Incumbents’ response to patent enforcement: In case of the 1994 Korean patent reform

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ABSTRACT

This paper investigates firms' responses in electronics and related equipment industry to the 1994 Korean patent reform. The empirical results show that incumbents with large fixed capital strategically respond to patent reform in that they significantly increase the patent applications without an associated increase in R&D expenditure after the patent reform. However, the incumbents’ strategic response in Korea is limited in that it is observed only in large-scale firms and in the short term. In the long-run, patent applications are more sensitive to firm size and R&D efforts. The empirical analysis also finds that the elasticity of patent applications with respect to R&D spending in Korea is much less than that of advanced countries such as the U.S.A.

Key word: Patent reform, innovation, strategic response

JEL Classification: L5, L6, O3

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Ⅰ. Introduction

The effectiveness of strong intellectual property rights as an innovation incentive mechanism has been a controversial issue in recent years. People favoring strong patent protection argue that it provides stable economic opportunities for inventors to appropriate the innovation results and offers better incentives for firms or inventors to put more innovative efforts into their research activities.

However, people skeptical to the effects of strong patent protection suspect that firms usually rely more on the 'secrecy' or 'lead-time' rather than 'legal protections' to appropriate their innovation outcomes, and hence the net effect of patent protection is limited. They argue that the effect of patent protection is even more limited to 'complex technology' such as electronics and machinery industries, in which firms need to combine numerous technologies to produce a final good and hence a single patent may not contribute much economic benefit (Cohen *et al*., 2000). The patent system in these industries may rather be utilized as a potential entry barrier by incumbents against their potential competitors through registering unnecessary 'sleeping patents' for the purpose of future 'bargaining chips' (Hall and Ziedonis, 2001).

The main goal of this paper is to determine whether the patent reform stimulated innovative efforts in the private sector and to explore if there is any strategic concern for incumbents attributable to patent enforcement in Korea. This issue is of considerable importance because the effect of patent protection is directly related with the degree of technology diffusion and associated social welfare issues. If the stronger patent protection works as a potential entry barrier against new innovative entrants without increasing further R&D effort of incumbents, the patent reform may reduce firms' innovation efforts and eventually decreases associated social welfare.

The analysis focuses on the 1994 Korea patent reform and innovation efforts in the Korean manufacturing sector, electronics and related equipment industry. The 1994 patent reform provides an important natural experiment in that it expanded patent length from 15 years to 20 years and reinforced other inventor's rights corresponding to the TRIPs (Trade Related Intellectual Property rights) agreement. The government officer and public perception of Korea agreeably recognizes that the 1994 patent reform effectively enforced the intellectual property rights of inventors to the level of advanced countries.

The analysis also focuses on the electronics and related equipment industry because this sector shows a significant increase in patent application rights after the 1994 patent reform. The related empirical analyses consider the number of patent applications as an indicator of innovation efforts and evaluate whether the 1994 patent reform effectively spurred the innovation efforts of the private sector (Seo *et al*., 2004). According to Cohen *et al*. (2000), however, the electronics and related equipment industry exhibits substantial complexity and the industrial characteristics lead firms which is not likely to rely on the legal protection. The industry also shows the characteristics of rapidly progressive and cumulative technology, which may also reduce the importance of patent protection. We investigate the paradox observed in the industry and provide a better understanding of the effects of patent reform.

A key empirical finding in this paper is that large sized firms show behavior consistent with the ‘patent thicket’ or ‘strategic response’ hypothesis. Large-size incumbents significantly increase the number of patent applications without the associated increase in R&D spending after patent reform. Contrasted with the large-size incumbents’ responses, however, small-medium firms did not show any significant change in both R&D spending and the number of patent applications. Thus, the empirical results suggest that large-size firms in the electronics industry increase the number of patent applications in a strategic motive against the potential entrants. However, the incumbents’ strategic behaviors are limited only to the short term in that its patent applications are more sensitive to firm size and R&D spending in the long-run.

The remainder of this paper is organized as follows: Section 2 briefly reviews the related theoretical and empirical literature and describes the 1994 Korean patent reform. Section 3 discusses the data and sample used for estimation and delineates the econometric model. Section 4 presents the regression results, and section 5 concludes this study.

Ⅱ. Patent Reform and Innovation Efforts

Literature Review

Theoretical literature on patent reform and innovation efforts has formally proved the relationship between patent scope and optimal innovation effort, and government policy makers and public interest groups have emphasized strong patent protection under this common perception. Contrary to general recognitions, however, recent empirical studies show somewhat mixed and even conflicted results regarding the effect of patent enforcement on innovation. Focusing on the analyses of aggregate or economy-wide responses, Gould and Gruben (1996), Kanwar and Evenson (2003), and Dincer (2007) argue the positive effect of stronger patent rights on economic growth, while firm-level analyses such as Cohen *et al*. (2000), Jaffe (2000), Hall and Ziedonis (2001), and Sakakibara and Brenstetter (2001) document no positive relations between strong patent rights and innovation efforts.

Gould and Gruben (1996) perform the country-wide cross-section analysis with the index of intellectual property rights developed by Rapp and Rozek (1990). They find that the degree of patent protection is positively correlated with economic growth and the influence of patent rights on economic growth is amplified in the country having more opened economic system. These results are supported by Kanwar and Evenson (2003). They argue that intellectual property rights as incentives for spurring innovation are significant and stronger intellectual property rights increase R&D expenditures not only in developed countries but also in developing countries. These studies focus on relatively long-run and macroeconomic effects.

