples includes the bias.

Independent variables

Independent variables are followings;

- 12 category dummy variables of inclusion of each category inventors[7] (in other words, whether the focal patent include each category inventors) or,

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[4] Measured by whether applicants request examination and how long patents are maintaining.
[5] Measured by patent maintaining periods.
[6] As we have defined the universe as the whole patents applied by all home electronics industry (31 Association for Electric Home Appliances members), averages of standardized inventor forward citation and standardized examiner forward citation are slightly differ from 0 (see, Appendix; Descriptions).
[7] We also tested numbers of each category inventors as explanatory variables instead of dummies. However, the fitness of the model is not improved.

- 3 category dummy variables of whether the patent includes only top 13-100% inventors/top 12% creators (*Only possible industrial designers dummy*: this represents the patent might be created by only industrial designers with high possibility), whether the patent created by a mixed group of industrial designers with high possibility and other attributes (*Possibly industrial designers and other category inventors group dummy*), and whether the patent created by only top 12% inventors except top 12% creators (*Only possible engineers dummy*: this represent a possible group of engineers[8])

Later category dummies are for the test of industrial designer's role in technology innovation. As discussed above, designers may contribute to technology creation by two ways; an integration of engineers and a user-oriented thinking. If the integration function is critical, designers may not create a superior invention without engineers. Therefore, we compared two types of patents; invented by only possibly industrial designers or not. In this comparison, patents invented by only possibly engineers are focused as contrast.

Control variables

Control variables include several bibliographic elements; the number of claims (*Claims*), an existence of US patent family (*US patent family dummy*), an average rate of US patent family existence calculated by all patents in same application year and same technology field[9] (*Average US patent family ratio*), an existence of joint applicants (*Joint application dummy*), an existence of joint applicants who are in the home electronics industry (*Joint application with home electronics firm dummy*). The number of claims is a one of technology value indicators. Suzuki & Goto(2006) reveals that after 1992[10] a number of claims correlates with a maintaining period of patents, a proxy of patent value. Yamada(2010) also mentions that claims are one of the indicators of patent value at least among the electronics industry. An existence of US patent family may indicate subjective value for applicants. Under the global competition, home electronics companies have a strong motivation to apply patents globally, especially, to USPTO as long as the invention is thought to be important.

We added some variables that represent applicant's behavior in patent prosecution, such as an existence of examination request, an existence of first track examination request, a number of appeals against examiner's decision of rejection. These variables may also relate a subjective patent value.

In addition, some patent objective value related elements were inserted into the formula; a number of invalidation trials and a number of requests for inspection of documents. Particularly, a number of invalidation trials is said to be general indicators of patent value (Yamada, 2010).

Meanwhile, we also examined some variables to control gaps of R&D capability and patent claim drafting skill[11], and to control the contribution of well-experienced co-inventor[12], however, these variables shows multicollinearity. Therefore, we did not include these control variables.

Descriptions of all variables are shown at table A2, Appendix.

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[8] Of course, most of inventors are engineers, however, we have adapted the strict borderline.

[9] Defined with IPC subclass.

[10] In this year, Japanese patent system adapted the multiple-claim system.

[11] Applicant dummies are inserted.

[12] We used the earliest application year among co-inventors (provided, however, that the observation window is limited from 1990-2009).

(4) Model for analysis

We applied the negative binomial distribution model in regression analysis, since the variance of dependent variable is higher than the average. Original dependent variable distributed from negative values to positive values, while negative binomial model can apply to positive value. So in the regression analysis, dependent variable is adjusted to be positive by adding minimum value (.756 for inventor forward citations and 1.056 for examiner forward citations) measured in all samples.

To test *Hypothesis 1*, we estimated a linear model formula by negative binomial regression (*Model A*, *B*). *Model A* is a simple model without any control variables. *Model B* is a baseline model, which includes control variables.

For the test of *Hypothesis 2*, we use a dummy variable whether the patent includes only top 12% creators except top 12% inventor (*Only possible industrial designers dummy*) as an explanatory variable instead of 12 inventor category dummy variables (*Model E*). Also, to contrast the impact of this inventors group, we added *Possibly industrial designers and other category inventors group dummy* and *Only possible engineers dummy* (*Model F*)[13].

Finally, to check the robustness, we tested *Model B* and *D* with short-term window data (*Model C* and *G* used patents applied from 1995 to 2004; *Model D* and *H* are from 2000 to 2009).

4. Results

Fundamental statistics of dependent variables are shown at Table 1 and regression results are at Table 2 and 3 (see also the correlation matrix at Appendix). Although technological quality is affected by various factors, such as technical trends, our result succeeded to explain it partially (at *Model B*, Pseudo R^2 indicates 0.1555) and to show a significant impact of specific categories of inventors on two types of forward citations.

(1) Designers' contribution to technology innovation

Regression results reveal that inventors who create relatively high quantity of industrial designs bring technological improvement. At *Model A* to *D*, all three categories of top 12% creator categories (*Top 12% inventor / top 12% creator dummy*, *Top 13-25% inventor / top 12% creator dummy*, and *Top 26-100% inventor / top 12% creator dummy*) indicate positive and almost commonly significant relation with both inventor and examiner forward citations. Especially, *Top 13-25% inventor / top 12% creator dummy* shows a consistently significant positive effect in each model. Inventors in this category are basically industrial designers; therefore, we can confirm a contribution of certain industrial designers to technology development.

As fundamental statistics show (see Table 1), these contributions are from some superior patents. While medians of performance are closer among categories, standard deviations are higher at top 12% creators than top 13-25% or 26-100% creators. Among patents holding at least one top 12% creators, some patents indicate remarkable large number of citations and they raise the average. In other words, top 12% creators invent outstanding technology. As discussed above, a consistent statistical significance is found at *Top 13-25% inventor / top 12% creator dummy*, a part of possible industrial designers. Consequently, *Hypothesis 1* is supported partially, and need to be modified. We confirmed that ***in a***

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[13] We also tested 12 inventor category dummies and 2 inventor group categories simultaneously. However, multicollinearity was found between both types of explanatory variables.

modularized and user-interface-oriented industry, industrial designers, who create relatively high quantity of industrial designs and certain amount of technologies, will contribute to the technological innovation.

Interestingly, the relative impact of industrial designers is high. In regard to inventor forward citations, correlations of possibly industrial designers (*Top 13-25% inventor / top 12% creator dummy* and *Top 26-100% inventor / top 12% creator dummy*) are clearly higher than other categories. At *Model B*, while top 13-100% creators or no design registration inventors show 0.0156 to 0.0443 in estimated coefficients, possibly industrial designers mark 0.0654 to 0.1116, holding roughly 1.5 to 3 times higher effect to inventor forward citation[14]. In regard to examiner forward citations, only *Top 13-25% inventor / top 12% creator dummy* indicates high coefficient same as top productive inventors (*Top 12% inventor / top 12% creator* and *Top 12% inventor / no design registration*). We will discuss this gap in a later section.

