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Do Patents Lead to an Increase in Firm Value? Evidence from Korea†

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Patents are widely used in the literature as a measure of firm-level innovation. It is regarded that patents improve a firm's operational environment and ultimately increase the value of the firm. However, the relationship between patents and firm value in Korea is under-explored in the literature due to the difficulty of constructing datasets. This paper examines whether patents in Korea increase the market value of a firm. To do this, I exploit novel data on firm-level patents and financial information of all listed Korean companies during the period of 1993-2015 and estimate the non-linear production-function type of Tobin's q equations on R&D, patents, and citations. Surprisingly, I find that patents and citations are weakly associated with firm value, while R&D is strongly associated with an increase in firm value. These results direct imply that policymakers in Korea should enhance patenting incentives to encourage firms to innovate.

Key Word: Innovation, Firm Value, Tobin's q, R&D, Patent
JEL Code: O30, O32, O34

I. Introduction

It has been extensively documented that innovative capabilities are important for firms' growth and performance. Measuring innovation by firms has always attracted much attention from researchers in economics. One method by which to do this is to measure innovation with R&D expenditures, but one problem is that not all R&D leads to technological progress, and they are an input into innovation processes, not an outcome of these processes. Patents are another frequently used measure of firms' innovative capabilities in the literature. The value of a patent is recognized in part by the patent office, which allows us to infer technological progress. The patent system requires three conditions to be met for the granting of a patent: utility, novelty, and non-obviousness.

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A large body of research has studied the relationship between patents and firm value. Since Griliches (1981) found a positive relationship between the market value of a firm and its patents, much subsequent research has shown that patents and their characteristics are associated with firm value. Hall, Jaffe, and Trajtenberg (2005) find that the quality of patents as measured by patent citations is correlated with firm value. Since then, citations have become a popular proxy for firms' technological advances.

However, one area less studied is whether the patents of a firm do in fact lead to an increase in firm value in the Korean context. Because patent systems differ across countries, the legal rights and economic value of a patent can vary depending on where it is granted. Considering patents as a proxy for innovation is relatively common in the research on Korean firms, and it is an important empirical question as to whether the relationship between patents and firm value still holds in Korea as it does in foreign contexts.

Several studies have assessed the effects of firms' patents in Korea, though these have limitations. Youn (2004) represents one of the first papers to investigate the relationship between patents and firm value in Korea. The author finds a positive effect of patents on firm value, but the analysis includes only 242 firms, excluding non-renewed patents. Jeong and Kim (2017) demonstrate a relationship between US patents held by Korean firms and firm value, but they focus only on firms with US patents, not Korean patents. It is difficult to uncover implications pertaining to the Korean patent system in such a case. Recently, there has been some effort to construct large-scale firm-level patent data for Korean firms. Lee, Lim, Kim, Song, and Jeong (2019) match firms in FnGuide with patents. However, they focus on constructing patent-firm data itself, not providing an analysis of the effects of patents.

This paper exploits the commercial database ORBIS Intellectual Properties (IP) provided by Bureau Van Dijk. By merging ORBIS IP with FnGuide 5.0, I construct panel data for all listed firms in Korea with patent grant information from 1993 through 2015. To the best of my knowledge, this is the first paper to investigate whether the patents of a firm do in fact increase firm value with large-scale firm-level patents and financial data in Korea.

This paper investigates how the characteristics of the patents of Korean firms affect the firms' market value. I estimate firm value (Tobin's q) equations driven by the Cobb-Douglas production function by means of non-linear least squared estimation, a standard approach in the literature. This specification enables me to compare the effects of patents in Korea with the results from overseas studies. I use three variables for measuring firms' innovation: R&D stock/assets, patent stock/R&D stock, and citation stock/patent stock (hereafter referred to as R&D/asset, patent/R&D, and citation/patent, respectively).

Interestingly, contrary to the expectation that patents in Korea lead to an increase in firm value, the coefficient of patent/R&D is positive but not statistically significant. The coefficient of citation/patent is found to be statistically significant, but the magnitude is low compared to those in earlier work. Tobin's q increases by 0.5% with a one-unit increase in citation/patent, which is weak compared to prior studies. On the other hand, R&D/asset is strongly correlated with Tobin's q. As R&D/asset increases by 1%p, Tobin's q increases by about 1%. The magnitude of the R&D/asset effect is similar to or greater than those in previous studies conducted overseas.

I also investigate whether the effects of patents on firm value vary across industries. Given that the importance of technology differs depending on the industry, the effect of patents on firm value can also differ across industries. Consistent with my expectation, I find that the effects of patents on firm value in knowledge-intensive industries such as pharmaceuticals are very strong, whereas conventional manufacturing industries such as metals show weak effects. These findings corroborate the previous analysis results of the paper.

Prior research suggests that citations represent importance differentially depending on the type. Who cites who indicates a linkage between technology (Li, Chambers, Ding, Zhang, and Meng, 2014) and knowledge flows (Alcácer and Gittelman, 2006). Self-citations, citations coming from subsequent patents owned by the same firm, are known to be strongly associated with the market value of a firm (Hall, Jaffe, and Trajtenberg, 2005). Based on prior research, this paper undertakes a closer examination of whether self-citations increase the market value of Korean firms more so than normal citations do (including both self- and non-self-citations). Self-citations closely related to the market value of a firm may mean that the analyses in this paper are consistent with those in the literature. The results show that self-citations are positively correlated with market value and that the economic significance is approximately five times larger than that associated with normal citations.

It is widely understood in financial economics that firm value represents the discounted sum of the income of the future. If patents are associated with firm value, the patents should be linked to future performance measures such as net income and sales. To find how firm value and patents are related, I estimate panel regressions of patent variables on firm performance variables. This analysis sheds light on the linkage between patents and firm value. Specifically, a variable that shows a strong effect on firm value, such as self-citations, is expected to predict future earnings better. Consistent with the previous analysis, the estimation results show that self-citation/patent does predict future earnings while patent/asset and citation/patent do not show a correlation with future earnings.

