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# South Korea's transition from imitator to innovator: The role of external demand shocks

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ABSTRACT

South Korean manufacturing firms have rapidly increased research and development (R&D) expenditure and the number of patent applications since the 1980s. This paper empirically argues that the increase in external market demand resulting from exchange rate changes had significant impacts on R&D expenditure of manufacturing firms in South Korea. Empirical analyses using South Korean firm-level panel data from 1981 to 1995 show that the exchange rate change was a significant driver of increased R&D expenditure. The South Korean firms whose exporting goods were similar to those produced in Japan were more sensitive to the exchange rate changes (especially Japanese yen's appreciation) than the firms whose exporting goods were less similar to Japanese exports. The result suggests a causal relationship between external demand and R&D expenditure.

## 1. Introduction

South Korea, officially the Republic of Korea, received the third largest number of patents in the United States in 2015 according to The United States Patent and Trademark Office (USPTO), followed by Germany and Taiwan.[1] Considering the fact that Korea was considered a technological *imitator* until the 1980s, this statistic is quite surprising. The number of patent applications filed by South Korean assignees in the United States (USPTO) started increasing sharply in the late 1980s. Fig. 1 illustrates this growth in U.S. patent applications by South Korean assignees, a shift which parallels the growth in the domestic patents of Korean firms.

The mid-to-late 1980s mark a clear trend break in Korea's technological development. What factor or factors powered Korea's rapid transition from imitator to innovator? There can be several possible explanations, including trade liberalization and wage increases.[2] In this paper, we emphasize the role of an *external demand shock* in driving increased demand for technological innovation within South Korean firms.

The primary goal of this paper is to explore the reasons for the surge in R&D expenditure by South Korean manufacturing firms in the late 1980s and early1990s. We highlight the *role of exchange rate changes* in increasing the potential for South Korean firms to profit from sales to foreign markets. The main hypothesis of this paper is that an important motivation for South Korean manufacturing firms (hereafter simply Korean firms) to become innovators was an increase in foreign demand for their goods resulting from exogenous movements in exchange rates. A sharp appreciation of Japanese yen created a significant potential opportunity for Korean firms to increase their exports to large external markets. This opportunity was greatest for Korean firms that were already producing products similar to those of their Japanese rivals. This sudden exchange rate shift conferred upon Korean firms a cost advantage over Japanese firms in large external markets, which allowed the firms to have higher mark-up for their exports. To fully realize this advantage, and to meet the demands of foreign customers for higher quality goods, Korean firms needed to invest in R&D and technology upgrading. To flourish in markets with strong intellectual property rights regimes, they also needed to acquire U.S. patents (which also required R&D expenditure). Korean firms' lower production costs (in dollars and other destination market currencies) dramatically raised the likelihood that Korean firms would be able to realize positive returns from these costly investments. This paper presents strong empirical evidence in support of this hypothesis.

Other scholars have argued that a shift toward stronger intellectual property rights (IPR) inside Korea was a primary driver of greater

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[1] The first and second places went to the United States and Japan, respectively.

[2] Liberalization can increase competition by inviting more foreign firms to South Korean domestic market. When the labor wage increases, firms can shift from low technology industries to high technology industries.

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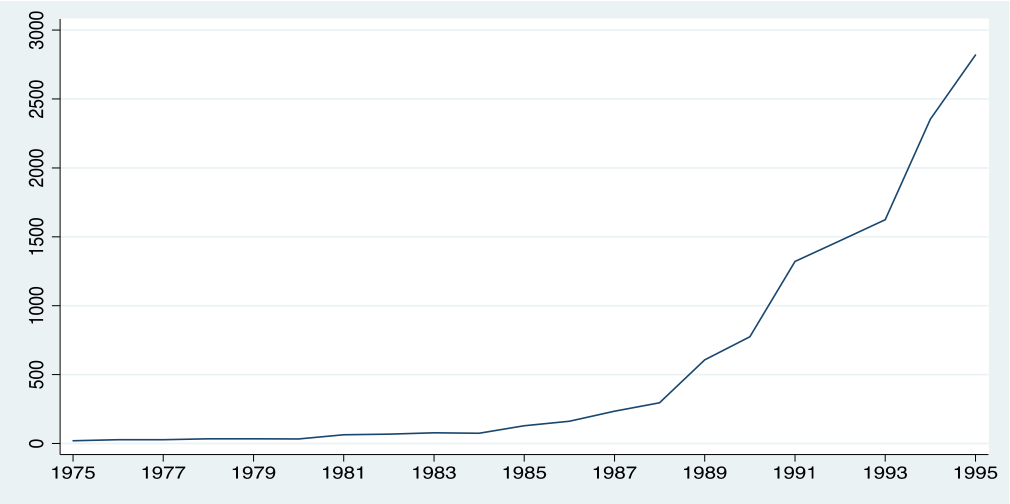


**Fig. 1.** Number of utility patent applications filed in the United States – South Korean assignees (1975–1995).
*The United States Patent and Trademark Office (USPTO).*

technological innovation in the mid-to-late 1980s.[3] Song (2006) argues that the Korean patent law reform of the mid-1980s was a primary cause of the increased R&D. This argument is limited by the reality that the Korean domestic market was relatively small compared to the size of the external markets to which Korea exported. Moreover, the big export-oriented firms were the major patentees in the 1980s. These firms already faced strong incentives to apply for patents in their major foreign markets such as the United States and Europe. Even in theory, it seems unlikely that the strengthening of patent protection in the small domestic market would have such a large effect on the behavior of Korean firms (Grossman and Lai, 2004). Furthermore, our empirical evidence strongly supports the idea that the exchange rate channel highlighted in our theoretical work has a clear impact on firm behavior.

In principle, technology promotion policies by the South Korean government could have driven the R&D surge in the late 1980s and early 1990s. We do not deny the possibility that public policies such as R&D subsidies and tax incentives can promote firm R&D expenditure. However, we put less importance on the role of these policies mainly for two reasons. First, there was no significant change in the direction or incidence of these government policies in the 1980s that was consistent with the striking trend break in innovative activity. Choi (1988) argues that the climate for firms to invest in R&D was mature enough in the mid- 1970s – subsequent changes in technology promotion policy were less important than the ones that came before. It is therefore hard to attribute a dramatic change in firm behavior to modest changes in policy. Second, firms do not decide to increase R&D solely because of government policies, such as financial incentives. They almost certainly would require a dramatic increase in expected payoffs (sales or profits) to successful R&D, before they would engage in a dramatic increase in the volume of R&D investment. Subsidies alone were not large enough to induce the huge increase in R&D investment that was actually observed. Finally, Kim and Dahlman (1992) insist that the South Korean government policies encouraging R&D investment in private sectors came into effect in the 1980s because of increased market demand for technological innovation – in other words, the policy regime changed because firms had already decided to increase their R&D expenditure. So, causality runs in the opposite direction from what advocates of the importance of industrial policy assert.

The remainder of this paper is organized as follows: Section II introduces some background information on the Korean economy, the similarities of the Korean economy and the Japanese economy, exchange rate changes, and Korean patent law reform. Section III briefly reviews the related previous research. Section VI describes the data used in this paper. Section V explains the key variables and econometric models used in the paper, and discusses several possible alternative hypotheses. Section VI presents the empirical results, and Section VII concludes with a summary of the key results and their policy implications.

## 2. Background

### 2.1. The economic growth of South Korea

South Korea achieved exceptionally rapid economic growth for about three decades after 1960. The highly accelerated economic growth of South Korea is referred to as the 'economic miracle on the Han River.' South Korea was one of the poorest countries in the world after the Korean War (1950–53). The economy of South Korea experienced a slow recovery from 1953 to 1961 that relied heavily on foreign aid. Rapid, sustained economic growth began with the introduction of the Five-Year Economic Development Plans introduced by Park Chung-hee's authoritarian government.[4] The first and second Five-Year Economic Development Plans (1962–66 and 1967–71) focused on building infrastructure and light industries such as textiles and footwear. The central aim of the third and fourth Five-Year Economic Development Plans (1972–76 and 1977–81) was to transform the light industries into heavy and chemical industries (HCI).