On the other hand, some studies focusing on relatively short-term and microeconomic effects document no empirical evidence regarding the effectiveness of stronger patent reform. Cohen *et al*. (2000) using the Carnegie-Mellon Survey show that the importance and the degree of patent dependency are quite different among industries because the degree of appropriation of innovation outcomes through legal protection is different and hence so is the effectiveness of enforced patent rights on innovation. The Carnegie-Mellon Survey exhibits that firms conceive secrecy, technological lead-time, and patent rights as important mechanisms to appropriate the economic benefit from innovation. The patent is, however, the least important instrument among them.[1] Cohen *et al*. (2000) show that patents are unambiguously the least central of the major appropriability mechanisms overall and no industry indicates patents as the most effective instrument.

The studies on firms' behavior using the industrial data of the U.S. and Japan, also find no empirical evidence that strengthened patent rights spur innovation in the private sector. Using U.S. R&D data, Jaffe (2000) finds no empirical evidence that expanded patent rights induced more innovative activities by firms. In particular, Jaffe argues that R&D investment in the U.S. had increased before patent enforcement occurred, and hence contrary to public perception, expanded patent rights did not contribute to the innovation.

Hall and Ziedonis (2001) investigate the semi-conductor industry using 1979-1995 data, and find that strengthened patent rights are only effective to R&D intensive small-size firms, but not to large-size conglomerates. Furthermore, they argue that expanded patent rights cause rapid increase of patent application in the 1980s without associated increases of R&D expenditures. Sakakibara and Branstetter (2001) also find no empirical evidence that the Japanese patent reform enacted in 1988 has spurred innovation in the private sector of the economy. Oh and Park (2008) uses the R&D expenditure as an indicator of innovation efforts and also provides empirical evidence that the 1994 Korea patent reform did not stimulate firms' innovative behaviors.

The previous empirical studies generally focus on the effects of patent reform on innovation using R&D expenditure or patent application data. But we observe that

[1] The survey results show that secrecy is the dominant mechanism in the chemicals and semiconductors industries, while the communications equipment, computer, steel, car and truck industries indicate that the key mechanism is 'lead-time.' Electrical equipment shows low scores in overall mechanisms implying that the appropriability of innovation itself is low.

there exists a significant discordance between R&D expenditure and patenting propensity. After the 1994 Korean patent reform, incumbents significantly increased the number of patent applications without the associated increase of R&D expenditure.

Thus, we investigate the reasons of the observed discordance between the trends of patent application and R&D expenditure. We use firm-level data and believe that the firm-level analysis of the narrowly defined industry can control industry heterogeneity and provides relatively better features regarding the responses of individual firms to patent reform.

Patent Reform and Incumbents' Response in Korea

The economic literature, in general, presumes that broader patent scope or extended patent length will induce more R&D efforts, and the positive relationship between patent scope and optimal R&D effort has widely been accepted to many economists and policy makers. The Korean government has joined the agreement on TRIPs and expanded patent scope corresponding to the agreement on TRIPs in December, 1993. The most noteworthy change of the reform is the expansion of patent length from 15 years to 20 years beginning with the date applied. After patent reform, the number of patent applications increased in a significant way especially in the electronics and related equipment industry.

Figure 1 shows the trend of patent applications during 1990-2006 in the main Korean manufacturing industries.[2] One of the interesting features is that the number of patent applications in the electronics and related equipment industry

[2] The data used in Figure 1 are the sample used in this paper. However, the trends of the sample are almost the same as those of the total patent applications of Korea.

(D323) jumped in 1995 just after the patent reform and continued to rise sharply through 1997, which is just before the 1998 financial crisis occurred in Korea. This suggests that the 1994 patent reform contributes to a pro-patent shift in Korean industry. On the other hand, here is no similar reaction in other sectors.[3]

[Place Figure 1 here]

An interesting point is that the electronics and related equipment industry is the representative industry showing the characteristics of 'complex technology' according to Cohen *et al*. (2000) which is the least-patent dependent industry to appropriate their innovation results.

The direct comparison of the number of patent applications and R&D expenditure provides better feature regarding the issues. Figure 2 describes the trends of R&D expenditures and the number of patent applications in the electronics and related equipment industry during the sample period.

[Place Figure 2 here]

Conversly to the significant increase in patent applications, R&D expenditures do not show any substantial change in both level and growth rate around the 1994 patent reform. This suggests that the upsurge of patent applications is attributable to the 1994 patent reform, but the innovation effort measured by R&D expenditure is not much affected by the reform.

[3] D29-35 (machinery and equipment and transport equipment) also shows a sharp increase in patent application in 1995 and 1996, however, this sector are combined with five different sectors except for D32 and its share of patent application is relatively smaller than that of D323. Thus, this paper focuses only on D323.

Figure 3 exhibits clearly different behaviors in the patterns of patent application and R&D expenditure between large and small-medium size firms. While large-size firms show a sharp increase in the number of patent application without significant change in the growth rate of R&D expenditures after the 1994 patent reform, small-medium size firms do not demonstrate significant changes in both variables.

[Place Figure 3 here]

In summary, Figure 2 and Figure 3 address two important issues to be explored in this paper. First, the innovative effort of the industry, which is measured by R&D expenditures, seems not to be stimulated by the 1994 patent reform. Second, the feature of patent applications shows quite different behaviors between large and small-medium size firms and addresses the possibility that patent reform is utilized as a defensive mechanism of dominant incumbent firms against innovative new entrants. We now try to understand this obvious conflict and turn to more accurate econometric models to investigate the response of incumbents to the 1994 Korean patent reform.