My sample includes all patents of listed Korean firms granted in all countries around the world. The sample enriches the credibility of the analysis by measuring exclusive rights to use technologies in the global market. However, one may raise the concern that multiple patents in the same patent family contain the same technology, meaning that patents can be over-counted relative to the knowledge contained in them. However, this is not the case here because the value of patents not only comes from the technology itself but also originates from legal protections. Nonetheless, I construct the sample only with the first patents in the patent families and check the robustness of the analysis. The results are consistent with the previous analysis, showing that patents and citations in Korea are weakly associated with the market value of a firm. I also check the robustness of the results by excluding the 1997-1998 Asian financial crisis and the 2008 global financial crisis periods to rule out the effect of exceptional economic shocks. The results are consistent with the main findings.

This paper has valuable implications for policymakers in Korea. The results imply that the Korean patent system does not play a critical role in increasing the market value of a firm. There have been studies positing that legal protection rights are weak in Korea compared to those in foreign countries. Ryu (2019) argues that the Korean patent system is very conservative in setting punitive damages in infringement cases and that there is no clear standard of willful infringement. Not only does the patent system weaken patent value per se, but also it reduces incentives for firms to file patents for valuable technologies. There is also the possibility that firms prefer to choose to keep their technologies secret instead of pursuing patent protection (Chung, 2017). Retaining secrecy of technology may be optimal for a firm but may not be socially optimal in that there would be no knowledge spillover. This paper provides evidence that the patent system in Korea should be improved. To promote knowledge spillover and achieve a socially optimal level of innovation, policymakers in Korea should enhance patenting incentives to promote innovation in Korea.

Patent incentives refer to the appropriability from which a firm can create economic value. It can take the form of strong exclusive rights with regard to the technology in patents. Heavy punishments in cases of patent infringement are one good example. Prior research suggests that the Korean patent system is not good at providing proper protection in infringement cases. This could result in a weak association between patents and firm value. Thus, I suggest that policymakers should improve the actual rights of patents so that firms have more of an incentive to file patents and furthermore to invest more resources in innovation.

The remainder of this paper proceeds as follows. Section 2 describes the patent data and financial data used in the analysis. Section 3 develops the estimation equations of patent variables and firm value. Section 4 presents the estimation results, and Section 5 reports robustness checks. Lastly, section 6 closes with a conclusion.

II. Data

I construct the sample by combining two large datasets, ORBIS intellectual property (IP) and FnData 5.0. ORBIS IP, provided by the commercial data provider Bureau Van Dijk, offers worldwide patent information. It includes approximately 115 million patents and also offers the information about which firm had ownership of the patents when they were granted. Prior studies usually match the names of companies to the names of the patent assignees on a one-by-one basis, a method subject to mismatching. ORBIS IP, as a commercial data provider, argues that they have developed their own matching algorithm over 30 years. It is less likely that the data contains matching errors compared to a hand-collected dataset.

I use Dataguide from FnData as a source of financial information pertaining to listed companies in Korea, such as accounting variables and stock returns. The database of FnData, a commercial data provider in Korea, is widely used in Korean financial academia and industries. The sample periods are from 1993 to 2015. Patent data is available prior to 1993, but the availability of research and development accounting in Dataguide began in 1993. Firms that are granted at least one patent during the sample period are included in the sample, and the total number of those firms is 1,931.

A. *Patent truncation issue*

When analyzing patent data, the data truncation issue can naturally arise. There are two types of truncation issues. The first stems from the time lag between the application and the grant. This usually appears when analyzing US patent data. In the US, not all applied patents were made available to the public before 1999, as only granted patents were published. This issue generates bias when constructing the sample.

The data in this paper is less subject to be affected by the application-grant lag issue. Korea became a member of the World Intellectual Property Organization (WIPO) in 1979 and joined in Paris Convention for the Protection of Industrial Property in 1980. Since then, all patents applied for in Korea are released 18 months after the application date regardless of their status. It is not likely for firms to discontinue the patent process deliberately after applying given that the contents of the patent will be released anyway. ORBIS IP originally included patent information published until 2018, and this paper analyzes patent data up to 2015 considering the 18-month lag between the application and publication. The data in this paper include all patents applied for during the sample period.

The second issue is the truncation of citations. The number of citations increases over time. Earlier patents will have more citations than later patents regardless of their true value. To handle this issue, I determine the distribution of the number of years until the patents are cited and assign weights to these numbers of citations. I assume a 30-year lifetime of patents and calculate the proportions of citations for each year. In this way, I can obtain the cumulative distribution function of grant-citation lag years. The adjusted numbers of citations are obtained by dividing the total number of citations observed in the last year of the sample by the cumulative distribution function value. For example, assume that a patent applied for in 2013 is cited twice up to the last year we can observe. I record the number of patent citations for March of 2019 (the end of the database) to utilize the maximum amount of information available.

Because I truncate the sample period to 2015, I assume that the patent has been cited through three years, 2013, 2014, and 2015. Then there are 27 years during which the patent may be cited later. I assume that citations of this patent will follow the cumulative distribution function and divide the citation number of ‘2’ in this case by the CDF value of ‘3’ years.

B. *Data and variables*

I consider only granted patents as valid patents of the firms. If a patent is not granted until the end of the sample period, it is not counted. I count a patent at the time of its application, not when it is granted. In other words, when the patent application is made, it is considered as knowledge capital accumulation, but only for patents that are granted eventually at the end of the sample period.