As the four Five-Year Economic Development Plans were implemented, they revealed many characteristics of economic growth in postwar South Korea. First, Park's military government was quite interventionist, exercising strong influence over the national economy. The military regime could be described as a "hard state," since it set national macroeconomic goals/policies and utilized direct interventions to influence individual firm's economic decisions, including the choice of products and markets.[5] In doing so, the military government centralized its political power in the office of the president.[6] The president

[3] Empirical results are mixed.

[4] The Chang Myeon government was formed by the street demonstrations against illegal election for Rhee's fourth term, referred as the '4.19 revolution'. The Chang Myeon government, however, was ousted by a military coup in 1961 by General Park Chung-hee. Park's military government implemented four Five-Year Economic Development Plans (1962-66, 1967-71, 1972-76, and 1977-81).

[5] The military government gave significant incentives, such as tax exemptions and subsidies, to the firms which achieved the goals set by the government. For example, the military government awarded substantial financial benefits to the firms which met their export quota for the year.

[6] The President was Park Chung-hee.

created four agencies under his direct control; the Central Intelligence Agency, the Council for Economics and Science, the Board of Audit and Inspection, and the National Security Council. In addition to these four agencies, the military government set up the Economic Planning Board to outline and implement economic plans.

Second, the close relationship between the government and chaebols should be noted.[7] Some chaebols were founded during the Japanese colonial period (1910–45). Many chaebols, however, were formed and developed during the period of rapid industrialization through their close relationship with the government. The military government needed a few select firms that could implement the government economic plans. At the same time, chaebols benefited from their relationships with the government, since the plans included preferential access to credit, subsidies, and tax exemptions for favored firms and industries.

Finally, South Korea has focused on encouraging exports since the 1960s. Thus, the economic growth of South Korea can be described, to some extent, as export-led industrialization. The government implemented several policies to promote exports. For example, exporters were able to get direct subsidies and tariff exemptions. They could also be exempted from indirect taxes. The importance of exports relates closely to the central hypothesis of this paper. The major patentees of South Korea were export-oriented firms in the 1980s. In fact, most of the chaebols were export-oriented. Hence, the rapid appreciation of Japanese yen could have given an opportunity to the firms to enter and expand in foreign markets, especially the United States markets. As a consequence, this exogenous Japanese yen exchange rate change could be a critical factor to increase the R&D of South Korean manufacturing firms.

### 2.2. The similarity of South Korean manufacturing industries with Japanese manufacturing industries

The main argument of this paper is based on the fact that there was a substantial degree of overlap in the product portfolios of leading South Korean manufacturing firms and their Japanese rivals by the time the yen underwent its sharp appreciation in the mid-1980s. The appreciation of the Japanese yen could be a large opportunity for South Korean firms to enter/expand in foreign markets (especially the U.S. market[8]) if the products they exported were similar to Japanese firms' exported goods. The main exporting products of the two countries were quite similar over the 1981 to 1995 period. We can observe the similarity in the distribution of exports across product categories, as measured by the Standard International Trade Classification (SITC) codes of the two countries.[9]

Fig. 2 illustrates distribution of total exports for the two countries across product categories at the two-digit SITC level.[10] Fig. 2 depicts the average of the period: 1981–1995. The proportions did not change significantly over time. Readers can observe a similar pattern during 1981 and 1986 (Appendix B). Japanese exports were concentrated in SITC 6 and 7 during the period. South Korea has high proportions in SITC 6, 7 and 8. The main overlap lies in SITC 6 and 7. We anticipate that the South Korean firms whose primary exporting products were in SITC 6 and 7 had greater benefits from yen's appreciation than the other firms. Appendix C shows the shares of total export by two-digit SITC code for 19 major trading countries.[11] We can detect that the structures of export goods of these countries are quite different, on average, from Japan and South Korea.[12]

South Korean and Japanese manufacturing firms exported similar goods in the late 1980s and early 1990s. This similarity explains how the appreciation of Japanese yen could be a significant opportunity for Korean firms in external market (especially the U.S. market).[13] In the remaining part of this section, we would like to describe the forces behind the similarity between Japanese and South Korean manufacturing industries.

First of all, we can note the relationship between two countries in the early twentieth century. Korea had an agricultural based economy before 1900. Manufactured goods were produced by a small number of artisans in particular population centers. Korea was annexed by Japan in 1910, and Korea remained a colony of Japan for the next 35 years. At the beginning of the colonial era, the Japanese colonial regime sought to raise agricultural production in Korea to meet growing Japanese demand for agricultural products, especially rice, in Japanese domestic markets. At the later part of the colonial era, Japan decided to mobilize Korea as a supply base for its war effort.[14] Consequently, Japan constructed large-scale industrial plants in Korea for war-related production.[15] The proportion of manufacturing products increased rapidly during this period.[16] Korea also imported raw materials and technological management systems from Japan after the Korean War, especially after the 1965 Korea-Japan Treaty that normalized bilateral ties between two countries. Amsden (1992) argues that Korea set Japan as its primary economic development model during 1970s and 1980s.

Another similarity lies in the export-based economic development model pursued in both countries. Although Japan had larger domestic markets compared to South Korea, both countries accomplished rapid economic growth, in part, through the expansion of export industries. The government gave economic incentives to those export-oriented industries in both countries, although these incentives were orders of magnitude stronger in Korea. The incentives included a low-interest rate for bank loans, tax exemptions, and direct subsidies from the government (Choi, 1988). Kuznets (1988) depicts the export share of GDP rising from 11% to 14% in Japan between 1965 and 1983. The export share of GDP changed more dramatically, by 28% points (from 9% to 37%), in South Korea during the same period. Export growth was, in fact, the chief national economic target until the late 1980s.

Finally, basic similarities in geography and in endowments of natural resources and other factors of production led to Korea and Japan building up similar manufacturing industries. The two countries are geographically very close. As a result, it was easy to trade with each other. South Korea imported intermediate materials and technologies from Japan, which further influenced the development of South Korean manufacturing industries in a way that kept them proximate to Japanese manufacturing industries. Both countries are poor in natural resources. Consequently, they have been heavily dependent on imported raw materials and fuels. Naturally, Korea and Japan chose to focus on exporting goods made from imported raw materials to overcome their limited natural resources. Well-educated workers were needed to accomplish this export-driven economic growth. This

[7] The chaebol, large family-owned conglomerates, were comparable to the zaibatsu industrial groups in prewar Japan.

[8] In the period of analyses (1981–1995), the biggest trade partner of those two countries was the United States. See section IV For more details.

[9] Refer to the appendix to learn about SITC.

[10] Fig. 2 covers SITC6, 7 and 8 since the proportions of other SITCs are close to zero. The figure with all SITCs is found in the appendix. Fig. 2 is drawn based on total exports to the world. The figure using exports to the United States shows similar patterns, which is available from the authors by request. The rationale behind using data on exports to the United States is explained in section IV.

[11] See the appendix for more details.

[12] The countries with somewhat similar exporting goods with Japan experienced a sharp appreciation of their currencies, which made firms in those countries hard to get price competitiveness over Japanese firms. For more details, refer to the appendix.

[13] The United States was the largest trade partner – both import and export - for both countries by far during the period. See section IV for more details.

[14] It is in the late- 1930s after the Japanese militarists began to increase their expansionism (just a few years before World War II).

[15] However, this policy did not benefit Korean people since almost all industries were owned by Japan-based firms or by Japanese firms in Korea.

[16] As a result, the agricultural production decreased. So these policies lowered the standard of living of Korean people by the decrease of food consumption because the export amount of agricultural production to Japan was not reduced.