Ⅲ. Econometric Model: Patent Production Function

The empirical analysis below investigates the influence of the 1994 patent reform of Korea. The main concern of the study is to explore whether the patent reform stimulates the innovation effort of private sectors and, if otherwise, what causes the significant increase of incumbents' patent application.

The tendency of patents is measured by the number of patent application and the innovation effort of individual firm is measured by real R&D expenditures and R&D expenditures per worker. Since Figure 2 exhibits that the size of firms may be an important feature to understand firms' behavior we separately run regressions by large-size and small-medium size firms for the same time periods.

We employ a patent production function first introduced by Pakes and Griliches (1980) and adopt a negative binomial regression model to explore the incumbents' response to patent reform in Korea. Because the number of patents is count variable, we basically use the Poisson model. However, the assumed equality of the conditional mean and variance is typically taken to be the major shortcoming of the Poisson regression model. Many alternatives have been suggested and the most common is the negative binomial model, which arises from a natural formulation of cross-section heterogeneity. The negative binomial regression model is an extension of the Poisson regression model which allows the variance of the process to be different from the mean. It introduces a certain kind of unobserved individual heterogeneity or over-dispersion into the Poisson model.

For the fixed effect over-dispersion models, let y_{it} be the count for the t^{th} observation of firm i. We begin with the model $y_{it} | \gamma_{it} \sim Poisson(\gamma_{it})$ where $\gamma_{it} \mid \delta_i \sim gamma(\lambda_{it}, 1/\delta_i)$ with $\lambda_{it} = \exp(X_{it}\beta + \varepsilon_{it})$ and δ_i is the dispersion parameter. This yields the model:

$$\Pr(Y_{it} = y_{it} | X_{it}, \delta_i) = \frac{\Gamma(\lambda_{it} + y_{it})}{\Gamma(\lambda_{it})\Gamma(y_{it} + 1)} \left(\frac{\delta_i}{1+\delta_i}\right)^{\lambda_{it}} \left(\frac{1}{1+\delta_i}\right)^{y_{it}}$$

Looking at within-group effects only, this specification yields a negative binomial model for the firm *i* with dispersion (variance divided by the mean) equal to $(1+\delta_i)$.

Firms' innovation effort of firm is measured by R&D expenditures and R&D expenditures per worker. We estimate the coefficient between innovation and patent applications controlling other factors and consider the coefficient as a productivity of R&D effort for the patent.

As previous studies have been documented, there may be economies of scale in generating patents due to the fixed cost of maintaining a legal department that handles intellectual property rights and related works (See Hall and Ziedonis, 2000; Lanjouw and Lerner, 1996; Lerner, 1995). We employ firm size measured by the number of worker into the regression equation to see if there exists any scale effect on the firm's patenting behavior.

The main goal of the study is to investigate the incumbents' responses to patent reform. Hall and Ziedonis (2000) argue that firms with large sunk costs in complex manufacturing facilities appear to have the largest incentives to expand their patent portfolios to safe guard against the threat of costly litigation and to negotiate access to external technologies on more favorable terms. Following Hall and Ziedonis, we also assume that the capital intensity of the firm indicates the significance of sunk costs and estimate how such characteristics influence patenting behavior under stronger patent regimes.

We also estimate a series of 'patent production functions' under various specifications that explore whether a change in firm level patenting behavior has taken place during the period associated with stronger patent reform, as suggested by the general trends shown in Figure 1.

Ⅳ. Data Sources and Empirical Results

Descriptive Summary

Following Hausman, Hall, and Griliches (1984) we adopt a negative binomial regression model with the sample period of 1990-2006 in the electronics and related equipment industry, and analyze how its R&D investment and patenting behavior are changed over the patent reform. Two different sources of data are combined by company name and industry code. The data for the number of patent application of individual firms are from the Korean Intellectual Property Office (KIPO), and R&D expenditure with other financial variables such as sales, number of workers, and tangible fixed asset are brought from the Korea Investors Service-Financial Analysis System (KIS-FAS).

We, in particular, focus on the electronics and related equipment industry, which have the characteristics of rapidly changing and cumulative technologies. By focusing on a specific industry, we can control the industrial heterogeneity and show better characteristics regarding the associated R&D activities of individual firms. This study uses the unbalanced firm level panel data of 35 individual firms in the electronics and related equipment industry and adopts only firms established before 1994 to investigate the incumbents' responses to the patent reform. We also limit our sample only to firms which have at least two-year occurrences in patent applications during the sample period. R&D expenditures are deflated by producer price index (PPI) to convert them into 2000 constant value.

Table 1 provides the summary statistics for the sample used in the regression. The maximum number of patent application is 17,832 which is the number of the patent application of Samsung Electronics Co. Ltd. in 2005. This firm also achieved the maximum amount of real R&D spending and the maximum number of employees in the sample in 2006, which are 16.3 billion US dollars and 85,813 workers, respectively.

[Place Table 1 here]

Comparisons of the mean and median in Table 1 exhibit severe skewed sample distributions for each variable. The mean of each variable is generally much larger than the medians implying that the innovation activities are generally dominated by large sized firms. The mean number of patent applications for each year is up to 545.2, but the median firm usually has zero patent applications per year. The average of R&D expenditure is 180.9 million U.S. dollars while the median firm spends at most 1.4 million dollars for their R&D activities. R&D intensity measured by 'R&D spending per worker,' firm size measured by the number of workers, and capital intensity measured by the tangible fixed asset per worker also exhibit the asymmetry among firms. The standard deviation is much larger than the mean value of each variable and the features of data imply that the over-dispersion of variance is substantial and the negative binomial model will fit better than the simple Poisson regression model.