Figure 1 reports the number of patents granted and the average number of citations for the listed companies in Korea. It shows a pattern consistent with those in previous studies. The number of granted patents has increased over time. Though it was less than 20,000 in 1993, it exceeded 60,000 by 2015. As the scale of the economy grows,

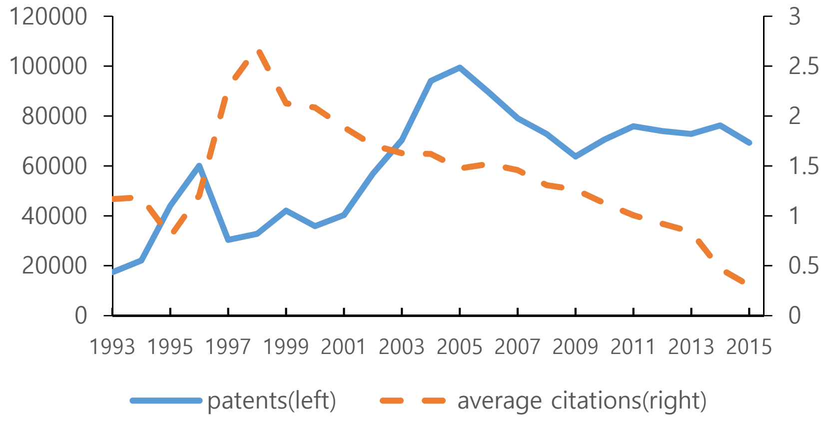

FIGURE 1. NUMBER OF GRANTED PATENTS AND AVERAGE FORWARD CITATIONS PER PATENT FOR LISTED COMPANIES IN KOREA

the importance of intellectual property on our economy also increases.

Figure 2 shows the total number of patents over the total R&D, the total citations over the total R&D, and the adjusted citations over the total R&D over the sample period. The denominators and the numerators are the aggregate quantities across firms. The R&D amounts are all adjusted according to the 2015 CPI level. Total patents over total R&D decreases from 1993 to 2015. In the early 1990s, firms obtained approximately 20 patents per billion won of R&D spending but obtained 1.5 patents per billion won in 2015. Both total patents and total R&D increase over time, but total R&D rises more rapidly. Total citations over total R&D decreases, but it is not clear as to whether adjusted citations over R& are decreased. The adjusted citations over R&D decreased during the 2000s but started to increase from 2010.

The independent variables in the following analysis, R&D/asset, patent/R&D, and citation/patent, are stock variables. They are defined as follows,

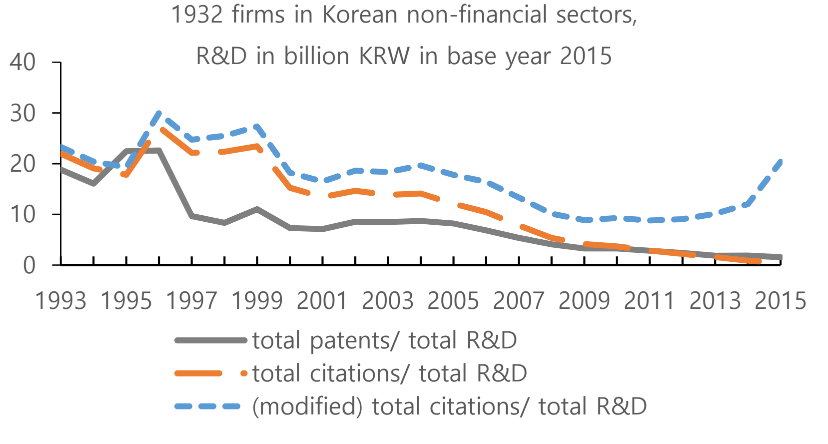

FIGURE 2. PATENTS AND CITATIONS PER R&D IN KOREA

Source: Orbis IP.

$$stock_t = (1 - dep) \times stock_{t-1} + input_i,$$

where $stock_t$ denotes R&D, patent, and citation stocks in year t, and dep is the depreciation rate, set here to 0.15, assuming that only 85% of knowledge capital remains and that 15% of it disappears every year. In addition, $input_i$ represents the annual flow of R&D, patents, and citations in year t. I use the R&D account in the financial statement footnote.

Calculating the citation stock value requires attention. At the firm level, the total truncation-corrected citation number in year τ from the patents granted in year t is represented by $C(t,\tau)$. The number of citation in year t for a firm is then defined as follows:

$$C(t) = \sum_{\tau=t}^{2019} C(t,\tau)$$

Citation stock increases when the patent is granted. This measure takes all of the citation information up to 2019 into account when the patent is granted. In this way, I address the issue of the time lag between the grant and the citation.

C. *Sample statistics*

I exclude observations with negative total assets, zero or negative market value, no R&D/total assets, no citations/patents, and no Tobin's Q. I replace no patents /R&D with zeros. Table 1 [Panel A] reports the sample statistics. The sample includes 1,931 firms and 21,460 observations. Variables in this sample show high skewness. Not only financial variables such as total assets and total liabilities but also patent variables such as patents stocks and citations stocks are skewed to the right. The high skewness features of the patent variables are similar to those found in earlier work.

Table 1 [Panel B] reports the correlations among R&D/Asset, patent/R&D, and citation/patent. The variables are not highly correlated with each other. Conventional

TABLE 1— SAMPLE STATISTICS

[Panel A] Summary Statistics

	Mean	Median	SD	Min	Max
Total assets (in bn KRW)	1,180	108	7,123	0.491	242,180
Total liabilities (in bn KRW)	710.9	49.2	4,216	0.188	131,976
Market values (in bn KRW)	515.9	52.6	4,089	0.186	224,190
R&D stocks (in bn KRW)	68.7	4.0	1,018	0	66,864
Patent stocks	335.5	6.7	4,052	0.004	139,488
Citation stocks (modified)	839.4	9.6	15,841	0	1,068,000
R&D/asset	0.084	0.036	0.267	0	16.92
Patent/R&D	32.3	1.7	868.2	0	67,375
Citation/patent	2.2	1.3	5.548	0	241.1
Q	1.3	1.0	1.1	0.212	38.4

Note: The total number of observation is 21,460 with 1,931 firms and the sample period is from 1993 to 2015.