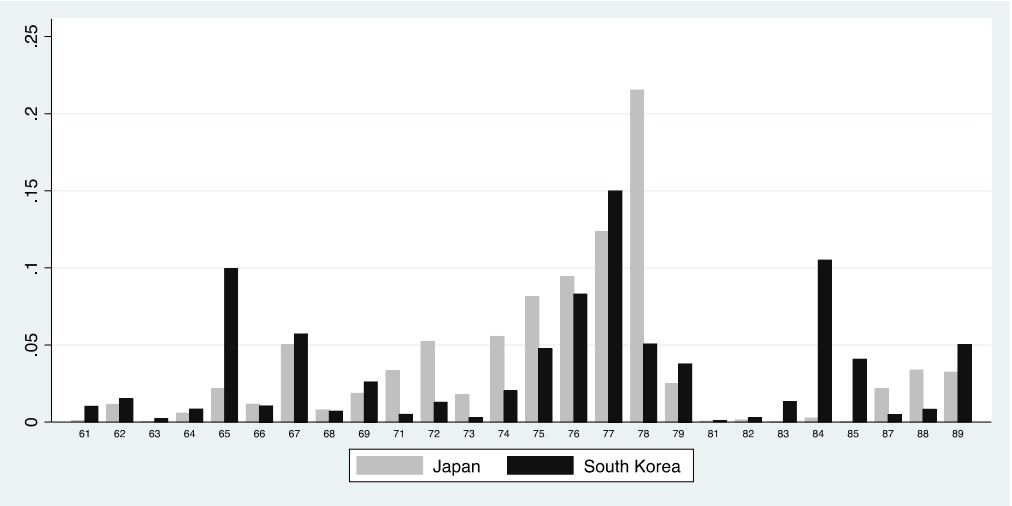


**Fig. 2.** Share of total export by two-digit SITC (South Korea and Japan, average from 1981 to 1995) – SITC (61 ~ 89).
*The Center for International Data at UC Davis.*

required putting emphasis on educating the future generations to supply skilled labor. Relatively high-quality labor was available because of a culture of respect for education and rapid improvement of the educational system. The availability of an educated labor force enabled both countries to achieve economic growth with limited natural resources. Human capital accumulation achieved through high quality education played a significant role in the similarity of structure of manufacturing industries of the two countries.

South Korean manufacturing firms were similar to Japanese manufacturing firms in many dimensions because of these direct and indirect influences of Japan on South Korea and of the similar geographical and environmental characteristics of the two countries.

### 2.3. Japanese yen's appreciation in the 1980s

There was a rapid appreciation of Japanese yen in the mid-1980s. The Japanese firms began to lose price competitiveness in their most important foreign markets. The rise of the yen's value could be an opportunity for South Korean manufacturing firms to enter/expand in those large external markets. We now want to explain why the periods of the 1980s and 1990s are appropriate time periods for the purpose of this paper. Knowing the broad contours of American macroeconomic policy in the 1980s can be beneficial in understanding the appreciation of Japanese yen.

Frankel et al., (1994) superbly describe the background and results of U.S. macroeconomic policy in the 1980s. The authors divide this policy history into three phases. The first phase (1981–1984) witnessed a sharp appreciation of the dollar. At the end of the 1970s, the U.S. Federal Reserve began raising interest rates to fight inflation. This procedure made the dollar more attractive to global financial investors. The dollar appreciated by 29% and 28% from 1980 to 1982 in nominal terms and real terms, respectively. The U.S. long-term interest rates kept growing during 1983 and 1984. This brought another appreciation of the dollar by 17% in nominal values and 14% in real values. The second phase (1984–1986) can be described as an "overshooting" of the dollar, leading to government policies aimed at promoting a shift to more reasonable values. During mid-1984 and early-1985, there was another 20% appreciation of the U.S. currency. U.S exporters lost price competitiveness between 1980 and 1985 because of the appreciation of the U.S. dollar, which brought political/economic attention in the United States. Another serious concern was that the latter phase of this appreciation was inconsistent with economic fundamentals. As Krugman (1985) notes, the dollar's strength can be partially viewed as a speculative bubble. The Plaza Accord in 1985 was mostly initiated by this concern and for the purposes of reducing the U.S. foreign trade deficit. On September 22, the G-5 agreed to a coordinated foreign exchange intervention designed to bring about the depreciation of the U.S. dollar.[17] The Japanese yen to the U.S. dollar exchange rate had fallen to 168.5 in 1986 after reaching its peak at 249 in 1982.[18] The third phase (1987–1990) can be characterized as a move toward stability, with a slight rebound of the dollar. During this period, the fluctuation of the dollar value became smaller than the previous two phases.

The large variation in exchange rates in the 1980s can be a good *natural experiment* for this paper's purpose, which gives a good reason for choosing the period of 1981 to 1995. The appreciation of Japanese yen was a chance for South Korean firms to enter/expand in external markets such as the United States and European countries, since they had advantages with price competitiveness over Japanese firms. The lowered hurdle driven by yen's appreciation, however, was no guarantee of healthy profits to South Korean firms in the external market. With enhanced price competitiveness, South Korean firms could have started being interested in penetrating/expanding the external market. However, they probably needed to *improve the quality* of their exporting products to meet the preferences of consumers in developed countries such the U.S. and European countries. At the same time, they had to prepare for competing with foreign firms in an environment with stronger intellectual property rights (IPR). The answer to those problems was to *increase R&D investments*. This paper investigates whether and to what extent the exchange rate changes have an impact on firms' R&D.

### 2.4. The Korean patent law reform

South Korea established its first formal patent law system in 1961. Yet, this patent law system was not in accordance with the Paris Convention for the protection of industrial property (Freeman, 1995). The Korean government collaborated with European countries to reach bilateral agreements upgrading its IPR system. Through this process, Korean patent law eventually came to conform to the 1967 Stockholm text of the Paris Convention for the protection of industrial property. Developed countries such as the United States, however, increased pressure on Korean government to enact even stronger IPR laws in the early 1980s. After the suspension of a Section 301 investigation by the U.S. government, Korean government decided to strengthen its IPR laws. Accordingly, the Korean National Assembly passed the new patent

[17] G-5 were the United States, Japan, West Germany, the United Kingdom and France.
[18] Data on exchange rates are year-averages collected from the United Nations. The dollar had already begun to depreciate in 1985 before the Plaza meeting. G-5, moreover, agreed on a statement "some further orderly appreciation of the non-dollar currencies is desirable."

act in 1986. The new law was effective as of July 1, 1987.

This patent law reform revised several articles of the old law. The three most prominent changes include: (i) the reform widened the coverage of patent law. New chemical and pharmaceutical products became patentable.[19] (ii) The new IPR law extended the patent protection period. The patent term changed to 15 years from the grant of the patent or 18 years from the application date, whichever was longer between them.[20] (iii) The years of patent protection could be extended if other regulatory requirements, such as the time needed to test the safety of the product, delayed the introduction of the product.

## 3. Literature review

### 3.1. The determinants of R&D

It is widely appreciated that R&D can increase productivity by generating knowledge. With this function, R&D investment has been recognized as one of the most important engines of economic growth in recent endogenous growth models.[21] Given its importance, researchers have studied the factors that determine R&D investment. The research has been done at the firm-level, the industry level, and the national level.[22] Among the many important variables identified by this research is the strength of patent protection. A growing body of theoretical and empirical research suggests that a stronger patent system could induce firms to invest more R&D, although it must be added that this result does not always obtain.[23]

Firms' R&D investment levels are also influenced by the market environments in which they operate. Much recent research has focused on market concentration and the efficiency of financial markets as key features of this market environment. However, the empirical results using these variables are mixed. We believe that the *size of the market* in which firms want to sell their products can be one of the most crucial determinants of R&D. We will discuss this in the following section. Researchers have also explored the internal characteristics of firms as factors determining their level of R&D spending. Probably, the most widely studied feature is the size of firms. Researchers have long debated the relationship between R&D intensity and firm size – and the empirical results are mixed. Other characteristics of interest include dividend payments, cash flow, net profit, and debt.

### 3.2. External market, exchange rate, and R&D

In this paper, we argue that one of the most important determinants of R&D is the *size of the market*. Firms, as profit maximizers, decide the level of R&D spending by performing a cost-benefit analysis. They increase R&D if the expected benefits from successful R&D investment also increase. The main benefits are additional sales of products incorporating the new technology. The expected sales of their new or quality-improved products become *larger* if they can sell these products in *larger markets*. In other words, the expected benefits from the same amount of R&D should be greater if the products are sold in larger markets. This paper asserts that the sharp appreciation of Japanese yen in the mid- 1980s allowed South Korean manufacturing firms to enter/expand in large external market more easily. This appreciation made Japanese products more expensive, and conferred on Korean firms a cost advantage over Japanese firms in those markets. The firms' expected sales in external markets like the United States and Europe became much bigger after Japanese yen's sharp appreciation. Needless to say, these external markets were orders of magnitude larger than the South Korean domestic market. Therefore, Japanese yen's unexpected sharp appreciation induced Korean manufacturing firms to raise their R&D investment.[24] As we will study in the following sections, the Korean firms competing with Japanese firms with similar products had more incentive to increase R&D investment than firms with dissimilar products.