Empirical Results

The purpose of this paper is to investigate the patent behavior of firms in the electronics and related equipment industry corresponding to the enforced 1994 Korea patent reform. The incumbents' responses to patent reform are measured by the number of patent applications and the columns of Table 2 report the estimation results using negative binomial fixed effect model under various specifications.[4]

[4] The empirical results of negative binomial random effect model are almost the same as those of the

The fixed effects for each firm with a constant term are not reported for simplicity.

[Place Table 2 here]

We first estimate the effect of R&D expenditure on the patent application, which indicates the estimated elasticity of patent applications with respect to R&D spending. The estimated coefficient is .374, which is somewhat lower than the estimates for the U.S.A. Hall, Griliches, and Hausman (1986) obtained an R&D elasticity of .52 for a sample of 642 firms. It was .75 in Hausman, Hall, and Griliches (1984) using the negative binomial regression model for 128 large firms for the whole manufacturing sector in the 1970s.[5] Hall and Ziedonis (2001) obtained an R&D elasticity of .989 for a sample of 95 U.S. semiconductor firms during 1979-1995. The estimated patent propensity with respect to R&D spending in developing countries like Korea seems to be lower than that of the advanced countries. The difference in R&D elasticity between developing and advanced countries can be understood with the 'catching up' nature of industry in the developing country and the inferior infrastructure of research related equipment or workers.

From column (2) through (6), we use R&D intensity measured by R&D expenditure per worker as an indicator for innovation efforts to control size effects on the patenting behaviors of firms. The main empirical results do not show any quantitatively different results. The innovation effort measured by R&D expenditure per worker shows a statistically significant and positive effect on patent

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fixed effect model. The results can be obtained from the authors by request.

[5] In this paper, the elasticity of patent application with respect to R&D spending for large-size sample is .329 with the standard error of .043 using the same variable in column (1).

applications.

The regression result also shows that capital intensity plays an important role in the propensity to patent. The estimated coefficient is .154 and statistically significant at the 1% significance level. As Hall and Ziedonis (2000) argue, this result implies that capital intensive firms in Korea are also concerned about the ‘hold up’ problem against the potential competitors and are likely to invest more aggressively in patent application.

One of the interesting regression results is regarding the effects of firm size and dummy variable for dominant firms. The estimates of firm size and dummy for Samsung and LG are statistically significant at 1% and 10% level, respectively and the coefficients are much larger than those of any other variables. This means that there exist large economies of scale in patenting and hence patenting is dominated by the large firms due to the large fixed cost of initiating legal procedures and the related works.

The coefficient of post-1994 dummy variable indicates that firms on average increased the number of patent application after the 1994 patent reform and reflects that the aggressive patent portfolio races occurred among incumbents after the patent reform even controlling other variables such as R&D spending, capital intensity, and firm size. However, the dummy variable for 1998 is not statistically significant.

Table 3 shows the empirical results by firm size.[6] The overall results in Table 3 are consistent with those in Table 2. The R&D effort and the size effect of the firm are statistically significant in both groups and the estimated effect of firm size in both groups are relatively larger than that of R&D intensity.

[6] We define the small-medium size firms as those with less than 500 workers.

[Place Table 3 here]

One of the noticeable results is that the 1994 patent reform is only effective for large-size incumbents. The estimated coefficient of post-1994 dummy variable is 0.445 and statistically significant at the 5% significance level for large-size incumbents, but it does not show statistical significance for small-size firms. The capital intensity, which represents the incumbents' strategic concern, loses its statistical significance when the post-1994 dummy is added. This implies that the effect of capital intensity shifts to the post-1994 dummy and the incumbents with large sunk costs strategically response to the enforced patent reform by increasing the number of patent applications.

In comparing the effects of firm size and innovative effort on patenting, the former is much larger than the latter in large-size firms relative to in the small-size firms. That is, the coefficient of size for large incumbents (.645) is five times bigger than the coefficient of R&D per worker (.125), while for the small-size incumbents, the contribution of size effect on patent applications is just twice as large than the effect of R&D effort (0.736 vs. 0.395). This implies that the large-size incumbents enjoy relatively more the economies of scale in patent application and its related management than small-size firms.

Table 4 shows the results of patent propensity by period. We selected four four-year intervals that allow for gradual responses to the regime shift. The first period, 1990-1993, examines the patenting behavior of firms under the weaker patent regime. The second period, 1994-1997, examines the determinants of patenting under the pro-patent regime. The Korean economy experienced a financial crisis in

December 1997 and the financial crisis resulted in substantial economic impact on firms' behavior. We identify the period of financial crisis with the 1998-2001 period.

The regression results in Table 4 show significant changes in incumbents' behaviors regarding patent applications. During the second period, the effect of innovation effort substantially decreased and is not statistically significant, while the estimated coefficient of capital intensity increased up to 0.966 and is statistically significant at the 1% significance level. During the period, the firm size also turns out to be a significant and positive factor on patent applications. The estimated results imply that higher capital intensive firms are more likely to increase patent applications under stronger patent enforcement and suggest that patent applications during this period are attributable to both the strategic concern and the economies of scale of firms.