(2) Mechanism of designer-involved technology innovation

Our regression results suggest one part of these effects comes from a coordination skill of industrial designers. At *Model F* to *H* for examiner forward citations, *Possibly industrial designers and other category inventors group dummy* (a dummy variable of inclusion of top 13-100% inventors/top 12% creators and other inventors) indicates positive and consistently significant effect to technological quality. For inventor forward citations, although one of three coefficients (at *Model G*) is not significant, results also show a positive effect of the focal dummy variable.

Only possibly industrial designers group dummy marked limited significance; it is significant at *Model E, F* and *G* for inventor forward citation and at *Model F* for examiner forward citation. The result seems to support *Hypothesis 2* partially, however, it is not robust. We did not gain any concrete conclusion about whether industrial designers can create technology innovation by their own accord.

We can conclude that *Hypothesis 2* is not statistically supported, and should be modified as follows: ***In a modularized and user-interface-oriented industry, industrial designers, who create relatively high quantity of industrial designs, will contribute to the technological innovation which is important for business by integrating engineers for the realization of certain product concept.***

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[14] As our independent variables are all dummies (values are 0 or 1), we did not calculate beta coefficients.

Table 1 Fundamental statistics of standardized inventor/examiner forward citation by inventor categories

	Standardized inventor forward citation			***Standardized examiner forward citation***		
	Average	***Median***	***Std. Dev.***	***Average***	***Median***	***Std. Dev.***
Top 12% inventor/ top 12% creator dummy	0.1504	-0.2590	1.3103	0.2844	-0.2168	1.4315
Top 12% inventor/ top 13-25% creator dummy	0.1009	-0.2656	1.4180	0.1631	-0.2501	1.3183
Top 12% inventor/ top 26-100% creator dummy	0.0509	-0.2705	1.1499	0.0633	-0.2781	1.1001
Top 12% inventor/ no design registration dummy	0.0456	-0.2705	1.1146	0.0989	-0.2589	1.1161
Top 13-25% inventor/ top 12% creator dummy	0.1764	-0.2673	1.5487	0.2427	-0.2285	1.3415
Top 13-25% inventor/ top 13-25% creator dummy	0.0515	-0.2573	0.9533	0.0651	-0.2846	1.1016
Top 13-25% inventor/ top 26-100% creator dummy	0.0025	-0.2705	0.8883	-0.0184	-0.3232	0.9632
Top 13-25% inventor/ no design registration dummy	0.0098	-0.2705	0.9858	0.0088	-0.3005	0.9980
Top 26-100% inventor/ top 12% creator dummy	0.1065	-0.2656	1.3839	0.1053	-0.2589	1.2218
Top 26-100% inventor/ top 13-25% creator dummy	0.0315	-0.2656	0.9513	-0.0099	-0.3232	0.9234
Top 26-100% inventor/ top 26-100% creator dummy	0.0041	-0.2705	0.9215	-0.0438	-0.3232	0.9390
Top 26-100% inventor/ no design registration dummy	-0.0228	-0.2851	0.9453	-0.0603	-0.3283	0.9089
Only possibly industrial designers group dummy	0.0775	-0.2851	1.5297	0.0308	-0.3232	1.1010
Possibly industrial designers and other category inventors group dummy	0.0282	-0.2735	1.1054	0.0832	-0.2648	1.1012
Only possibly engineers group dummy	0.1451	-0.2599	1.3061	0.2328	-0.2285	1.3622
(All Sample)	0.0034	-0.2769	1.0084	0.0097	-0.3013	1.0080

Table 2 Negative binomial regression result for technological quality of patents and their inventors' category