There is a large body of research investigating the impact of exchange rate changes on productivity, product quality, product prices, and cost competitiveness. Also, there are many studies on the impact of exchange rate uncertainty on investment.[25] However, we believe that there are only a few previous studies on the impact of exchange rate changes on R&D investment, and prior empirical research using firm-level data is especially limited. This paper helps fill this void in previous research. Campa and Goldberg (1999) is one of the few studies in this area. Using industry-level investment data for manufacturing industries in the United States, Japan, Canada and the United Kingdom, these authors argue that the depreciation of home currency causes industries to increase investment. They also show that more export-oriented industries are more sensitive to exchange rate changes when deciding on the level of R&D investment. Another closely related paper is Nucci and Pozzolo (2001), which shows that the depreciation of domestic currency has a positive effect on investment due to the enhanced price competitiveness; conversely, it has a negative effect on investment due to the increase in the price of imported inputs. On the other hand, Landon and Smith (2009) use aggregate and sector-level investment data to argue that there is a negative effect of currency depreciation on investments. Goldberg (1993) uses U.S. industry-level investment data to show that currency depreciation was associated with decreased investment in the 1980s. Using data on 360 U.S. manufacturing firms for the period from 1975 to 1987, Zietz and Fayissa (1994) find that only R&D intensive firms respond to the U.S. dollar's appreciation by increasing R&D investment.[26] This finding is in accordance with the results of their previous empirical research (Zietz and Fayissa, 1992). The authors use the real effective exchange rate as an indicator of intense import competition. They argue that severe import competition tends to raise R&D spending only in high-tech but not in low-tech U.S. industries.

We differentiate our paper from previous research with four features noted below. Firstly, this paper investigates how *Japanese* exchange rate changes can affect *South Korean* manufacturing firm's innovative behavior. In other words, we focus on studying competition in external markets driven by the Japanese yen's sharp appreciation, not competition in South Korea's domestic market. Therefore, we consider not only the South Korean exchange rate (won to dollar) but also the Japanese exchange rate (yen to dollar).[27] The reason that we focus on the Japanese exchange rate is threefold: (i) Japan was one of the main competitors of South Korea in many large external markets in the 1980s and 1990s.[28] (ii) The competition between the two countries in foreign

[19] Patent scope or breath is a crucial determinant of the value of the patent right (Jaffe, 2000). It can increase the propensity to patent.

[20] It was 12 years from the grant of the patent before the reform.

[21] Early works include Griliches (1980), Mansfield (1988), and Cohen and Levinthal (1989). Lots of follow-up studies have been done.

[22] This paper focuses on the firm-level analysis. We do not introduce all the determinants highlighted by this research stream in detail in this paper. The readers who want to learn more about the determinants can refer to Wang (2010), Lee and Hwang (2003), Varsakelis (2001) and Becker and Pain (2003).

[23] There are still many papers that argue about the negative sides of strong patent system. Their main arguments are; (i) patent cannot be an effective way to extract returns from inventions and (ii) it can hinder the flow of knowledge which can defer total innovation of society. The empirical results about the relationship between strong IPR and innovation are mixed.

[24] As we discussed in the earlier section (II. Background), there are more incentive to invest in R&D when Korean firms decide to enter bigger (and probably more advanced) external market in order to meet sophisticated tastes of the consumers and to prepare for surviving in those markets with stronger intellectual property rights (IPR).

[25] See Campa and Goldberg (1995), Darby et al. (1999), Servén (2003), Bahmani-Oskooee and Hajilee (2013), and Kandilov and Leblebicioglu (2011).

[26] They classify the firms as "R&D intensive" if their R&D investment is at least 3% of sales revenue.

[27] Most of the previous studies on the relationship between exchange rate and investment focus on the appreciation (or depreciation) of domestic currency.

[28] The biggest trade partner of South Korea and Japan was the United States from 1981 to 1995. Also Japan was the second largest destination of South Korean exports during the period.

market was highly intensive since the South Korean exporting products were similar to Japanese exporting products.[29] (iii) Moreover, there was a sharp appreciation of Japanese yen in the middle 1980s which can be regarded as a *natural experiment*. Secondly, we introduce the *proximity* concept to classify firms by using firm-product-level export data, not by just using the industry they belong to.[30] The notion of proximity reflects how close each South Korean manufacturing firm's exporting products are to aggregate Japanese exports.[31] A firm has close proximity to Japanese firms if its main exporting products are similar to Japanese major exporting goods. This classification method can be more accurate for capturing the *different sizes of opportunity* for each South Korean manufacturing firm that reacts to the Japanese yen's appreciation. When the yen appreciated, South Korean manufacturing firms could gain price competitiveness in the external markets where they were competing with Japanese firms, which led their expected sales and mark-up to increase. Importantly, a firm with higher proximity was expected to have a bigger opportunity to enter/expand in large external markets than a firm with lower proximity. We expect that those firms had more incentive to increase R&D expenditure after the sharp exchange rate shifts. Lastly, we use *firm-level* data on South Korean manufacturing firms from 1981 to 1995. This can give us a more detailed and nuanced understanding of firms' innovative behavior than using country-level or industry-level data.

### 3.3. IPR, R&D, and patent

A growing literature has examined the impact of stronger IPR on innovations. While it seems reasonable to believe that a stronger patent system would induce more R&D spending, according to Cohen et al., (2000), patents are not necessarily the most effective mechanism to extract returns from inventions. This paper analyzes interviews of managers of 1478 R&D labs in the U.S. manufacturing sector in 1994.[32] Its findings suggest that secrecy and lead-time are used even more often than patents as a mechanism for appropriating the returns from R&D spending. This paper also examines the reasons that firms patent and do not patent. The authors argue that the most important reason that firms avoid patenting is because firms are worried that their rivals can easily invent around their patents. The paper suggests that the key reasons to patent are preventing copying, blocking the development of substitutes by rivals, preventing lawsuits, and using patents for negotiating. These survey results show that firms in different industries can have different incentives to patent. Patent reform can, therefore, give different impacts across industries.

Jaffe (2000) introduces the theoretical and empirical analysis of patent scope. The author explains, using several different approaches, how wider patent scope can have an impact on the propensity to patent. The author also finds that expanded IPR did not necessarily contribute to the increased number of patents. Lerner (2000) studies whether broader patent coverage is more attractive to patentees than narrow coverage. This result suggests that broader patent scope can have a positive impact on innovation by increasing the propensity to patent. Branstetter and Sakakibara (2001) estimate the impact of the 1988 Japanese Patent Law reform on firms' R&D and patent applications. They conclude that there are no significant impacts of the patent law reform on either R&D spending or patent applications. Branstetter (2004) reviews several empirical studies which conclude that a stronger domestic IPR has little impact on the patenting of indigenous innovators. Hall and Ziedonis (2001) suggest that stronger patents only induce more R&D investment in R&D intensive small firms. The empirical results of the impact of strong IPR on firms' innovation are thus mixed.

There are a small number of empirical papers on the relationship between IPR regime change and R&D/patent applications using South Korean manufacturing firms' data. Song (2006) explores the contributions of IPR changes in Korea to rapidly surging R&D and patent applications. The author compares the trends of patent applications by Japan and Germany in the United States and South Korea. Using *country-level* data on R&D and patent applications, he claims that the rapid increase in patent applications by Japan and Germany in Korea around 1986–1987 was mainly a unique experience. He also argues that the patent application growth rates by Japan and Germany in South Korea during 1983–1991 was significantly higher than those in the United States. Oh and Park (2013) provide empirical evidence that the 1994 Korean Patent Law reform had no significant impacts on firms' behavior on innovation. They insist that the demand side aspects such as technological opportunity and competition in markets are significant factors for firm's R&D investment. In sum, the empirical results are fairly mixed.

## 4. Data

*Sample firms and period.*– The period of our dataset is from 1981 to 1995. The original dataset consists of 346 manufacturing enlisted firms in the Korean Stock Exchange (KSE). The actual number of firms used in analyses varies according to analytical method since data on some variables are not available for all firms in some years. We keep only firms for which at least three consecutive years of R&D investment, sales and exports data were available between 1981 and 1995, which yields an unbalanced panel of 149 South Korean manufacturing firms. Table 1 shows the number of firms in each industry. The column of "Original" presents the number of firms we originally collected. On the other hand, the column of "Selected" contains the number of firms with at least three consecutive years of R&D expenditure, sales and exports data from 1981 to 1995. The main reason that we lose firms from our original sample is that their financial data were insufficient, especially in the 1980s. One concern should be if our "Selected" sample reasonably represents our "Original" sample. Table 1 helps address this concern by indicating that the shares of firms in each industry in those two columns (Original and Selected) are alike. In other words, the "Selected" firms closely reflect the full sample in terms of their distribution across industries.