[Place Table 4 here]

An interesting point of the results is that the strategic behaviors of incumbents are limited only to the short period. The estimated coefficient of capital intensity turns out to be small and insignificant during the economic crisis and afterward (periods III and IV). On the other hand, innovation efforts recovered in explaining incumbents' patenting behaviors during and after the economic crisis. These results suggest that the patenting behavior of incumbents experienced a structural change during the sample periods. During the pro-patent regime (period II), incumbents strategically responded to the enforced patent reform, but during and after the economic crisis, this strategic response disappeared with the increasing importance of R&D efforts and economies of scale in patenting.

Table 5 shows the empirical results regressed by firm size and period. According to the results, incumbents' strategic behaviors attributable to the 1994 patent reform are observable only for large-sized incumbents in the second period, while capital intensity in the small-sized firm did not show any statistical significance to patent applications during the any sample period.

For large incumbents, the relative contribution of firm size on patent applications increases after the patent reform. Even if the innovation effort is also significantly effective for patenting behavior, the estimated coefficient decreases from .695 into .251, while the estimates of firm size increases to .982. This implies that the number of patent applications is highly correlated with firm size and hence the associated economies of scale are increasingly important for a firm's patent strategy.

[Place Table 5 here]

Overall, the regression results show that the 1994 patent reform is effective to firm's patent propensity. The effect is, however, limited to large incumbents only in the short term in the spirit of the 'strategic response' hypothesis. Another outcome pertains to the importance of the firm size on the patent application. The results suggest that the economies of scale in applying for patents become a more important factor in explaining the increased number of patent applications in both small and large-size incumbents.

Ⅴ. Concluding Remarks

This paper examined incumbents' responses to the 1994 Korean patent reform in the electronics and related equipment industry and investigated whether the reform effectively induced more innovation efforts of incumbents and, otherwise, what caused the significant upsurge in the number of patent application rights after the patent reform in Korea.

Basic statistical analysis show that the 1994 patent reform significantly increased the number of patent applications without an associated increase in R&D expenditures. But there exists a discordance in responding to the patent reform between large and small incumbents. The large-size incumbents increased their number of patent applications without an associated increase in R&D expenditures, while small-size incumbents did not respond at all in either R&D expenditures or the number of patent applications.

The regression results show that R&D efforts and firm size are important factors in explaining incumbents' patenting behavior for both of large and small-size firms. However, capital intensity is an important factor for large incumbents in particular, to explain the upsurge of patent application rights after the patent reform. The statistical significance of capital intensity for large incumbents sharply increases during the period II (1994-1997), but loses its significance after the period. For the small incumbents, however, analysis did not show any statistical significance during the whole sample period. Taking into account the fact that the patent reform did not spur R&D expenditure in large-size incumbents, the regression result implies that the large-size incumbents with high fixed costs strategically respond to the patent enforcement, which is a consistent result with the 'patent thicket' or 'strategic response' hypothesis.

The empirical results also show that the importance of firm size in patenting propensity is getting important for both large and small-size firms. After the economic crisis, the estimated coefficient of firm size increases and shows statistical significance for both large and small incumbents. This implies that economies of scale are increasingly important factor in explaining firms' patenting propensity.

One thing that we need to notice from the regression results is that the importance of R&D effort for the large size incumbent loses its significance right after the patent reform, but recovers its significance since the economic crisis (1998-2001) of Korea. But contrary to R&D efforts and firm size, capital intensity loses its statistical significance right after the economic crisis. These empirical results suggest the possibility that the strategic motive of large incumbents in patenting sustains only for the short time period and the motivation of patenting behavior might have changed with the economic crisis. Most Korean firms have experienced substantial change in corporate governance during the economic crisis. We can imagine that such an experience of fundamental change in the business environment may drive the change of motivation in patenting behavior. A more detailed treatment of these issues awaits further work.