	Dependent: Standardized inventor forward citation				*Dependent: Standardized examiner forward citation*			
	Model A	***Model B***	***Model C***	***Model D***	***Model A***	***Model B'***	***Model C'***	***Model D'***
	1995-2009	*1995-2009*	*1995-2004*	*2000-2009*	*1995-2009*	*1995-2009*	*1995-2004*	*2000-2009*
			Base: B	*Base: B*			*Base B'*	*Base: B'*
Independent variable								
Top 12% inventor / top 12% creator dummy	0.1432 *** (0.0124)	0.0319 ** (0.0125)	0.0076 (0.0150)	0.0470 *** (0.0152)	0.1977 *** (0.0100)	0.1434 *** (0.0102)	0.1491 *** (0.0122)	0.1527 *** (0.0124)
Top 12% inventor/ top 13-25% creator dummy	0.1021 *** (0.0090)	0.0230 ** (0.0090)	-0.0074 (0.0111)	0.0298 *** (0.0110)	0.1141 *** (0.0074)	0.0673 *** (0.0075)	0.0462 *** (0.0092)	0.0781 *** (0.0091)
Top 12% inventor/ top 26-100% creator dummy	0.0545 *** (0.0051)	0.0351 *** (0.0051)	0.0297 *** (0.0061)	0.0360 *** (0.0063)	0.0329 *** (0.0042)	0.0155 *** (0.0043)	0.0039 (0.0052)	0.0212 *** (0.0053)
Top 12% inventor/ no design registration dummy	0.1521 *** (0.0029)	0.0443 *** (0.0030)	0.0418 *** (0.0036)	0.0373 *** (0.0037)	0.2086 *** (0.0024)	0.1186 *** (0.0025)	0.1291 *** (0.0030)	0.1054 *** (0.0031)
Top 13-25% inventor / top 12% creator dummy	0.1776 *** (0.0257)	0.1116 *** (0.0257)	0.1041 *** (0.0313)	0.0913 *** (0.0307)	0.1725 *** (0.0212)	0.1320 *** (0.0217)	0.1038 *** (0.0265)	0.1258 *** (0.0259)
Top 13-25% inventor/ top 13-25% creator dummy	0.0572 *** (0.0204)	0.0242 (0.0204)	0.0282 (0.0252)	0.0224 (0.0247)	0.0629 *** (0.0169)	0.0437 ** (0.0172)	0.0569 *** (0.0212)	0.0105 (0.0210)
Top 13-25% inventor/ top 26-100% creator dummy	0.0140 (0.0095)	0.0074 (0.0095)	0.0218 * (0.0112)	0.0024 (0.0119)	0.0045 (0.0079)	-0.0043 (0.0080)	-0.0128 (0.0096)	-0.0085 (0.0102)
Top 13-25% inventor/ no design registration dummy	0.0509 *** (0.0027)	0.0267 *** (0.0027)	0.0271 *** (0.0033)	0.0235 *** (0.0034)	0.0441 *** (0.0023)	0.0223 *** (0.0023)	0.0283 *** (0.0028)	0.0109 *** (0.0029)
Top 26-100% inventor / top 12% creator dummy	0.1229 *** (0.0295)	0.0654 ** (0.0296)	0.0360 (0.0354)	0.1010 *** (0.0347)	0.0986 *** (0.0248)	0.0594 ** (0.0253)	0.1245 *** (0.0296)	0.0257 (0.0304)
Top 26-100% inventor/ top 13-25% creator dummy	0.0360 (0.0287)	0.0343 (0.0286)	0.0301 (0.0367)	0.0449 (0.0340)	0.0035 (0.0243)	-0.0110 (0.0247)	0.0093 (0.0315)	-0.0006 (0.0295)
Top 26-100% inventor/ top 26-100% creator dummy	0.0393 *** (0.0125)	0.0250 ** (0.0125)	0.0138 (0.0149)	0.0267 * (0.0155)	0.0100 (0.0106)	-0.0061 (0.0107)	0.0063 (0.0128)	-0.0200 (0.0134)
Top 26-100% inventor/ no design registration dummy	0.0167 *** (0.0029)	0.0156 *** (0.0030)	0.0133 *** (0.0036)	0.0134 *** (0.0037)	-0.0126 *** (0.0024)	-0.0184 *** (0.0025)	-0.0202 *** (0.0030)	-0.0246 *** (0.0031)
Control variable								
Joint application dummy		0.0192 *** (0.0051)	0.0150 ** (0.0061)	0.0269 *** (0.0064)		-0.0050 (0.0043)	0.0026 (0.0052)	-0.0089 (0.0054)
Joint application with home electronics firm dummy		0.1113 *** (0.0218)	0.0821 *** (0.0259)	0.0885 *** (0.0252)		0.0208 (0.0191)	0.0167 (0.0224)	0.0426 (0.0218)
US patent family dummy		0.0772 *** (0.0032)	0.0818 *** (0.0039)	0.0754 *** (0.0038)		0.1590 *** (0.0026)	0.1605 *** (0.0032)	0.1627 *** (0.0032)
Average US patent family ratio (defined by Year & IPC)		-0.1255 *** (0.0124)	-0.1471 *** (0.0184)	-0.1062 *** (0.0150)		-0.3442 *** (0.0104)	-0.4324 *** (0.0155)	-0.2872 *** (0.0126)
Claims (standardized)		0.0222 *** (0.0012)	0.0193 *** (0.0013)	0.0219 *** (0.0014)		0.0792 *** (0.0008)	0.0810 *** (0.0009)	0.0762 *** (0.0011)
Examination request dummy		0.0986 *** (0.0028)	0.0940 *** (0.0034)	0.1017 *** (0.0036)		0.1847 *** (0.0024)	0.1960 *** (0.0028)	0.1785 *** (0.0030)
Firsttrack Examination Request Dummy		0.0053 (0.0100)	0.0144 (0.0132)	0.0300 *** (0.0115)		0.0750 *** (0.0082)	-0.0312 *** (0.0112)	0.1263 *** (0.0094)
Appeals against examiner's rejection (standardized)		0.0193 *** (0.0011)	0.0178 *** (0.0013)	0.0209 *** (0.0015)		0.0297 *** (0.0009)	0.0307 *** (0.0011)	0.0267 *** (0.0012)
Invalidation trial (standardized)		0.0157 *** (0.0005)	0.0130 *** (0.0006)	0.0176 *** (0.0008)		0.0188 *** (0.0004)	0.0190 *** (0.0004)	0.0151 *** (0.0007)
Request for inspection of documents (standardized)		0.0015 *** (0.0006)	0.0013 ** (0.0006)	0.0009 (0.0007)		0.0016 *** (0.0005)	0.0016 *** (0.0005)	0.0016 *** (0.0006)
Standardized examiner forward citation		0.2265 *** (0.0007)	0.2448 *** (0.0008)	0.2241 *** (0.0009)				
Standardized inventor forward citation						0.1204 *** (0.0004)	0.1330 *** (0.0005)	0.1215 *** (0.0005)
(Intercept)	-0.3987 *** (0.0032)	-0.4196 *** (0.0044)	-0.4156 *** (0.0055)	-0.4229 *** (0.0058)	-0.0812 *** (0.0026)	-0.1118 *** (0.0037)	-0.1116 *** (0.0046)	-0.1150 *** (0.0049)
Log-Liklihood	-1,890,188	-1,799,450	-1,246,695	-1,172,967	-2,174,734	-2,100,656	-1,466,886	-1,365,016
Pseudo R-Squared (Nagelkerke)	.0063	.1555	.1810	.1473	.0190	.1523	.1726	.1443
Observations	877,229	877,229	614,387	568,320	877,229	877,229	614,387	568,320

Standard errors are in parentheses

* significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level

Table 3 Negative binomial regression result for technological quality of patents and their inventors composition