The column "Original" contains the number of South Korean manufacturing firms we originally collected. The column "Selected" includes firms with at least three consecutive years R&D investment, sales and export data.

*Exchange rates.*– We collect data on two exchange rates; i) yen to dollar nominal exchange rate and ii) won to dollar nominal exchange rate from Organization for Economic Cooperation and Development (OECD).[33] As we discuss in the following section, we construct a yen appreciation dummy variable, expressed as *YD*, whose value is 1 from 1986 to 1995 that is one of our key variables.

*R&D and Sales.*– Data on firm characteristics, including firm-level R&D expenditure and sales are taken from the Korea Listed Companies Association (KLCA).[34] Annual R&D investment and sales are collected. The nominal values of R&D and sales data are transformed to real

[29] See Fig. 2 and the appendix.

[30] Proximity is discussed more in detail in section V.

[31] They are total exports *to the world* by each product type (two-digit Standard International Trade Classification). We use another proximity using data on exports to *the United States*. The results are qualitatively the same. Those results are available from the authors upon request.

[32] This is called the Carnegie–Mellon Survey.

[33] The appendix includes figures of the real exchange rate changes.

[34] The Korea Listed Companies Association (KLCA) was founded on Dec 18, 1973 after the number of listed companies surpassed 100. As a non-profit incorporated association consisting of listed companies (issuers of stock certificates) registered at the Korea Exchange the aim of the KLCA is to protect the interests of the listed companies and their investors, and ultimately contribute to the development of the capital market. (source: http://www.klca.or.kr/) KLCA provides two decent databases; Total Solution (TS2000) and Fixed Solution (FS2000).

**Table 1**
Sample firms and industries.

| Industry | Number of firms | |
|---|---|---|
| | Original | Selected |
| Beverages | 2 | 2 |
| Chemicals and chemical products (except Medicine) | 56 | 29 |
| Coke, coal and refined petroleum products | 2 | 0 |
| Electrical machinery | 15 | 6 |
| Electronic components, computer, radio, television and communication equipment | 38 | 16 |
| Food products | 27 | 11 |
| Furniture | 4 | 1 |
| Leather, bag and shoes | 3 | 0 |
| Medical and pharmaceutical products | 36 | 21 |
| Medical, precision and optical/watches and clocks | 5 | 1 |
| Metal working machinery (except machinery and furniture) | 6 | 2 |
| Motor vehicles and trailers | 33 | 12 |
| Non-metallic mineral products | 19 | 9 |
| Other machinery and equipment | 22 | 6 |
| Other product manufacturing | 1 | 1 |
| Other transport manufacturing | 5 | 0 |
| Primary metal | 26 | 12 |
| Pulp, paper and paper products | 11 | 3 |
| Rubber products and plastic products | 15 | 9 |
| Sewn wearing apparel and fur articles | 5 | 3 |
| Tobacco products | 1 | 0 |
| Textile products (except sewn wearing apparel) | 11 | 5 |
| Wood products (except furniture) | 3 | 0 |
| Total | 346 | 149 |

values using GDP deflator. The appendix (section A) explains how the R&D data is constructed for our sample firms.

*Exports*. −We need two different levels of export data. The first export data is *country level*. The Center for International Data at UC Davis offers rich data on country-level exports and imports categorized by SITC.[35] We, therefore, are able to know the SITC-specific export amounts of the two countries. The analyses of this paper mainly require data on exports of South Korea and Japan in order to find out the main export products (or SITC) from these countries. Besides, we also need to collect data on exports and imports by SITC categories of main countries such as the United States and European countries.[36] The purposes of collecting these data are twofold. First, we can compare countries' exports by SITC.[37] This analysis allows us to determine which countries export similar goods to exporting goods from Japan. Second, we can illustrate the share of each country's exports by its destination countries. This analysis permits us to study which countries target similar external market to those of Japan. In other words, we can decide which countries compete with Japan in its main external market. *Firm-product-level* export data on South Korean manufacturing firms are collected from the Korea Listed Companies Association (KLCA). This dataset provides information on firms' exports by specific product types. We use this data to calculate firm's proximity by assigning Standard International Trade Classification (SITC) to each exporting product type and by comparing them to Japanese exporting goods in terms of SITC.[38] We transform the nominal values of exports to the real values using GDP deflator.

[35] The data contain information on four-digit SITC. For the purpose of this paper, we use two-digit SITC.

[36] We collect data on export of major exporting countries in order to compare those countries' export patterns with South Korea and Japan. For more details, see the appendix.

[37] We compare two-digit SITC exports not only of Japan and South Korea, but also 19 major exporting countries. See the appendix for more details.

[38] Proximity measures to what extent the firm's exports are similar to exports from Japan in terms of SITC. See section V for more details.

### 4.1. Industry-level R&D investment

Before analyzing firm-level R&D investment, it is worth observing industry-level R&D investment. Fig. 3 shows us how total R&D investment of each industry changed over time.

All industries show an upward trend of R&D investment during the period. It is easy to recognize the sudden upsurge of total R&D of the top three industries in the mid- 1980s when the Japanese yen appreciated. The firms in the electrical and electronic industry had the highest level of R&D expenditure. The transport and automobile industries display the second highest level of R&D expenditure. Chemicals, plastics, and oils follow the top two industries. The other three industries also show an upward trend of R&D spending, even if it is hard to observe because of relatively small amount of R&D investment compared to the top three industries.[39] It is not surprising, since a large portion of R&D investment came from the chaebols that belong to the top three industries. Fig. 3 strengthens our argument that firms with close proximity to Japanese manufacturing firms responded to the appreciation of yen more largely than the ones with distant proximity. The main exporting products of the firms in the top two industries are under SITC categories 7 and 8 to which the largest exports from Japan belong. However, this simple comparison is still insufficient evidence to verify our arguments. We, therefore, will show further convincing evidence using firm-level analyses in the following sections.

### 4.2. Exchange rate changes

Fig. 4 displays the monthly movements of exchange rates from 1981 to 1995. Each exchange rate is rescaled so that it is set to one in January 1981.[40] The vertical dashed line denotes January 1986.

The yen to dollar exchange rate started decreasing from 1985, primarily driven by yen's appreciation against the U.S. dollar. As shown in Fig. 4, there was a sharp decrease from 1985 to 1986. More precisely, the Japanese yen appreciated by 36.2% against the U.S. dollar from January 1985 to December 1986.[41] Afterward, the exchange rate stayed low and declined further. Hence, the value of Japanese yen against the U.S. dollar during the late 1980s was almost twice its value during the early 1980s. This evidence provides a rationale for creating a *yen's appreciation dummy variable* (its value is 1 from 1986) in the following section. The yen to won exchange rate shows a very similar pattern with the yen to the U.S. dollar exchange rate during the period. In contrast, the won to U.S. dollar exchange rate was relatively stable.[42]

### 4.3. Export patterns of South Korea and Japan

In this section, we introduce the patterns of South Korean exports and Japanese exports during 1981–1995. We have already shown Fig. 2, which illustrates the proximity (or similarity) of exports between South Korea and Japan.

Fig. 5 displays the trends of Japan's total exports and South Korea's exports *to the world*. Total exports from Japan were about six and four times larger than South Korea's total exports in 1985 and 1995, respectively. Both countries generally increased their total exports during this period. The slope of the Japanese export graph became slightly gentler starting in the late of 1980s, probably because Japanese firms lost price competitiveness due to the yen's sharp appreciation. On the other hand, the slope of the Korean export graph became steeper after 1986. It seems that Korean firms were benefiting from the yen's appreciation in terms of price competitiveness in the mid- 1980s.

Fig. 6 illustrates total exports *to the United States* from South Korea

[39] See the appendix for more details.

[40] The raw exchange rates are found in the appendix.

[41] It changed from 254.18 to 162.05.

[42] See the appendix for more details.