TABLE 1— SAMPLE STATISTICS (CONT'D)

[Panel B] Correlation Coefficients

	R&D/total assets	Patents/R&D	Citations/patents
R&D/total assets	1		
Patents/R&D	-0.0108	1	
Citations/patent	0.0457	-0.0074	1

wisdom is that R&D firms may have a more efficient patent production and/or citation process, but the data shows that not all active R&D firms are efficient in terms of gaining patents or receiving citations.

III. Empirical specification

I construct the relationship between Tobin's q for a firm and associated patent variables and R&D expenditures as defined in the previous section. A firm generates revenue and earnings with its physical capital and knowledge. The value of the firm can be thought of as a function of these variables. I follow the standard form of the knowledge production function in the literature.[1] An advantage of this specification is that I can compare the estimation results with those in earlier studies conveniently and obtain policy implications for Korea through such a comparison. The firm value function is expressed as shown below:

$$V_{i,t} = q_t(A_{i,t} + \gamma K_{i,t}) \tag{1}$$

Firm t's value in year t is $V_{i,t}$, consisting of physical capital $A_{i,t}$ and knowledge capital $K_{i,t}$, as shown in equation (1). This type of function assumes that the constant-return-to-scale and marginal shadow price of capital, q_t is identical across firms. The parameter γ is the price of knowledge capital relative to that of physical capital.

Taking the log on both sides of the equation (1) gives

$$\log V_{i,t} = \log q_t + \log A_{i,t} + \log\left(1 + \frac{K_{i,t}}{A_{i,t}}\right).$$

Subtracting $\log A_{i,t}$ on both sides yields the following equation,

$$\log Q_{i,t} = \log\left(\frac{V_{i,t}}{A_{i,t}}\right) = \log q_t + \log\left(1 + \gamma\frac{K_{i,t}}{A_{i,t}}\right) + \varepsilon_{i,t},$$

where $\varepsilon_{i,t}$ is a statistical error.

[1]Hall, Jaffe, and Trajtenberg (2005).

For convenience, I decompose knowledge capital to physical capital $\frac{K_{i,t}}{A_{i,t}}$ into three parts: R&D/Asset $\frac{R_{i,t}}{A_{i,t}}$, patent/R&D $\frac{P_{i,t}}{R_{i,t}}$, and citations/patent $\frac{C_{i,t}}{P_{i,t}}$. I assume that the linear combination of $\frac{R_{i,t}}{A_{i,t}}$, $\frac{P_{i,t}}{R_{i,t}}$, and $\frac{C_{i,t}}{P_{i,t}}$ can approximate $\frac{K_{i,t}}{A_{i,t}}$. This gives the following equation:

(2) $$\log Q_{i,t} = \log q_t + \log\left(1 + \gamma_1 \frac{R_{i,t}}{A_{i,t}} + \gamma_2 \frac{P_{i,t}}{R_{i,t}} + \gamma_3 \frac{C_{i,t}}{P_{i,t}}\right) + \varepsilon_{i,t}$$

This paper uses equation (2) for the analysis. I estimate γ_1, γ_2, and γ_3 by means of non-linear least squared estimation. Each parameter correspondingly measures the effects of R&D/Asset, patent/R&D, and citations/patent on the value of the firm.

IV. Estimation

A. *Estimation*

This section reports the estimation results of the equations presented in the previous section. Table 2 shows the non-linear least squared estimation results according to equation (2). Column (1) presents how R&D/asset and patent/R&D affect Tobin's q of the firm. Interestingly, although the coefficient of R&D/asset is positive and statistically significant, the coefficient of patent/R&D is negative. This result is not consistent with prior studies in a foreign context, which report a positive relationship between patents and the market value of a firm.

The variable D in the table is a dummy variable that takes a value of one when there is no R&D stock and is zero otherwise. The coefficient of D is positive but not statistically significant, meaning that patent stock or citation stock without R&D does not affect the market values of firms.

Table 2 column (2) reports the coefficients of all three independent variables, i.e., R&D/asset, patent/R&D, and citation/patent. While R&D/asset and citation/patent have positive and statistically significant coefficients, the coefficient of patent/R&D is not significant. The coefficients of R&D/asset and citation/patent are 1.151 and 0.006, respectively. The economic significance of the citation/patent variable is not as large as in prior studies. The magnitude of the citation coefficient is nearly ten times larger in foreign studies than in the results here.

One possibility is that legal protection in the Korean patent system is not strong enough to boost firm value. There have been many legal studies pointing out the weaknesses of this protection. Ryu (2019) reports that the Korean patent system is very conservative with regard to imposing punitive damages in cases of infringement. Punitive damages were introduced in 2019 in Korea. Therefore, there are too few judicial precedents to establish a clear standard of willful infringement. Furthermore,

TABLE 2— NON-LINEAR REGRESSIONS OF TOBIN'S Q ON PATENT VARIABLES

	(1)	(2)	(3)
R&D/asset	1.140***	1.151***	1.109***
	(6.26)	(6.22)	(6.11)
Patent/R&D	-4.15e-06	-3.97e-06	-3.68e-06
	(-1.53)	(-1.47)	(-1.38)
Citation/patent		0.00589***	
		(4.22)	
D (R&D = 0)	0.0474	0.0484	0.0505*
	(1.54)	(1.58)	(1.65)
Citation/patent Dummy Variables			
1-1.3			0.0320
			(1.61)
1.3-2.5			0.0475***
			(2.84)
2.5-6.5			0.0676***
			(3.75)
6.5 or above			0.0931**
			(2.55)
Year-fixed effects	Y	Y	Y
R-squared	0.1437	0.1462	0.1471
# of obs.	21,460	21,460	21,460

Note: Standard errors are cluster-robust errors at the firm level. *** p<0.01, ** p<0.05, * p<0.1. t-statistics are reported in parentheses.

the responsibility of proving that the patents are infringed falls on the patent owners. The cost is substantial for patent owners to be given actual legal protection in Korea.