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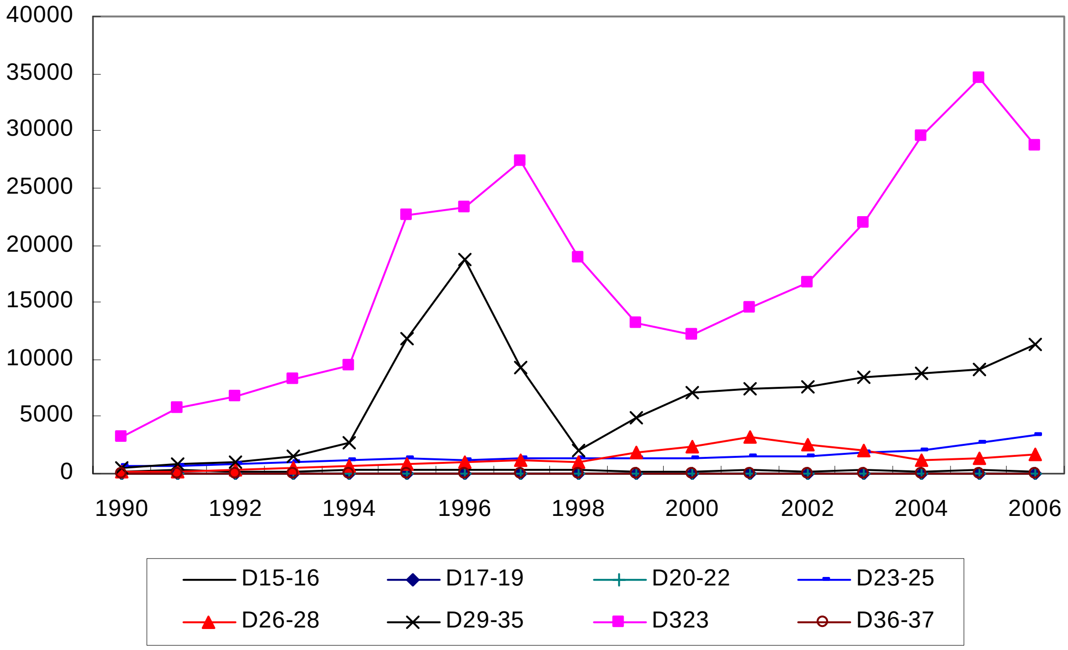
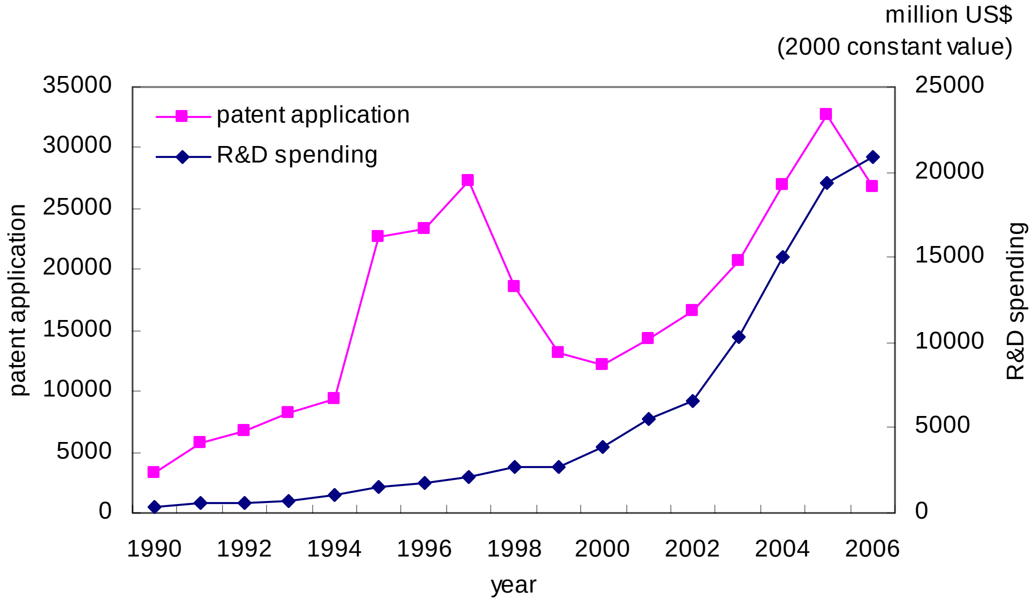
Figure 1. Number of patent applications in Korean manufacturing (1990-2006)



Note: D15-D16: food products, beverages and tobacco; D17-D19: textiles, textile products, leather and footwear; D20-D22: wood, pulp, paper, paper products, printing and publishing; D23-D25: chemical, rubber, plastics and fuel products; D26-D28: other non-metallic mineral, basic metals and fabricated metal products; D29-D35: machinery and equipment and transport equipment except D323; D323: electronics and related equipment industry; D36-D37: manufacturing n.e.c. and recycling.
Source: The Patent Trends in Korea, 2007, Korean Intellectual Property Office.

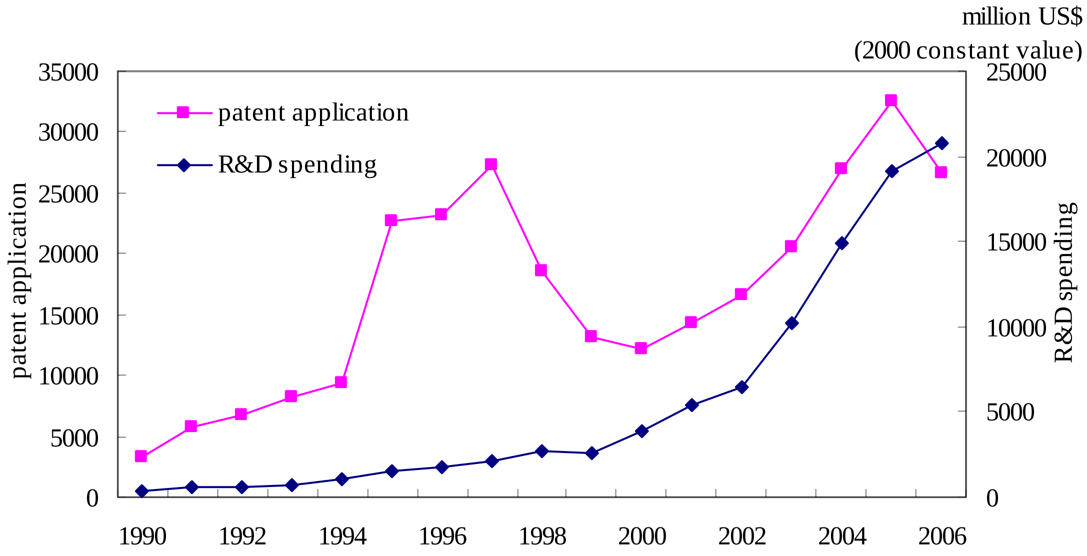
Figure 2. R&D expenditure and the number of patent applications of D323