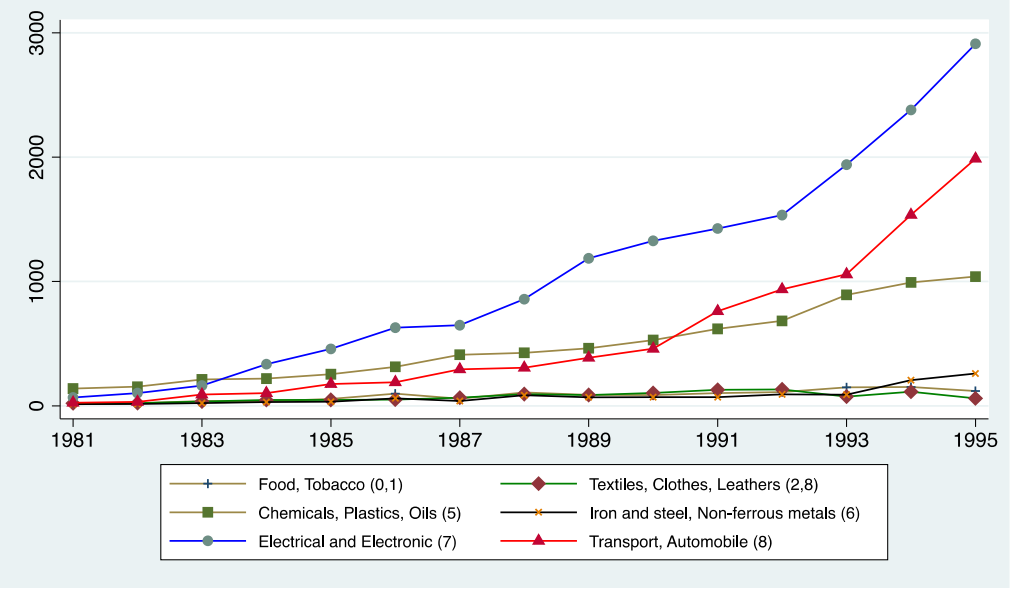


**Fig. 3.** R&D investment of South Korean manufacturing firms (Billion won, constant). Note: One-digit SITC in parentheses. *Korean Statistical Information Service, Statistics Korea.*

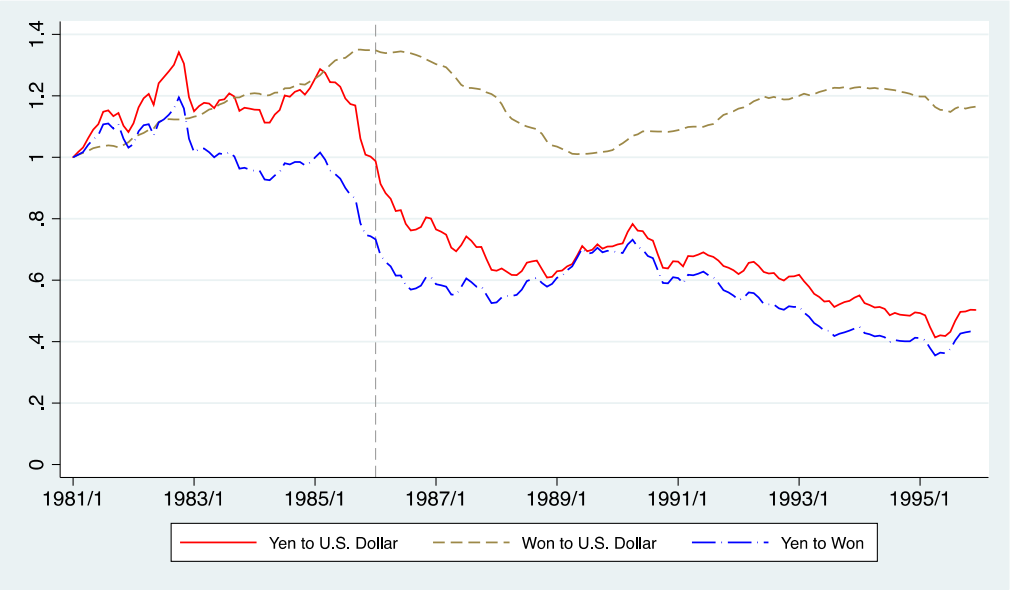


**Fig. 4.** Exchange rates (monthly, nominal, 1981–1995, January 1981 = 1). *Board of Governors of the Federal Reserve System (The United States) and Statistics Korea (KOSTAT, Statistics Department of South Korea).*

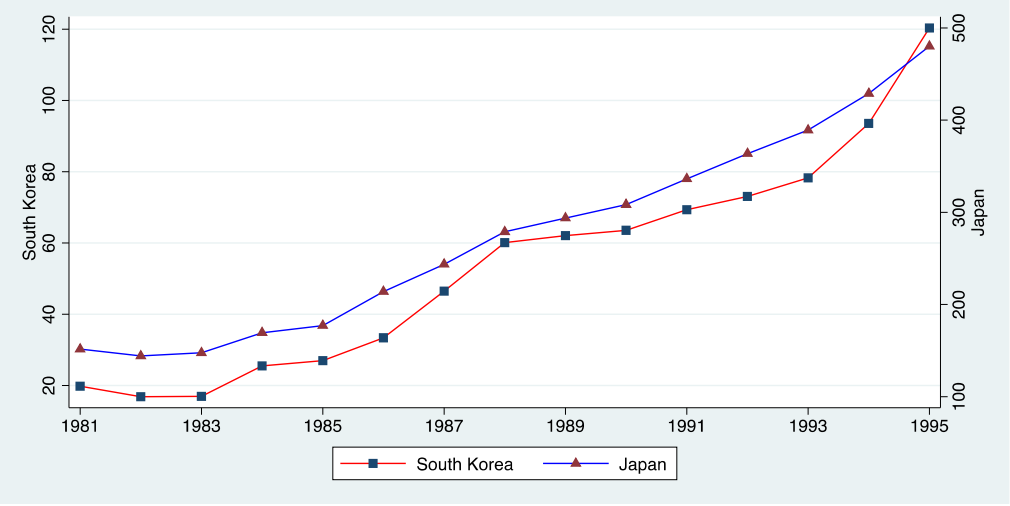


**Fig. 5.** Total exports (billions U.S. dollar, nominal): South Korea and Japan. *The Center for International Data at UC Davis.*

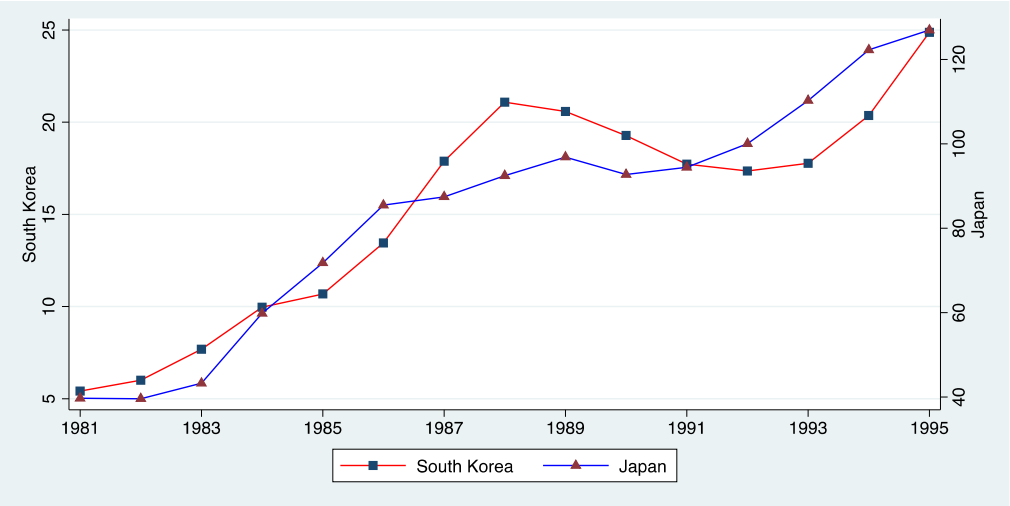


**Fig. 6.** Total exports to the United States (billions U.S. dollar, nominal): South Korea and Japan.
*The Center for International Data at UC Davis.*

and Japan from 1981 to 1995. The rationale for introducing Fig. 6 is twofold. First, the United States was the largest external market for South Korea and Japan during the period. In the early 1980s, about 40% of these two countries' exports went to the United States. The share has decreased since the early 1980s and it became about 30% in the early 1990s. However, the U.S. market was still the biggest external market for both countries in the early 1990s as well. Therefore, we can safely assume that South Korea and Japan mainly competed with each other in the same external market (the U.S. market) during this period.[43] Second, it is worth showing export patterns of South Korea and Japan to a *single* external market where Korean firms were actually competing with Japanese firms.[44]

Fig. 6 seems to explain relatively clearly the impact of Japanese yen's sharp appreciation on exports of South Korea and Japan in the mid-1980s. As shown in Fig. 6, the rate of export growth from Japan to the United States started decreasing after 1986. On the other hand, South Korea's exports to the United States accelerated in 1986. The drop in South Korean export during the late 1980s and the early 1990s can be largely explained by inflation and increased domestic demand in South Korea.[45] In addition, the South Korean won appreciated by 14% against the U.S. dollar from 1987 to 1990; it generally depreciated in the early 1990s.