	Independent variable: Standardized inventor forward citation				***Dependent: Standardized examiner forward citation***			
	Model E	***Model F***	***Model G***	***Model H***	***Model E***	***Model F***	***Model G***	***Model H***
	1995-2009	*1995-2009*	*1995-2004*	*2000-2009*	*1995-2009*	*1995-2009*	*1995-2004*	*2000-2009*
			Base: F	*Base: F*			*Base F*	*Base F*
Independent variable								
Only possibly industrial designers group dummy	0.0875 **	0.0871 **	0.0932 **	0.0658	0.0285	0.0531 *	0.0269	0.0601
	(0.0368)	(0.0368)	(0.0435)	(0.0441)	(0.0319)	(0.0319)	(0.0382)	(0.0379)
Possibly industrial designers and other category inventors group dummy		0.0780 ***	0.0401	0.0938 ***		0.1755 ***	0.2040 ***	0.1573 ***
		(0.0229)	(0.0280)	(0.0270)		(0.0190)	(0.0230)	(0.0227)
Only possibly engineers group dummy		-0.0018	-0.0035	-0.0022		0.0638 ***	0.0675 ***	0.0651 ***
		(0.0026)	(0.0031)	(0.0032)		(0.0022)	(0.0026)	(0.0027)
Control variable								
Joint application dummy	0.0263 ***	0.0258 ***	0.0212 ***	0.0322 ***	-0.0087 **	0.0040	0.0124 **	-0.0016
	(0.0050)	(0.0050)	(0.0060)	(0.0063)	(0.0042)	(0.0043)	(0.0051)	(0.0054)
Joint application with home electronics firm dummy	0.1098 ***	0.1098 ***	0.0787 ***	0.0872 ***	0.0089	0.0189	0.0109	0.0407 *
	(0.0218)	(0.0218)	(0.0259)	(0.0252)	(0.0191)	(0.0191)	(0.0225)	(0.0218)
US patent family dummy	0.0815 ***	0.0816 ***	0.0864 ***	0.0788 ***	0.1721 ***	0.1700 ***	0.1733 ***	0.1719 ***
	(0.0032)	(0.0032)	(0.0039)	(0.0038)	(0.0026)	(0.0026)	(0.0032)	(0.0032)
Average US patent family ratio (defined by Year & IPC)	-0.1438 ***	-0.1433 ***	-0.1619 ***	-0.1284 ***	-0.3799 ***	-0.3703 ***	-0.4533 ***	-0.3217 ***
	(0.0123)	(0.0123)	(0.0182)	(0.0148)	(0.0103)	(0.0103)	(0.0154)	(0.0124)
Claims (standardized)	0.0231 ***	0.0231 ***	0.0203 ***	0.0224 ***	0.0825 ***	0.0815 ***	0.0836 ***	0.0779 ***
	(0.0011)	(0.0011)	(0.0013)	(0.0014)	(0.0008)	(0.0008)	(0.0009)	(0.0011)
Examination request dummy	0.1026 ***	0.1026 ***	0.0972 ***	0.1062 ***	0.1964 ***	0.1928 ***	0.2034 ***	0.1878 ***
	(0.0028)	(0.0028)	(0.0033)	(0.0036)	(0.0024)	(0.0024)	(0.0028)	(0.0030)
Firsttrack Examination Request Dummy	0.0088	0.0089	0.0175	0.0334 ***	0.0916 ***	0.0851 ***	-0.0209 *	0.1352 ***
	(0.0100)	(0.0100)	(0.0132)	(0.0115)	(0.0082)	(0.0082)	(0.0112)	(0.0094)
Appeals against examiner's rejection (standardized)	0.0196 ***	0.0196 ***	0.0181 ***	0.0212 ***	0.0310 ***	0.0305 ***	0.0316 ***	0.0274 ***
	(0.0011)	(0.0011)	(0.0013)	(0.0015)	(0.0009)	(0.0009)	(0.0011)	(0.0012)
Invalidation trial (standardized)	0.0158 ***	0.0158 ***	0.0131 ***	0.0178 ***	0.0191 ***	0.0192 ***	0.0194 ***	0.0153 ***
	(0.0005)	(0.0005)	(0.0006)	(0.0008)	(0.0004)	(0.0004)	(0.0004)	(0.0007)
Request for inspection of documents (standardized)	0.0015 ***	0.0015 ***	0.0012 **	0.0009	0.0015 ***	0.0015 ***	0.0015 ***	0.0015 **
	(0.0006)	(0.0006)	(0.0006)	(0.0007)	(0.0005)	(0.0005)	(0.0005)	(0.0006)
Standardized examiner forward citation	0.2276 ***	0.2275 ***	0.2459 ***	0.2250 ***				
	(0.0007)	(0.0007)	(0.0008)	(0.0008)				
Standardized inventor forward citation					0.1232 ***	0.1227 ***	0.1357 ***	0.1234 ***
					(0.0004)	(0.0004)	(0.0005)	(0.0005)
(Intercept)	-0.3743 ***	-0.3740 ***	-0.3732 ***	-0.3810 ***	-0.0374 ***	-0.0616 ***	-0.0579 ***	-0.0758 ***
	(0.0034)	(0.0035)	(0.0044)	(0.0047)	(0.0028)	(0.0029)	(0.0037)	(0.0040)
Log-Liklihood	-1,799,787	-1,799,775	-1,246,886	-1,173,146	-2,104,205	-2,103,303	-1,468,985	-1,366,478
Pseudo R-Squared (Nagelkerke)	.1550	.1550	.1806	.1469	.1468	.1482	.1681	.1407
N	877,229	877,229	614,387	568,320	877,229	877,229	614,387	568,320

Standard errors are in parentheses

* significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level

5. Discussion

Firms can introduce inimitable innovation by integrating design-driven approach and technology-driven development (Verganti, 2009). Our interest is in a driver of a part of such an innovation: design-driven technology innovation. Our findings are; (a) some technology innovations are brought by certain industrial designers, who have a capability to mark top class productivity in design creation and to create a certain amount of novel technology, (b) their impacts on technology innovation are superior to or same as other categories of inventors, and (c) such innovations, especially innovations brought numerous subsidiary patents, are basically achieved by mixed groups of industrial designers and engineers.

(1) An industrial designer as a technology innovation catalyst

Our result provides a robust evidence of catalysis function of highly productive and technology familiar industrial designers for some technology innovations being important for business (see, result (c) in above). We assume these designers coordinate engineers and create technology innovation.

This result empirically expands a discussion raised by Fujimoto(1991) (predicted in modularized and user-interface oriented industry, industrial designers can play a role as an integrator in the product development process). From the early stage of product development process, certain designers can contribute to the integration of team members and to improve development team performance.

Considering features of industrial designers as Walsh(1992) mentions, such contribution to the integration may be yielded by visualization skill of designers and not by leadership of designers. At least in Japanese home electronics companies, industrial designers face difficulty in exerting leadership in product development team. The most part of our sample companies is technology-oriented[15], therefore, their engineers tend to have a stronger voice than designers. Under such a situation, the path of designers' contribution could be limited; they achieve innovation through their assisting activities, such as visualization. We assume industrial designers informally integrate engineers.

Of course, in some cases, industrial designers exercised his or her strong leadership and brought technology innovations. In a case of a steam-less rice cooker sold in 2008 from Mitsubishi Electric, designers made a proposal of an innovative concept of the product and took an initiative in inventing a novel mechanism of rice cooking (JPO, 2011). While conventional cookers emit steam and damp furniture, their steam-less cooker aimed to fit various interior decorations by designing their shapes to be elegant and by introducing a novel steam-less cooking mechanism. They succeeded in developing such a technology, however, facing an objection from the sales department, designers and engineers endeavored to create an additional benefit to consumers. Finally, in 2007, they succeeded to develop an original cooking program, which does not only emit any steam but also improve its taste. The product marked more than 40 thousand unit sales in first 10 month and became one of blockbuster products (Miyao, 2010). Nonetheless, our hearing investigation to several designers revealed such a designer-leaded development case is rare.