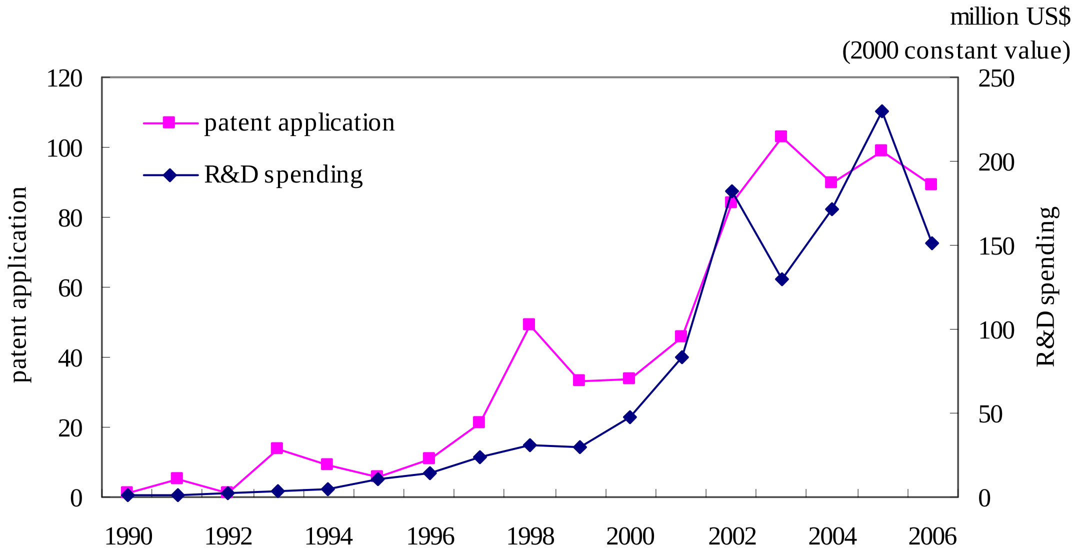
Source: 1. Korea Investors Service-Financial Analysis System, database, 2007.
2. Korean Intellectual Property Office, The Patent Trends in Korea, 2007.

Figure 3. R&D Expenditure and the number of patent applications by firm size in D323

a. Large-size incumbents



b. Small-size incumbents



Source: See Figure 2.

Table 1. Summary statistics during 1990-2006 (obs. = 529)

Variable	Mean	Median	Std. Dev.	Min	Max
Patent application[1]	545.2	0.0	2,208.2	0	17,832.0
R&D spending (2000 constant million US$)[2]	180.9	1.4	1,207.6	.004	16,318.3
R&D spending per worker (2000 constant thousand US$)	20.3	6.1	51.7	.013	879.1
Number of workers	3,512.4	221.0	10,933.4	1	85,813.0
Tangible fixed asset per worker (2000 constant thousand US$)	85.0	45.2	110.4	.599	982.2

Note: 1. The number of patent application of 75 percentile in the sample is 4.
2. Purchasing power parity used here is 753.2 Korean Won per US dollar of 2000.

Table 2. Empirical results of patenting propensity
Dependent variable = number of patent applications

variable	(1)	(2)	(3)	(4)	(5)	(6)
LnRndr	.374 ***					
(Log R&D)	(.027)					
LnRndrwk		.224 ***	.217 ***	.199 ***	.184 ***	.184 ***
(Log R&D per worker)		(.023)	(.052)	(.054)	(.054)	(.054)
LnCapint			.180 **	.140 *	.154 *	.154 *
(Log P&E per worker)			(.081)	(.085)	(.082)	(.083)
LnSize			.440 ***	.468 ***	.402 ***	.402 ***
(Log workers)			(.046)	(.049)	(.061)	(.061)
Post-1994				.296 #	.340 *	.339 *
(Dummy for post-1994)				(.191)	(.179)	(.181)
Dummy for Samsung-LG					.696 *	.697 *
					(.366)	(.366)
Dummy for 1998						.006
						(.194)
Log-likelihood	-1034.5	-1090.0	-1027.2	-1026.0	-1024.2	-1024.2
Wald chi-squared	188.4	44.58	228.3	232.0	266.4	266.4
No of obs.	529	529	529	529	529	529

Note: ***, **, * and # indicates 1%, 5%, 10% and 15% significance level, respectively. The figures in parentheses are standard errors.

Table 3. Empirical results of patenting propensity by firm size

variable	small-size incumbents (1)	(2)	large-size incumbents (3)	(4)
LnRndrwk	.404 ***	.395 ***	.160 **	.125 *
	(.088)	(.092)	(.075)	(.068)
LnCapint	.094	.091	.193 *	.125
	(.126)	(.126)	(.115)	(.115)
LnSize	.737 ***	.736 ***	.572 ***	.643 ***
	(.194)	(.194)	(.094)	(.098)
Post-1994		.164		.445 **
		(.463)		(.219)
Log-likelihood	-363.9	-363.8	-629.7	-627.6
Wald chi-squared	61.9	61.18	98.9	99.8
No of obs.	382	382	132	132

Note: 1. ***, **, and * indicate 1%, 5% and 10% significance level, respectively. The figures in parentheses are standard errors.
2. The dummy variables for year-1998 and Samsung-LG are dropped from the regression equation since those variables are not statistically significance.