It is critical to know the two countries' *target external market*. South Korean manufacturing firms would not be able to capture large benefits from competitive prices over Japanese products driven by the yen's sharp appreciation, if these two countries do not export to the *same countries*. On the other hand, South Korean manufacturing firms would have big advantages with competitive prices over Japanese products if their exports go to the same external market. Fig. 7 shows the share of *South Korea's exports by destination country*.[46] The overwhelmingly biggest buyer of South Korea's products was the United States from 1981 to 1995 – on average about 32% of South Korea's exports went to the United States. In addition, the majority of South Korea's exports were purchased by the United States and Japan. For example, 56% of South Korea's exports went to these two countries in 1986, 40% to the United States and 16% to Japan. Other main markets for South Korea's exports include Germany, Hong Kong, Canada, United Kingdom, Saudi Arabia, France, Singapore, and Panama. However, the exports to these countries are much less than the exports to the United States and Japan.

As can be seen in Fig. 8 that illustrates the share of *Japan's exports by destination country*, Japan had depended prominently on the United States as the largest major market for its exports from 1981 to 1995.[47] In 1986, the destination of 40% of Japan's exports was the United States. The share fell to about 30% in the early 1990s, which however still dominated other destination countries by a large margin.

Figs. 7 and 8 clearly show that South Korea and Japan mainly exported to *similar countries* (seven of the top nine destination countries overlap). In addition, these figures undoubtedly illustrate that the biggest external market of South Korea and Japan was the United States during the period.

## 5. Empirical specifications

This paper mainly exploits whether and to what extent exchange rate changes have impact on South Korean manufacturing firms' R&D investment. In this section, we introduce our main hypothesis, alternative hypotheses, key variables, and the econometric models.

### *5.1. Main hypothesis: Did Japanese yen's appreciation in the late 1980s trigger South Korean manufacturing firms' R&D increase?*

#### *5.1.1. Yen appreciation dummy*

As we discussed earlier, we want to show if Japanese yen's sharp appreciation had a significant impact on R&D expenditure of South Korean manufacturing firms. We construct Japanese *yen's appreciation dummy variable* (*YD*) based on Fig. 4 to capture the sharp yen's appreciation since 1986. We define the yen appreciation dummy (*YD*) as follows:

$$YD = \begin{cases} 1 \ if \ year \geq 1986 \\ 0 \ if \ year < 1986 \end{cases} \quad (1)$$

This Japanese yen appreciation dummy variable (*YD*) equals to one in the year of 1986 and after.

We need to discuss the rationales of choosing the Japanese yen's appreciation dummy (*YD*) over the raw exchange rate and to provide a clear explanation of the construction of *YD*.[48] We think the theoretical framework in Dixit and Pyndyck (1994) is useful to justify the use of

[43] In other words, the United States was the biggest external market where South Korean manufacturing firms and Japanese manufacturing firms competed each other during the period. In addition, the other major external markets of these two countries were very similar, which are found in Figs. 7 and 8.

[44] For more details, see the appendix.

[45] Inflation caused higher labor costs, which raised the prices of products made in South Korea.

[46] The list of countries is the top 10 major markets for South Korea's exports in 1986. The list barely changes over time during the period from 1981 to 1995.

[47] The list of countries is the top 10 major markets for Japan's exports in 1986. The list barely changes over time during the period between 1981 and 1995.

[48] We are grateful to anonymous referees for their comment on this.