A similar case is reported by Hasegawa(2012). He studied Japanese food manufacturers and found that designers projected user-needs oriented goals, which are technically hard to achieve, however, given

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[15] 10 of 16 companies publish official technical reports, and one had published until 1999. Also, in annual reports, most of these companies highlighted their superiority in technology (and limited in product design).

the challenging goal setting, they enhance an enrollment of engineers, and succeed in bringing a technological innovation.

Besides industrial designers can coordinate engineers and other functions by their visualization skill, our results support the statistically stable contribution of *Top 13-25 % inventor/top 12% creator* alone. What is an obstacle to the integration between industrial designers in general and engineers? One of the most reasonable answers is an absorptive capacity of engineers. On the integration process, each team member must share the same language and utilize heterogeneous knowledge of other members, however, certain common knowledge are required for collaboration (Cohen and Levinthal, 1990). Such common knowledge might be a certain in-depth technological knowledge. Therefore, industrial designers, who have relatively little knowledge about technology (*Top 26-100 % inventor/top 12% creator*), never display a robust effect on technology innovation.

(2) An industrial designer as a counter-contextual innovator

We also observed notably higher regression coefficients on possibly industrial designers (*Top 13-25% inventor/ top 12% creator* and *Top 26-100% inventor/ top 12% creator*) in *Standard inventor forward citation* estimation model. On the other hand, coefficients on same attribution in *Standard examiner forward citation* estimation model remain the same level as certain attributions (such as *Top 12% inventor/ top 12% creator*, *Top 12% inventor/ top 26-100% creator* and *Top 12% inventor/ no design registration*).

Similar gaps between inventor forward citations and examiner forward citations are found in the effect of team composition: we discovered a significant correlation only between examiner forward citations and *possibly industrial designers and other category inventors group dummy*. As explained previously at 3.(3), inventor forward citations and examiner forward citations are differ in essence. What is a proper explanation of these gaps?

A possible factor in the former phenomena is a novelty in the technological context. Top-level design productive and certain level technology productive industrial designers more frequently contribute to the creation of counter-contextual invention. Their inventions are so unique that a large number of inventors focus on them to refer their approaches or subject matters of such radical inventions (then, they gather a lot of inventor forward citations), however, limited number of companies follow them directly as applying improved inventions (therefore, examiner forward citations are not so much aggregated).

If these inventions are counter-contextual, their forward citations from their own company might be relatively small due to the “socialization” of organization. As March(1991) theoretically argues, constituent members of an organizational grow more alike and it hinders their learning. Once socialized, the company tends to exploit existing technology context and has difficulty in exploring a new context of technology. Every organization tends to be “socialized”, as a result, technological development becomes rigid to their technological context[16].

Table 4 shows average and median ratios of citations from third parties. In fact, two possibly industrial designers categories indicate a high ratio of outward citations. This result represents industrial designers create a new context of technology in relatively high frequency and therefore collect fewer citations from subsidiary patents created by same organization due to the socialization.

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[16] Rigidness is not always harmful for organization. Patel & Pavit(1997) argued that long-term commercially successful companies have their own technological competence.

This interpretation is consistent with a discussion raised by Yaegashi(2012). He notes industrial designers sometimes explore new technologies by exploiting a new meaning of the product instead of exploiting existing context of product.

Such a potential of industrial designers is beneficial to business entities to sustain a growth. Scholars argue that a balance between an exploitation and exploration of technological knowledge enhance commercial success for long periods (Benner and Tushman, 2003; He and Wong, 2004). But an organizational socialization constricts an exploration. Some solutions have been presented, such as a recruiting (Levinthal and March, 1993) or a spin-off (Cirillo, Stefano and Valentini, 2013). Our study suggests a novel option: an involvement of certain industrial designers into R&D team.

Next, the latter, the gap in the effects of the team composition may be accounted for by the same standpoint: a technological context. Counter-contextual inventions (which gather a relatively large number of inventor forward citations and they are larger than the number of examiner forward citations), may be brought by collaborations between engineers and certain industrial designers, and by industrial designers, who have little ties with an existing technological context. We can interpret our regression results as these two actors create counter-contextual innovation at random, thereby, no consistently significant results are found.

As well as such technological breakthroughs, these industrial designers frequently catalyze commercially important inventions (which gather relatively large number of examiner forward citations). In accordance with our regression estimations, joint teams of engineers and certain industrial designers stably bring these inventions. We assume their mechanism that industrial designers introduce user-driven concept or idea, then integrate varied knowledge from engineers, and achieve a commercially attractive technology innovation.

Table 4 Fundamental statistics of outward forward citation ratio

	Outward inventor forward citation ratio			*Outward examiner forward citation ratio*		
	Average	*Median*	*Std. Dev.*	*Average*	*Median*	*Std. Dev.*
Top 12% inventor/ top 12% creator dummy	73.9%	100.0%	39.8%	80.9%	100.0%	31.9%
Top 12% inventor/ top 13-25% creator dummy	70.5%	100.0%	41.7%	76.8%	100.0%	35.0%
Top 12% inventor/ top 26-100% creator dummy	70.7%	100.0%	41.9%	77.2%	100.0%	35.0%
Top 12% inventor/ no design registration dummy	72.8%	100.0%	40.9%	79.8%	100.0%	33.1%
Top 13-25% inventor/ top 12% creator dummy	81.9%	100.0%	34.1%	86.2%	100.0%	28.5%
Top 13-25% inventor/ top 13-25% creator dummy	74.1%	100.0%	40.3%	81.4%	100.0%	32.3%
Top 13-25% inventor/ top 26-100% creator dummy	73.0%	100.0%	41.0%	81.3%	100.0%	32.4%
Top 13-25% inventor/ no design registration dummy	74.3%	100.0%	40.2%	82.4%	100.0%	31.6%
Top 26-100% inventor/ top 12% creator dummy	81.3%	100.0%	35.4%	86.3%	100.0%	29.2%
Top 26-100% inventor/ top 13-25% creator dummy	76.3%	100.0%	39.4%	84.2%	100.0%	30.3%
Top 26-100% inventor/ top 26-100% creator dummy	74.9%	100.0%	40.1%	82.7%	100.0%	32.1%
Top 26-100% inventor/ no design registration dummy	77.8%	100.0%	38.4%	85.0%	100.0%	29.8%
Only possibly industrial designers group dummy	85.3%	100.0%	32.1%	88.5%	100.0%	26.8%
Possibly industrial designers and other category inventors group dummy	72.8%	100.0%	40.9%	79.5%	100.0%	33.3%
Only possibly engineers group dummy	80.5%	100.0%	35.5%	85.0%	100.0%	29.9%
(All Sample)	75.0%	100.0%	39.9%	82.1%	100.0%	31.8%

6. Conclusions and implications for practitioners

(1) Conclusions and implications

We have gained empirical evidence for the benefit of industrial designers to technology innovation. In home electronics industry, industrial designers, who create a certain amount of designs and technology through their career, can assist to invent highly evaluated technology. Such assistance may be brought by coordination skill of industrial designers. We can assume that industrial designers, utilizing their visualization skill, enhance common understanding of targeted innovation. However, such enhancement can be obtained only when these designers have certain technical capability.