Table 4. Patenting Propensity by four-year intervals

Variable	Period I: 1990-1993	Period II: 1994-1997	Period III: 1998-2001	Period IV: 2002-2006
lnRndrwk	.515***	.015	.619 ***	.248**
	(.155)	(.088)	(.219)	(.106)
LnCapint	.585	.966***	.101	-.127
	(.409)	(.288)	(.267)	(.178)
LnSize	.422	.473***	.122	.699***
	(.256)	(.132)	(.151)	(.103)
Log-likelihood	-100.4	-152.7	-185.3	-282.8
Wald chi2	45.2	31.5	19.6	66.7
No of obs.	40	75	96	157

Note: ***, ** and * indicate 1%, 5%, and 10% significance level, respectively. The figures in parentheses are standard errors.

Table 5. Results by firm size and four-year intervals

Variable	Period I: 1990-1993	Period II: 1994-1997	Period III: 1998-2001	Period IV: 2002-2006
		Small-size firm		
LnRndrwk	.722	.509*	.757***	.120
	(.997)	(.283)	(.315)	(.197)
LnCapint	.400	-.201	.471	-.085
	(3.684)	(.718)	(.334)	(.227)
LnSize	6.047	.579	.315	1.505***
	(4.481)	(.516)	(.498)	(.434)
Log-likelihood	-7.3	- 32.0	-63.7	-130.0
Wald chi2	2.1	3.9	10.8	13.1
(p-value)	(.543)	(.275)	(.013)	(.004)
No of obs.	12	47	72	117
		Large-size firm		
LnRndrwk	.611***	-.069	.695**	.251*
	(.174)	(.075)	(.353)	(.141)
LnCapint	.456	1.122***	-1.272**	-.294
	(.428)	(.282)	(.502)	(.300)
LnSize	.062	.124	.886**	.982***
	(.386)	(.308)	(.392)	(.192)
Log-likelihood	-90.7	-116.2	-112.7	-136.0
Wald chi2	43.8	16.4	13.1	55.0
(p-value)	(.000)	(.001)	(.004)	(.000)
No of obs.	28	28	23	36

Note: ***, ** and * indicate 1%, 5% and 10% significance level, respectively. The figures in parentheses are standard errors.

For the referees

Empirical results using negative binomial random effect models

Table A1. Empirical results of patenting propensity
Dependent variable = number of patent applications

variable	(1)	(2)	(3)	(4)	(5)	(6)
LnRndr	.387 ***					
(Log R&D)	(.027)					
LnRndrwk		.228 ***	.224 ***	.206 ***	.192 ***	.192 ***
(Log R&D per worker)		(.033)	(.051)	(.053)	(.053)	(.053)
LnCapint			.177 **	.136 *	.148 *	.149 *
(Log P&E per worker)			(.079)	(.083)	(.080)	(.081)
LnSize			.462 ***	.489 ***	.422 ***	.422 **
(Log workers)			(.045)	(.048)	(.059)	(.059)
Post-1994				.299 #	.345 **	.342 *
(Dummy for post-1994)				(.188)	(.175)	(.177)
Samsung-LG					.707 **	.710 **
					(.356)	(.356)
Dummy for 1998						.020
						(.189)
Log-likelihood	-1231.6	-1292.7	-1223.3	-1222.1	-1220.1	-1220.1
Wald chi-squared	210.2	46.6	257.0	261.0	300.0	299.9
No of obs.	529	529	529	529	529	529

Note: ***, **, * and # indicate 1%, 5%, 10% and 15% significance level, respectively. The figures in parentheses are standard errors.

Table A2. Patenting propensity by four-year intervals

Variable	Period I: 1990-1993	Period II: 1994-1997	Period III: 1998-2001	Period IV: 2002-2006
lnRndrwk	.413***	.017	.642 ***	.280***
	(.131)	(.081)	(.168)	(.092)
LnCapint	.919***	1.058***	.116	-.131
	(.353)	(.220)	(.245)	(.161)
LnSize	.780***	.610***	.211#	.781***
	(.181)	(.117)	(.141)	(.090)
Log-likelihood	-180.0	-268.7	-326.0	-443.5
Wald chi2	94.8	64.7	37.1	123.1
No of obs.	89	128	140	172

Note: ***, ** and * indicate 1%, 5%, and 10% significance level, respectively. The figures in parentheses are standard errors.

Table A3. Results by firm size and four-year intervals

Variable	Period I: 1990-1993	Period II: 1994-1997	Period III: 1998-2001	Period IV: 2002-2006
		Small-size firm		
LnRndrwk	.428	.130	.645***	.310**
	(.417)	(.152)	(.185)	(.148)
LnCapint	1.259	.606**	.422#	-.109
	(.896)	(.287)	(.260)	(.188)
LnSize	-.802	.051	.289	1.062***
	(.985)	(.265)	(.273)	(.216)
Log-likelihood	-27.7	- 76.0	-151.8	-249.8
Wald chi2	4.2	5.6	19.2	28.2
(p-value)	(.242)	(.135)	(.000)	(.000)
No of obs.	57	96	108	135
		Large-size firm		
LnRndrwk	.483***	-.077	.496**	.237*
	(.158)	(.088)	(.242)	(.129)
LnCapint	.700*	1.308***	-1.182***	-.281
	(.386)	(.236)	(.350)	(.278)
LnSize	.597	.863***	1.788***	1.188***
	(.331)*	(.240)	(.173)	(.176)
Log-likelihood	-147.9	-180.9	-148.4	-182.3
Wald chi2	61.9	50.0	196.7	93.6
(p-value)	(.000)	(.000)	(.000)	(.000)
No of obs.	32	32	32	37

Note: ***, **, * and # indicate 1%, 5%, 10% and 15% significance level, respectively.
The figures in parentheses are standard errors.