The other possibility is that firms intentionally do not apply for a patent for their valuable technologies. Chung (2017) empirically shows that firms choose strategically between secrecy and pursuing patent protection depending on the risk of information disclosure. The weaker the patent protection is, the less incentive there is for firms to apply for a patent. Firms would instead choose to keep their valuable technologies secret.

Although the economic significance of the citation/patent variable on firm value is not as strong as in prior studies, the estimation result does not at all imply that citations have no economic effect on the market value of a firm. I also analyze the effect of the citation/patent variable by constructing citation/patent dummy variables and examining the effects of each of these. I break citation/patent into five groups: less than 1, 1-1.3, 1.3-2.46, 2.46-6.5, and greater than 6.5. They correspondingly represent less than 42%, 42%-50%, 50%-75%, 75%-95%, and greater than 95% in the sample. Table 2 column (3) reports the results of the estimation with the dummy variables depending on citation/patent percentile included in the regression. The economic significance of dummy variables with higher percentiles is greater. Firms with 1-1.3 citations/patent have a 0.032 higher log q than those with less than one citation/patent. The effect increases as firms enter a higher citation/patent group, implying that the citation/patent variable does play a role to some extent with regard to increasing the value of a firm, and not only for a specific group of firms.

To understand the previous analysis quantitatively, I calculate the degree of semi-elasticity. This enables us to interpret the magnitude of the effects of patents and

TABLE 3— SEMI-ELASTICITIES

	Mean	Median
R&D/asset	0.084	0.036
Patent/R&D	32.3	1.7
Citation/patent	2.2	1.3
Elasticity		
Partial logQ/ partial (R&D/asset)	1.036	1.097
Partial logQ/ partial (patent/R&D)	n/a	n/a
Partial logQ/ partial (citation/patent)	0.005	0.006

R&D conveniently. Taking the derivatives of each independent variable in equation (2) yields the following equation:

$$\frac{\partial \log Q}{\partial X_i} = \hat{\gamma}_i (1 + \hat{\gamma}_1 X_1 + \hat{\gamma}_2 X_2 + \hat{\gamma}_3 X_3)^{-1}.$$

The independent variables are R&D/asset, patent/R&D, and citation/patent.

Table 3 reports the semi-elasticity outcomes of the R&D/asset and citation/patent variables on log q. When R&D/asset increases by 1%p, Tobin's q increases by approximately 1%. One unit of increase in citation/patent is associated with a 0.5% increase in Tobin's q. The semi-elasticity of patent/R&D is not reported because it is not statistically significant in the previous estimation.

Consistent with the previous analysis, R&D/asset plays a more important role in increasing firm value, while the effect of citation/patent on firm value is limited. This implies that the patents of Korean firms are weakly associated with an increase in firm value.

B. *Cross-industry analysis*

A cross-industry analysis is implemented to investigate further the impact of patents on firm value. The importance of patents can vary across industries because technologies work in different ways depending on the market environment. Technology in some industries, such as pharmaceuticals, is crucial for sustaining the competitiveness of a firm, while other components, such as the scale of the economy, may be more important in other industries. Thus, it is necessary to check whether knowledge-intensive industries enjoy stronger effects of patents.

Five industries[2] are chosen to represent the various degrees of patenting activity.[3] I add those industry dummy variables and interaction terms to equation (2). Industries are categorized according to KSIC (Korea Standard Industry Code) two-digit codes. Chemicals, pharmaceuticals, metals, electronic parts, and medical precision categories are selected for use here. Chemical firms according to KSIC 20

[2]It is not possible to report the analysis results of all industries because there are more than 50 industries with KSIC two-digit codes. My findings for other industries are available upon request.

[3]Most patents were granted in electric parts during the sample period. Companies categorized into the chemicals, pharmaceuticals, and medical precision groups are so categorized in the order of the number of granted patents, with metals firms having the fewest patents granted in the sample.

are involved in the "manufacture of chemicals and chemical products; except pharmaceuticals and medicinal chemicals." Pharmaceuticals according to KSIC 21 are involved in the "manufacture of pharmaceuticals, medicinal chemical and botanical products." For metals, KSIC 25 stipulates the "manufacture of fabricated metal products, except machinery and furniture." Electronic parts companies according to KSIC 26 undertake the "manufacture of electronic components, computers; visual, sounding and communication equipment." Lastly, companies in the medical precision KSIC 27 group undertake the "manufacture of medical, precision and optical instruments, watches and clocks."

The most noteworthy industry is pharmaceuticals in the sense that it is a highly R&D-intense industry, and patent protection is crucial for firms to earn revenue, as developing new drugs requires considerable time and effort, whereas copying developed drugs is relatively easy.

The estimation equation with the industry effect is as follows.

$$(3)\quad \log Q_{i,t} = \log q_t + \log\left(\begin{array}{l} 1+\gamma_1 \dfrac{R_{i,t}}{A_{i,t}} + \gamma_2 \dfrac{P_{i,t}}{R_{i,t}} + \gamma_3 \dfrac{C_{i,t}}{P_{i,t}} \\ +\gamma_4 D_j \dfrac{R_{i,t}}{A_{i,t}} + \gamma_5 D_j \dfrac{P_{i,t}}{R_{i,t}} + \gamma_6 D_j \dfrac{C_{i,t}}{P_{i,t}} \end{array}\right) + \sum_j \gamma_j D_j + \varepsilon_{i,t}$$

In equation (3), the dummy variable D_j and the parameter γ_7 denotes the industry fixed effects and the corresponding coefficient. The parameters γ_4, γ_5, and γ_6 are correspondingly the coefficients of the interaction effects between the industry and knowledge capital variables for the R&D/asset, patent/R&D, and citation/patent variables.