We also found that industrial designers may bring heterogeneous innovation into the organization. We can construe that industrial designers define technical challenges and/or provide counter-contextual solutions to technical issues by utilizing their user-oriented thinking skill.

Our findings deliver a concrete idea in the innovation team management for the implementation of design driven innovation strategy, especially targeting a crossing field between design-driven and technology-push as follows:

***Implication**: Top productive and technology familiar designers should be involved in an R&D team to enhance a technology innovation. Such an innovation frequently explores a new technological context of the organization, thereby; it assists a sustainable commercial success.*

(2) Remaining issues and limitations

Despite our contribution to design driven innovation theory, several questions are still open to future research .

First, we did not specify any skills or careers of industrial designers to be a innovation driver. We only confirmed correlations between technology quality and a future/past design/technology productivity of each inventor. Further investigation could conduct toward a relation between past experience and a performance.

Second, our study based on organizational product development theory, however, our result may be explained from theories on creativity. Numerous empirical studies reveal diversity in career or skill improves team performance (Horwitz and Horwitz, 2007). Industrial designers usually experience different careers from engineers. Thereby, they may ameliorate R&D team performance by bringing diversity. Our very next study will examine this subject matter.

Third, our study revealed nothing about a formal role of industrial designers to catalyze technology innovation or an effective management of team with industrial designers. In this regard, Florida(2002) provides some analogies. His study, examining the growth rate of cities, found that drivers of growth are talent, technology and tolerance. He advocates not only scientists or engineers but also designers support creative economy, a source of growth of cities, and a tolerance of society attracts such diversified talents. Back to technology development, industrial designers are sometimes extraneous to the R&D team. It may be required to manage tolerance in the team.

Finally, our result is based on a Japanese electronics industry where industrial designers frequently collaborate with engineers. For example, Sony has been the well-known company in design-and-technology driven product development from 1980s (Walsh, 1992). Sony has given a certain mandate to industrial designers for producing design-oriented products. Such practice might have a spillover effect to competitors. An additional research could investigate an applicability of these findings to other industries and to other countries.

Also, we must mention two limitations of our study. Firstly, our finding is not evidence of commercial success, but a proof of a technological achievement as a basis of competitiveness. An empirical study on Japanese mobile phone products already revealed that a relative weight between design and functions gradually slides depending on maturity of the market (Akiike, 2013). Presumably, approaches of industrial designers to realize commercially successful technology and product development might be varied based on market phases. Secondly, although we have set a border of inventor's category carefully, our analysis still contains certain naiveness as we used categorical variables (inventors categories) in explanatory variables. These variables are proxy of design-related skills and attributions of inventors. Future study should be conducted to state these variables directly.

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Appendix

Table A1 List of sample companies

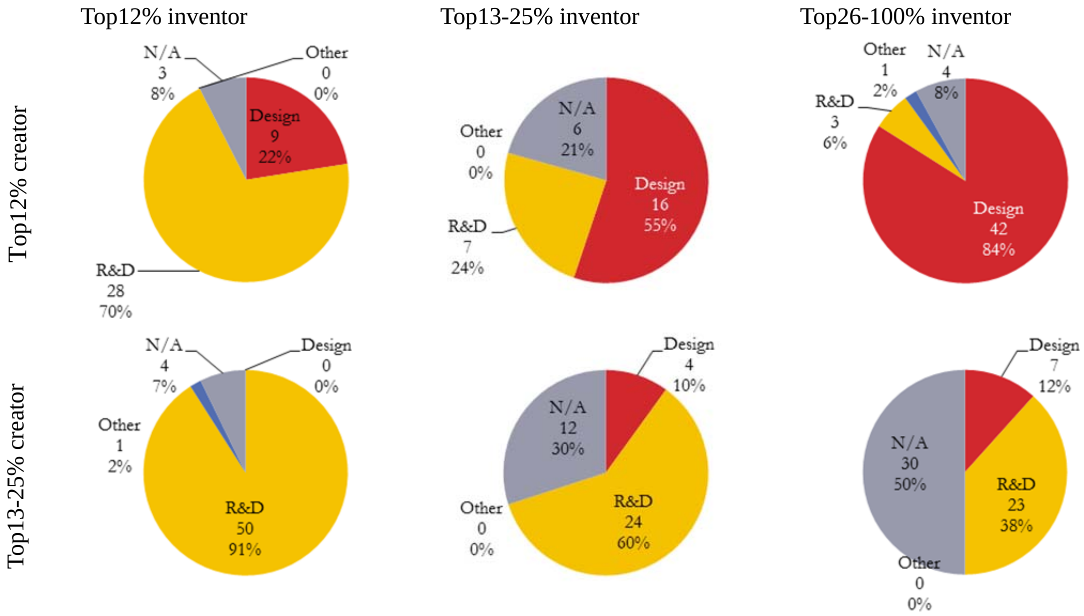
Company Name	*Major Products*	*Number of Patent Applications (1995-2009)*	*Number of Design Right Registrations (1995-2009)*	*Number of Inventors*
Panasonic	Home appliance	186,510	19,472	40,007
Canon	Camera, office machinery	137,220	1,214	13,542
Toshiba	Heavy electronics, home appliance	109,916	7,063	33,521
Hitachi	Heavy electronics, home appliance	86,812	3,375	41,303
Sony	Consumer electronics	97,838	2,766	23,663
Mitsubishi Electronic	Heavy electronics, home appliance	70,920	4,057	22,995
Sharp	Home appliance	54,229	6,563	13,515
NEC	IT System, home appliance(-1999)	61,933	1,276	21,797
JVC Kenwood	Consumer electronics	18,982	2,246	4,061
Daikin	Air conditioner	12,929	1,568	2,834
Yamaha	Audio, music instrument	11,096	506	1,941
Pioneer	Consumer electronics	9,193	548	3,738
Fujitsu General	Air conditioner, home appliance(-2008)	6,535	809	1,010
Zojirushi	Kitchen Appliance	1,549	312	249
Tiger	Kitchen Appliance	1,329	354	192
Corona	Heating equipment	1,238	328	376