Table 4 reports the estimation results of equation (3). The effect of the patent variables on firm value is strong in knowledge-intensive industries such as pharmaceuticals. Column (1) is the baseline result in Table 3. Column (2) is the result without the interaction effect. Firms in the pharmaceuticals and medical precision groups have a high book-to-market ratio in general. A high book-to-market ratio usually implies a high marginal product of capital. It is natural that pharmaceutical and medical precision firms are such industries. As such, the industry effect on firm value is consistent with the findings of prior research.

Table 4 column (3) shows interesting results. For firms in the chemicals category, the interaction term coefficient of R&D/asset offsets the coefficient of R&D/asset, meaning that R&D/asset does not affect firm value for these firms. On the other hand, patent/R&D affects firm value negatively for firms in the chemicals category.

In the pharmaceutical industry, the citation/patent variable is important for increasing firm value. The effect of the dummy variable itself on log q is 0.156 in column (2), but the statistical significance disappears when considering an interaction effect with independent variables. This implies that the high q in pharmaceutical firms comes from the effects of R&D and patent variables and not from unobserved factors in this industry. The coefficient of the citation/patent variable in pharmaceuticals increases drastically from 0.006 to 0.052 when

TABLE 4—NON-LINEAR REGRESSIONS OF TOBIN'S Q ON PATENT VARIABLES: INDUSTRY EFFECTS

	(1)		(2)		(3)	
Chemical			-0.0192	(-0.57)	0.0476	(1.20)
Pharmaceutical			0.156***	(3.77)	0.0347	(0.65)
Metal			-0.0430	(-1.11)	-0.0725	(-1.35)
Electronic parts			0.00352	(0.19)	0.135***	(4.69)
Medical precision			0.137***	(2.92)	0.188**	(2.11)
R&D/asset interaction	1.151***	(6.22)	1.076***	(5.77)	1.647***	(9.79)
Chemicals					-1.661***	(-9.19)
Pharmaceuticals					0.622	(0.77)
Metals					1.560	(0.98)
Electronic parts					-1.418***	(-5.96)
Medical precision					-0.738	(-1.22)
patent/R&D interaction	-3.97e-06	(-1.47)	-3.28e-06	(-1.09)	-1.44e-05**	(-2.13)
Chemicals					0.00147	(1.01)
Pharmaceuticals					0.00254	(1.09)
Metals					1.57e-05**	(2.29)
Electronic parts					0.000634	(1.45)
Medical precision					0.00243	(0.48)
citation/patent interaction	0.00589***	(4.22)	0.00602***	(4.32)	0.00600***	(4.50)
Chemicals					0.00539	(0.59)
Pharmaceuticals					0.0459**	(2.00)
Metals					0.00665	(0.63)
Electronic parts					-0.00381	(-1.30)
Medical precision					-0.00478	(-0.97)
D (R&D = 0)	0.0484	(1.58)	0.0511	(1.68)	0.0697**	(2.33)
Year-fixed effects	Y		Y		Y	
R-squared	0.1462		0.1543		0.1727	
# of obs.	21460		21460		21460	

Note: Standard errors are cluster-robust errors at the firm level. *** p<0.01, ** p<0.05, * p<0.1. t-statistics are reported in parentheses.

interaction effects are considered.

Firms in the metal industry appear to be irrelevant with regard to patent variables. The interaction effects on the metal group are not statistically significant, except for patent/R&D. The interaction effect for patent/R&D is 0.0000157, which reduces the effect of patent/R&D to nearly zero for the metal group. In the electronic parts industry, the effect of R&D/asset decreases compared to the benchmark case. In medical precision firms, the effects of R&D/asset, patent/R&D, citation/patent do not deviate much from the benchmark levels. In sum, the role of patents in increasing firm value varies across industries, and knowledge-intensive industries such as pharmaceuticals show a strong effect of the citation/patent variable.

C. *Self-citations*

elf-citations are citations associated with patents for which the assignee firm is identical to that of the cited patent. A self-citation is a special type of citation, and it has important meanings. Prior research shows that the importance of self-citations with regard to technological advances is higher than citations by others. We can keep track of the evolution of technology with self-citations. In this section, I more closely

TABLE 5— NON-LINEAR REGRESSIONS OF TOBIN'S Q ON PATENT VARIABLES: SELF-CITATIONS

	(1)	(2)	(3)
R&D/asset	1.151***	1.140***	1.166***
	(6.22)	(6.24)	(5.96)
Patent/R&D	-3.97e-06	-4.01e-06	-3.90e-06
	(-1.47)	(-1.48)	(-1.42)
Citation/patent	0.00589***		
	(4.22)		
Self-citation/patent		0.0350**	0.0336**
		(2.23)	(2.05)
[Self-citation/patent] * log(patent portfolio)			0.00453
			(0.57)
D(R&D = 0)	0.048	0.048	0.054
	(1.58)	(1.58)	(1.49)
Year-fixed effects	Y	Y	Y
R-squared	0.1462	0.1448	0.1475
# of obs.	21,460	21,460	19,392

Note: Standard errors are cluster-robust errors at the firm level. *** p<0.01, ** p<0.05, * p<0.1. t-statistics are reported in parentheses.

examine the effects of self-citations on the market value of a firm. If self-citation more aptly captures technology, it should have strong effects on firm value.

When dealing with self-citations, it is important to consider the patent portfolio, which is the number of patents of a firm. If a firm owns many patents, the number of self-citations grows naturally. One should control for the patent portfolio; otherwise, the effect of self-citations is actually the effect of the patent portfolio.

Table 5 reports the estimation results of equation (2), including self-citations. The self-citation/patent variable is a stock variable identical to citation/patent except that the numerator is the self-citation stock. It has the same depreciation rate of 0.15, and it only increases when a firm cites the patent whose owner is the firm itself. Consistent with expectations here, the coefficients of the self-citation/patent variable is larger than that of the citation/patent variable. Table 5 column (1) presents the baseline result. Column (2) includes the coefficient of the self-citation/patent variable. The effects of self-citation/patent are approximately five times that of the citation/patent variable.

Column (3) includes the interaction term of self-citation/patent with a log patent portfolio. The interaction term is assumed to control for the number of patents owned by a firm. After controlling for the patent portfolio, the effect of self-citation/patent on firm value is economically and statistically significant as well.

D. *Firm's operating performance and patents*

In this section, I investigate whether R&D, patents, and citations can predict the future operating performances of firms. In the previous sections, I examined the relationship between only patent variables and firm value by utilizing the Cobb-Douglas production function. Because firm value is ultimately the sum of the present value of future earnings, there should be predictability of future earnings for variables that are strongly associated with firm value, such as self-citations. I adopt panel regressions to examine this because the purpose of this analysis is to determine simple predictability outcomes.

In panel regressions, I use the following equation for the estimation.

$$Y_{i,t} = \beta_1 + \beta_2 \frac{R_{i,t-1}}{A_{i,t-1}} + \beta_3 \frac{P_{i,t-1}}{R_{i,t-1}} + \beta_4 \frac{C_{i,t-1}}{R_{i,t-1}} + control + \varepsilon_{i,t}$$

Here, $Y_{i,t}$ is a firm operation variable. It is net-income/asset, operating-income/asset, and sales/asset. The control variables, $control$, include the log of market capitalization, firm-fixed-effect dummy variables, and year-fixed-effect dummy variables. The independent variables are R&D to assets, patents to R&D, and citations to patents, as defined in the previous sections.

The sample is identical to that used in the previous analysis. All variables are winsorized at the 1% and 99% level and normalized to a standard deviation of one to exclude the effects of extreme value observations.

Table 6 reports the panel regressions results. R&D/asset is negatively correlated with net-income/asset and operating-income/asset. A one standard deviation increase in R&D/asset is associated with a 0.16 standard deviation decrease in net-income/asset and operating-income/asset, as R&D is expensed and decreases current profits mechanically. Patent/R&D is not correlated with net-income/asset, operating-income/asset, or sale/asset.

The coefficients of citation variables are interesting in that citation/patent is negatively correlated with the profit and sales variables, while self-citation/patent is positively correlated with the dependent variables. A one standard deviation increase in citation/patent decreases the market value by approximately 0.038–0.04 standard deviations. On the other hand, a one standard deviation of self-citation/patent boosts market value by 0.033-0.038 standard deviations. Consistent with the previous

TABLE 6— REGRESSIONS OF OPERATING PERFORMANCE VARIABLES ON PATENT VARIABLES

VARIABLES	(1) Net income/asset	(2) Operating income/asset	(3) Sales/asset
R&D/asset	-0.163***	-0.158***	0.00369
	(-7.972)	(-8.327)	(0.225)
Patent/R&D	-0.00529	-0.00262	0.00565
	(-0.636)	(-0.305)	(0.674)
Citation/patent	-0.0381***	-0.0400***	-0.0369***
	(-2.925)	(-3.367)	(-3.406)
Self-citation/patent	0.0343***	0.0377***	0.0328***
	(4.352)	(4.260)	(4.080)
Size	-0.100***	-0.183***	-0.639***
	(-3.322)	(-6.727)	(-25.94)
Year-fixed effects	Y	Y	Y
Firm-fixed effects	Y	Y	Y
# of obs.	19,507	19,507	19,507
R-squared	0.497	0.520	0.635

Note: Standard errors are cluster-robust errors at the firm level. *** p<0.01, ** p<0.05, * p<0.1. t-statistics are reported in parentheses.

TABLE 7— REGRESSIONS OF OPERATING PERFORMANCE VARIABLES ON PATENT VARIABLES: LONG-RUN EFFECT

Variables	(1) Net income/asset	(2) Operating income/asset	(3) Sale/asset
R&D/asset	-0.0411**	-0.0592***	-0.0197
	(-2.032)	(-3.379)	(-1.397)
Patent/R&D	0.00554	-0.00381	-0.00485
	(0.611)	(-0.417)	(-0.548)
Citation/patent	-0.0277**	-0.0322***	-0.00445
	(-2.157)	(-2.641)	(-0.405)
Self-citation/patent	0.0254***	0.0244***	0.00607
	(3.335)	(2.789)	(0.737)
Size	-0.346***	-0.293***	-0.190***
	(-11.09)	(-11.01)	(-7.371)
Year-fixed effects	Y	Y	Y
Firm-fixed effects	Y	Y	Y
# of obs.	15,912	15,912	15,912
R-squared	0.624	0.661	0.725

Note: Standard errors are cluster-robust errors at the firm level. *** p<0.01, ** p<0.05, * p<0.1. t-statistics are reported in parentheses.

analysis, these results implies that self-citations are closely related to technological advances and that their importance is much higher.

A patent has the characteristic of a real option (Bloom and Reenen, 2002). It can take several years for firms to utilize the technology of a patent. In such cases, current patents can affect firm value through future operational outcomes in the long run. It takes a long time to initiate the effect of patents, and the effects last for long periods of time. A one-year time lag may not be enough to capture the predictability of patent variables. To address this concern, I construct three-year cumulative dependent variables. The estimation equation is as follows.

$$Y_{i,t,t+2} = \beta_1 + \beta_2 \frac{R_{i,t-1}}{A_{i,t-1}} + \beta_3 \frac{P_{i,t-1}}{R_{i,t-1}} + \beta_4 \frac{C_{i,t-1}}{R_{i,t-1}} + control + \varepsilon_{i,t}$$

$Y_{i,t,t+2}$ denotes the three-year cumulative dependent variables.