Table A2 Descriptions of variables

	Dummy	*Descriptions*
Standardized inventor forward citations	No	A number of subsidiary patents, which cite the patent observed. Citations by examiners are excluded. Standardization is achieved by calculating an average and a standard deviation among patents of same application year and same technology field.
Standardized examiner forward citation	No	A number of subsidiary patents, in which examination procedure the patent is referred by examiners. Standardization is achieved by calculating an average and a standard deviation among patents of same application year and same technology field.
Joint application dummy	YES	Whether the patent filed by multiple applicants. (Holding multiple applicants=1; No=0)
Joint application with home electronics firm dummy	YES	Whether the patent filed jointly by competing home electronics manufactures. A joint application of group companies is excluded. (Holding competing applicants=1; No=0)
US patent family dummy	YES	Whether the invention of the patent filed to USPTO. A patent family is defined by INPADOC. (Holding a US patent family=1; No=0)
Average US patent family ratio	No	An average ratio of patents holding a US patent family among patents of same application year and same technology field.
Claims	No	A number of claims of the patent. *In the regression, this variable is standardized among observed samples
Examination request dummy	YES	Whether the applicant requests an examination of the filed patent. (Yes=1; No=0)
First track examination request dummy	YES	Whether the applicant requests a first track examination of the filed patent. (Yes=1; No=0)
Appeals against examiner's rejection	No	A number of appeals to JPO against examiner's rejection. *In the regression, this variable is standardized among observed samples
Invalidation trial	No	A number of trials at JPO for invalidation requested by third parties. *In the regression, this variable is standardized among observed samples
Request for inspection of documents	No	A number of requests by third parties for inspection of patent documents. *In the regression, this variable is standardized among observed samples

Figure A1 Affiliations of Top25% creator inventors in three sample companies (1)

[Company A]



[Company B]

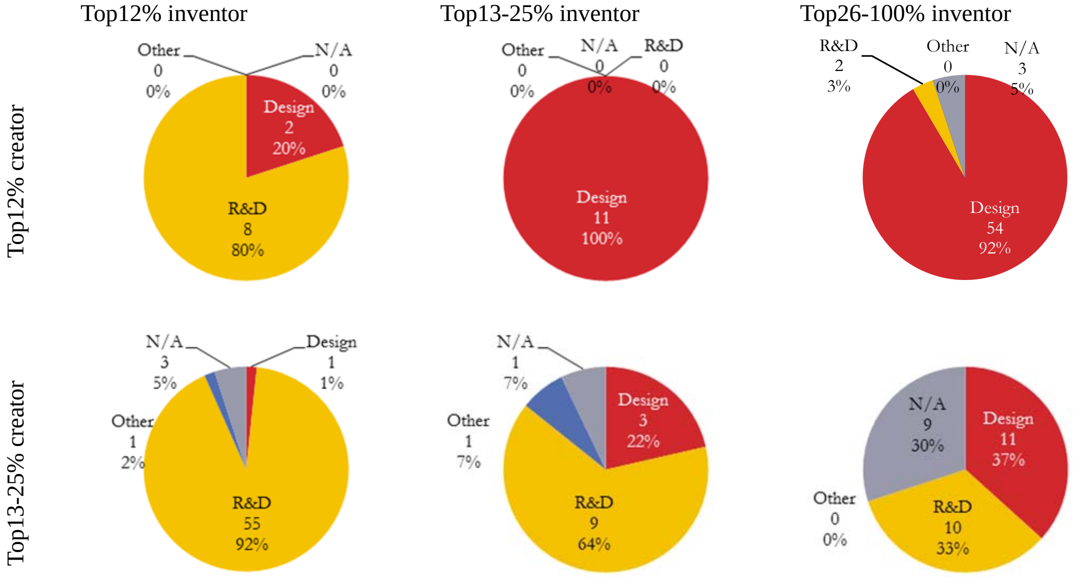


Figure A2 Affiliations of Top25% creator inventors in three sample companies (2)
[Company C]

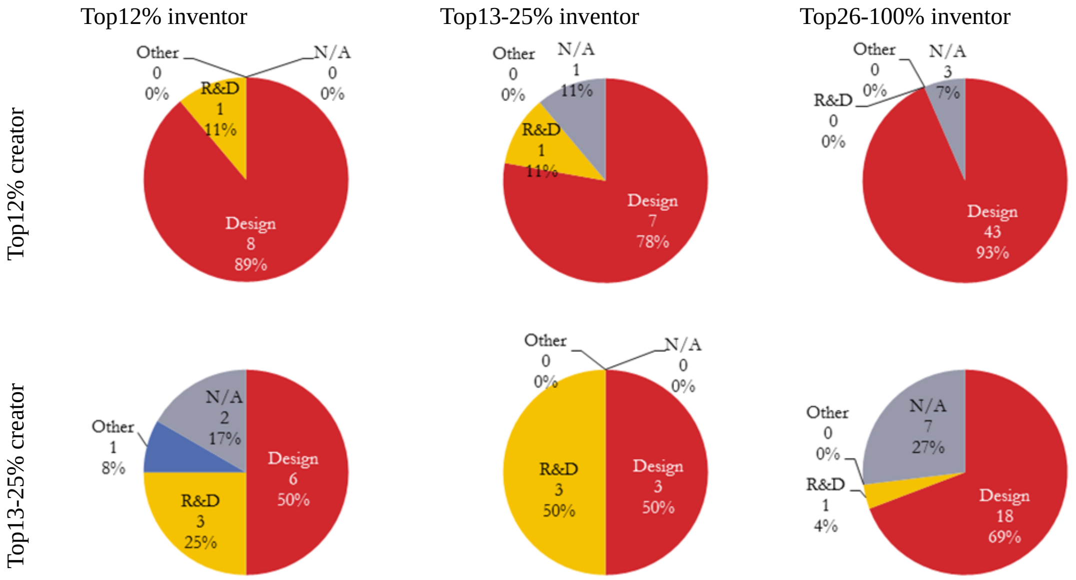


Table A3 Fundamental statistics of non-discrete variables

	Min	*Max*	*Average*	*Std. Dev.*
Standardized inventor forward citation	-0.756	95.001	0.0334	1.0084
Standardized examiner forward citation	-1.054	45.343	0.0966	1.0080
Claims	0	278	7.6055	6.6716
Average US patent family ratio	0.000	0.7796	0.2277	0.1065
Appeals against examiner’s rejection	0	2	0.0448	0.2071
Invalidation trial	0	10	0.0001	0.0160
Request for inspection of documents	0	110	0.0658	0.5270

Table A4 Correlation matrix of variables(1/2)