Table 7 displays the long-run effect of knowledge capital on a firm's operation. The results are consistent with the previous analysis. R&D/asset is negatively correlated with the profit variables. A one standard deviation increase in R&D/asset is associated with a 0.04 standard deviation decrease in three-year cumulative net-income/asset. The coefficient is 0.11-0.12 standard deviations smaller than the coefficients of a one-year lag analysis. A one standard deviation increase in citation/patent leads to a 0.027-0.045 standard deviation decrease in profit variables. On the other hand, a one standard deviation increase in self-citation/patent is associated with a 0.025 standard deviation increase in profit variables. In sum, the cumulative technological advance is positively associated with long-term profit generation.

V. Robustness Check

This section presents the results of additional analyses as a robustness check. The Korean economy experienced major economic shocks during the 1997-1998 Asian financial crisis and during the 2008 global financial crisis. At those times, firm values depreciated abruptly. To mitigate the concern that the results in the previous section stem from those extreme periods, I run a subsample analysis to determine if the results still hold after excluding such periods.

Table 8 reports the estimations with the same analysis of equation (2) with the subsample period of 2010-2015. The results are not different from the baseline results. R&D/asset plays a crucial role in increasing firm value, while the coefficient of patent/R&D is not economically or statistically significant. Citation/patent is positively associated with firm value increase as well.

The scope of the knowledge capital captured by patents consists of two features: the knowledge itself contained in the patents and the right of legal protection. Patent protection is limited to the country where the patent is granted. Hence, it quite often occurs that firms file patents in multiple countries with the same technology. Similar or the same technology patents in different countries are collectively referred to as a “patent family.” In the previous analysis, I count patents without considering patent families, as the value of patents comes not only from the technology itself but also originates from legal protection as well.

However, one may raise the concern that patent families can inflate the number of patents. To address this point, I consider the first patent in the patent family as the effective case and compute the patent stock with that item. This is a very conservative approach because the remaining patents in the family are considered as valueless.

Table 9 reports the estimation results with alternative patent stock data. Similar to the previous results, patent/R&D does not affect firm value. The effect of citation/patent increases slightly to 0.008. In short, after excluding patent families, R&D/asset is the most important factor with regard to increasing firm value in Korea.

TABLE 8— NON-LINEAR REGRESSIONS OF TOBIN’S Q ON PATENT VARIABLES: 2010-2015

	(1)	(2)
R&D/asset	1.2450***	1.2680***
	(8.55)	(8.52)
Patent/R&D	-3.14E-06	-2.91E-06
	(-1.58)	(-1.49)
Citation/patent		0.006954***
		(3.13)
D (R&D = 0)	0.1656***	0.1656***
	(4.03)	(4.04)
Year-fixed effects	Y	Y
R-squared	0.1465	0.1496
# of obs.	8,488	8,488

Note: Standard errors are cluster-robust errors at the firm level. *** p<0.01, ** p<0.05, * p<0.1. t-statistics are reported in parentheses.

TABLE 9— NON-LINEAR REGRESSIONS OF TOBIN'S Q ON PATENT VARIABLES: PATENT FAMILY ADJUSTED VARIABLES

	(1)	(2)
R&D/asset	1.2521***	1.2665***
	(7.28)	(7.24)
Patent/R&D	-6.30E-06	-6.04E-06
	(-1.69)	(-1.63)
Citation/patent		0.00838***
		(4.74)
D (R&D = 0)	0.0512***	0.0508***
	(1.67)	(1.66)
Year-fixed effects	Y	Y
R-squared	0.1502	0.154
# of obs.	21,265	21,265

Note: Standard errors are cluster-robust errors at the firm level. *** p<0.01, ** p<0.05, * p<0.1. t-statistics are reported in parentheses.

VI. Conclusion

By taking advantage of a novel patent database, I investigate the relationship between firm-level patents and firm value in Korea. I estimate the non-linear production-function type of Tobin's q equations on R&D, patents, and citations. The effect of R&D/asset is much higher in Korea than the effects reported in the literature, though surprisingly, patent/R&D is not associated with an increase in firm value. Firm value rises with citation/patent, but the magnitude is much smaller than the results in prior studies. Self-citation, which can track the technological advance of a firm, plays an important role in the increase in firm value. Overall, the results of the analysis here imply that the patent system in Korea does not play a role in boosting firm value.

The findings can be interpreted in two ways. One is that the patent system in Korea does not provide adequate protection. There have been many legal studies pointing out the weakness of patent protection in Korea. Proving infringement and accessing potential damage are too costly and burdensome for firms in Korea. Even if firms prove that an infringement took place, economic compensation is too low compared to the actual damage from the infringement. In many cases, patents in Korea may not be giving actual exclusive rights to the patent assignee, which can lead to a weak association between patents and firm value.

The second possible interpretation is that firms do not file patents with valuable technologies that have a risk of information disclosure, as Chung (2017) argues that firms choose strategically between secrecy and pursuing patent protection. Due to the weak patent protection in Korea, firms tend to choose secrecy when there is a risk that their technologies will be replicated by competitors.

Regardless of which mechanism better explains the main findings of this paper, the results provide clear implications for policies pertaining to the patent system in Korea. Policymakers in Korea should set up proper institutional and legal systems so that patents held by Korean firms can increase the value of these firms. Reinforcing patent protection will lead to the active patenting of valuable technologies, as firms will have more of an incentive to apply for a patent. If firms tend to apply for more patents, knowledge spillover in the economy will be stimulated. Thus, policymakers in Korea should enhance patenting incentives to promote innovation in Korea.

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