	Variables	Total	1)	2)	3)	4)	5)	6)	7)	8)	9)	10)	11)	12)	13)
1)	*Standardized inventor forward citation*	–	1.000												
2)	*Standardized examiner forward citation*	–	0.369	1.000											
3)	*Top 12% inventor / top 12% creator dummy*	*8,012*	0.014	0.026	1.000										
4)	*Top 12% inventor/ top 13-25% creator dummy*	*16,455*	0.013	0.021	0.149	1.000									
5)	*Top 12% inventor/ top 26-100% creator dummy*	*56,770*	0.012	0.014	0.071	0.147	1.000								
6)	*Top 12% inventor/ no design registration dummy*	*507,502*	0.049	0.104	-0.010	-0.013	0.013	1.000							
7)	*Top 13-25% inventor / top 12% creator dummy*	*1,805*	0.008	0.010	0.136	0.035	0.010	-0.028	1.000						
8)	*Top 13-25% inventor/ top 13-25% creator dummy*	*3,195*	0.003	0.003	0.045	0.077	0.031	-0.035	0.044	1.000					
9)	*Top 13-25% inventor/ top 26-100% creator dummy*	*16,167*	0.000	-0.004	0.035	0.069	0.098	-0.071	0.026	0.060	1.000				
10)	*Top 13-25% inventor/ no design registration dummy*	*316,237*	0.005	-0.001	-0.024	-0.037	-0.061	-0.203	-0.015	-0.010	-0.020	1.000			
11)	*Top 26-100% inventor / top 12% creator dummy*	*1,452*	0.004	0.004	0.052	0.012	0.004	-0.029	0.141	0.031	0.012	-0.013	1.000		
12)	*Top 26-100% inventor/ top 13-25% creator dummy*	*1,657*	0.001	-0.001	0.032	0.037	0.006	-0.032	0.058	0.085	0.024	-0.012	0.095	1.000	
13)	*Top 26-100% inventor/ top 26-100% creator dummy*	*9,155*	0.000	-0.005	0.023	0.026	0.047	-0.075	0.039	0.054	0.103	-0.030	0.038	0.066	1.000
14)	*Top 26-100% inventor/ no design registration dummy*	*312,736*	-0.019	-0.052	-0.032	-0.049	-0.094	-0.384	-0.014	-0.009	-0.022	-0.135	-0.005	0.001	-0.001
15)	*Only possibly industrial designers group dummy*	*941*	0.002	0.001	-0.003	-0.005	-0.009	-0.038	0.340	-0.002	-0.004	-0.025	0.344	0.150	-0.003
16)	*Only possibly engineers group dummy*	*313,756*	0.018	0.054	-0.072	0.034	0.109	0.572	-0.034	-0.045	-0.102	-0.560	-0.030	-0.032	-0.077
17)	*Possibly industrial designers and other category inventors group dummy*	*2,246*	0.007	0.011	0.149	0.040	0.017	-0.023	0.675	0.061	0.033	-0.008	0.580	0.102	0.062
18)	*Joint application dummy*	*59,961*	0.010	0.005	-0.002	0.001	0.010	-0.004	0.008	0.007	0.011	0.059	0.000	0.009	0.017
19)	*Joint application with home electronics firm dummy*	*2,364*	0.012	0.011	-0.001	-0.005	-0.009	0.000	-0.002	-0.001	-0.003	0.014	-0.002	0.001	0.001
20)	*US patent family dummy*	*203,539*	0.088	0.155	0.006	0.005	-0.016	0.131	-0.006	-0.004	-0.011	0.011	-0.006	-0.005	-0.014
21)	*Average US patent family ratio (defined by Year & IPC)*	–	-0.002	-0.003	-0.034	-0.049	-0.114	0.003	-0.017	-0.019	-0.046	0.009	-0.014	-0.009	-0.028
22)	*Claims (standardized)*	–	0.060	0.134	-0.008	-0.017	-0.032	0.091	-0.004	-0.014	-0.028	0.002	-0.005	-0.010	-0.024
23)	*Examination request dummy*	–	0.087	0.147	0.021	0.018	0.032	0.119	0.004	0.013	0.013	0.000	0.004	0.008	0.011
24)	*Firsttrack examination request dummy*	*509,153*	0.032	0.052	0.027	0.016	0.014	0.047	0.002	0.002	0.002	-0.012	-0.002	0.003	-0.002
25)	*Appeals against examiner’s rejection (standardized)*	*10,816*	0.055	0.085	0.007	0.010	0.010	0.051	0.003	0.001	0.000	-0.001	0.002	0.003	0.001
26)	*Request for inspection of documents (standardized)*	–	0.102	0.120	0.017	0.015	0.015	0.023	0.001	0.008	0.006	0.003	-0.001	0.004	0.005
27)	*Invalidation trial (standardized)*	–	0.011	0.011	0.003	0.002	0.003	0.000	0.000	0.001	0.002	0.001	0.000	0.000	0.000

Table A5 Correlation matrix of variables (2/2)

	Variables	14)	15)	16)	17)	18)	19)	20)	21)	22)	23)	24)	25)	26)
14)	*Top 26-100% inventor/ no design registration dummy*	1.000												
15)	*Only possibly industrial designers group dummy*	-0.024	1.000											
16)	*Only possibly engineers group dummy*	-0.555	-0.024	1.000										
17)	*Possibly industrial designers and other category inventors group dummy*	-0.002	-0.002	-0.038	1.000									
18)	*Joint application dummy*	0.129	-0.004	-0.102	0.009	1.000								
19)	*Joint application with home electronics firm dummy*	0.043	-0.002	-0.031	-0.002	0.192	1.000							
20)	*US patent family dummy*	-0.046	-0.011	0.057	-0.004	-0.009	0.023	1.000						
21)	*Average US patent family ratio (defined by Year & IPC)*	0.013	-0.011	-0.008	-0.017	-0.049	0.012	0.253	1.000					
22)	*Claims (standardized)*	-0.041	-0.006	0.049	-0.005	-0.021	0.007	0.182	0.148	1.000				
23)	*Examination request dummy*	-0.050	-0.003	0.063	0.008	0.040	0.029	0.332	0.068	-0.033	1.000			
24)	*Firsttrack examination request dummy*	-0.035	-0.001	0.038	0.001	-0.007	0.005	0.139	0.042	0.014	0.095	1.000		
25)	*Appeals against examiner's rejection (standardized)*	-0.026	-0.002	0.031	0.005	0.011	0.014	0.127	-0.010	-0.028	0.184	0.048	1.000	
26)	*Request for inspection of documents (standardized)*	-0.003	-0.002	0.005	0.001	0.044	0.037	0.060	-0.054	0.002	0.091	0.083	0.106	1.000
27)	*Invalidation trial (standardized)*	0.001	0.000	-0.001	0.000	0.002	0.005	0.003	-0.003	-0.001	0.005	0.014	0.002	0.072