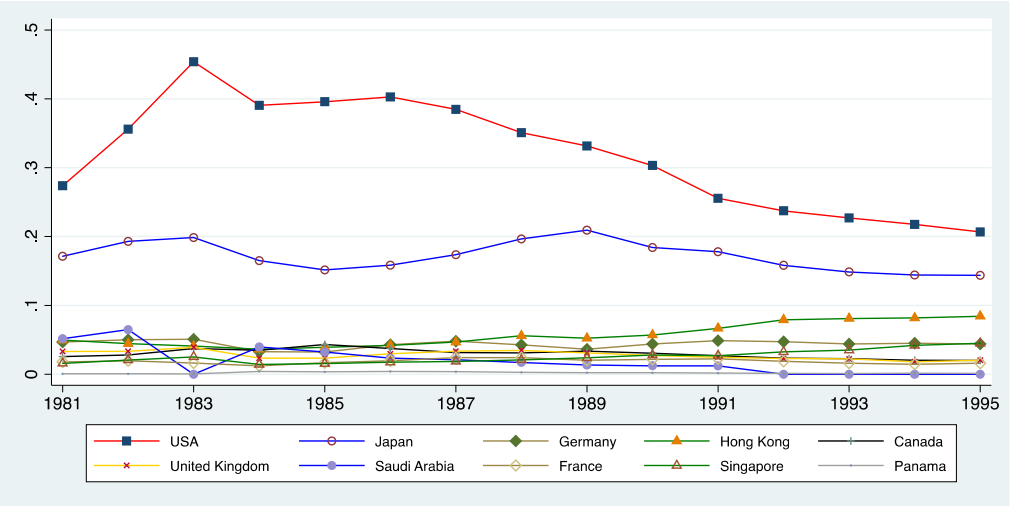


**Fig. 7.** Share of South Korea's exports by destination country.
*The Center for International Data at UC Davis.*

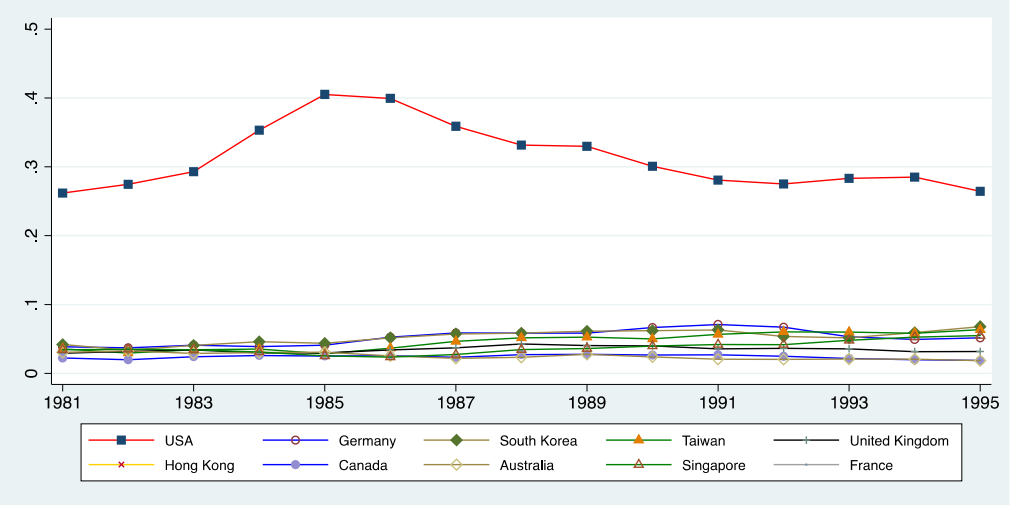


**Fig. 8.** Share of Japan's exports by destination country.
*The Center for International Data at UC Davis.*

the Japanese yen's appreciation dummy variable (*YD*). That being said, this paper is strongly linked to the literature on R&D investments as sunk cost and irreversibility of R&D investment. Dixit and Pyndyck (1994) provides a theoretical framework to understand the capital investment decisions of firms by making two important assumptions; (1) R&D investments are partially or completely irreversible – they consider that R&D investments are sunk costs if they are firm- or industry-specific, and (2) the future value of R&D projects (investments) are unknown – there are uncertainties of the economic environment. Therefore, an *opportunity cost* arises when firms invest R&D today. In other words, there exists an *option value* of waiting for better information to make an investment decision. For these reasons, firms would like to invest in R&D (or increase R&D expenditure) only if they expect the future payoff from that R&D investment *exceeds* the cost of the R&D today. In our paper, we hypothesize that the *sharp appreciation* of Japanese yen around 1986 could make firms expect the future value of their R&D investments to be significantly higher than the current cost of R&D. In other words, the sharp/abrupt exchange rate changes could be significant enough to alter firms' R&D strategies (including R&D investment levels) – but only a *large* yen appreciation can affect firms' R&D investments (significantly). The major exchange rate shift in 1985–86 meets this threshold. On the other hand, we do not consider the relatively smaller exchange rate changes in later years were critical enough to motivate firms to increase (or decrease) their R&D expenditures significantly. In addition, R&D investments are generally made to support specific projects, and these R&D projects often have time horizons that significantly exceed one year. Therefore, it is natural to expect firms will not change their R&D strategies significantly every year in response to relatively insignificant exchange rate changes. So, we focus on the exchange rate changes around 1986, even if the exchange rate also fluctuated somewhat throughout our whole sample period.

### 5.1.2. Proximity dummy

It is expected that each firm should be affected *differently* by exchange rate changes according to its share of revenues associated with its export goods. South Korean and Japanese manufacturing firms produce and export thousands of types of products. Therefore, we introduce a new variable called *proximity*. The South Korean manufacturing firms with a *similar* pattern (or product type) of export with Japan's export were supposed to have a higher similarity (or proximity), so that they get larger benefits from Japanese yen's appreciation. The other firms with *dissimilar* exporting goods with Japan, on the other hands, could probably not find a big opportunity from the appreciation of Japanese yen. Therefore, *proximity* measures the different impacts of the exchange rate changes on each firm's R&D investment. This variable helps us divide our sample firms into two groups; the *close*-proximity group and the *distant*-proximity group.[49]

[49] Close-proximity firms have 1 as the value of the proximity dummy variable and distant-proximity firms have 0.

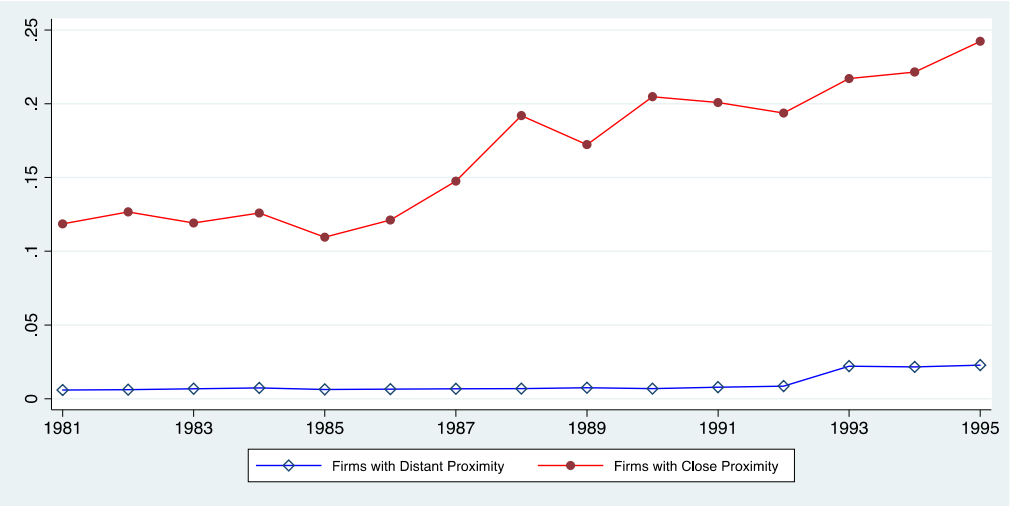


**Fig. 9.** Proximity – Firms with Distant proximity vs. Firms with Close Proximity.
*The Korea Listed Companies Association.*

We construct two types of vectors ($A_{it}$ and $A_{jt}$) to use in a manner similar to the proximity measure developed by Jaffe (1986). $A_{it}$ is a vector which contains information on export amounts of Korean *firm i* by two-digit SITC in year *t*.[50] $A_{jt}$ is a vector that has *Japanese national level* export amounts by two-digit SITC in year *t*. We measure the proximity of a firm *i* in year *t* using the angular separation of the vectors $A_{it}$ and $A_{jt}$. The equation for this is given as:

$$proximity_{it} = \frac{A_{it}A_{jt}'}{(A_{it}A_{it}')^{\frac{1}{2}}(A_{jt}A_{jt}')^{\frac{1}{2}}} \quad (2)$$

Theoretically, the value should range from zero to one. The value is zero for firms whose vector ($A_{it}$) is orthogonal to the vector of Japanese export patterns ($A_{jt}$). On the other hand, the value is one for firms whose vector ($A_{it}$) is identical to $A_{jt}$. The firms with the similar exporting products to Japanese exporting products should have a high $proximity_{it}$. Each firm can have different $proximity_{it}$ values for each year *t*. We calculate the *average proximity* ($proximity_i$) for each firm over the period, from 1981 to 1990.[51] We, then, compute the median value of the average proximity of the firms. We construct a new variable called *proximity dummy* ($PD_i$) using the average proximity of each firm and the median value of all sample firms.

$$PD_i = \begin{cases} 1 \ if \ proximity_i \geq Median \ (proximity) \\ 0 \ if \ proximity_i < Median \ (proximity) \end{cases} \quad (3)$$

The firm whose average proximity is higher than the median has 1 for proximity dummy ($PD_i$). As a result, the proximity dummy ($PD_i$) for each firm does not change over time. In sum, this proximity dummy indicates if the firm's exporting goods are similar to Japanese exporting goods.[52] Therefore, we expect the firms whose value of the proximity dummy is one respond to Japanese yen's sharp appreciation by increasing R&D investment more than the other firms with proximity dummy value zero. In Fig. 9, the average proximity of the two groups of firms is presented. Firms with distant proximity and close proximity have 0 and 1 for proximity dummy, respectively. We can notice that the gap between the two groups of firms is large and the gap is increasing, which underpins the validity of proximity dummy.

### 5.1.3. Export ratio dummy

Some people can predict that the sharp appreciation of Japanese yen would make export-oriented firms increase more R&D than domestically-oriented firms. We define the share of exports as the ratio of total exports to total sales.

$$Share \ of \ exports_{it} = \frac{Exports_{it}}{Sales_{it}} \quad (4)$$

Where *i* indexes individual firm and *t* indexes year. $Exports_{it}$ is the value of total exports by firm *i* in year *t*. $Sales_{it}$ denotes total sales of firm *i* in year *t*. We calculated the average share of exports for each firm from 1981 to 1990.[53] Following the logic of constructing the proximity dummy, we use the median value of the average share of exports of sample firms to define an *export ratio dummy* ($ER_i$).

$$ER_i = \begin{cases} 1 \ if \ Share \ of \ exports_i \geq Median \ (Share \ of \ exports) \\ 0 \ if \ Share \ of \ exports_i < Median \ (Share \ of \ exports) \end{cases} \quad (5)$$

In sum, $ER_i$ is a dummy variable equal to one if the firm's average share of exports is above the median of sample firms' average share of exports.[54] We construct an interaction term using $ER_i$ and *YD*.

### 5.1.4. Interaction terms

We would like to create our key variables, which are interaction terms with the yen appreciation dummy (*YD*), proximity dummy ($PD_i$)

[50] It is a column vector.

[51] The empirical results using the average proximity using different periods, such as 1981–1985, 1981–1986, and 1981–1995, are qualitatively the same. Those results are available from the authors upon request.

[52] Measuring the proximity of each firm in each year obviously gives us benefits – most importantly, we can use more information on proximity by using raw firm-year proximity values than using the proximity dummy variable. However, using the firm-year proximity variable instead of the proximity dummy variable has two significant shortcomings: (1) First, proximity value of each firm fluctuates over time because exports of the firm vary over time. Exports in a specific year can be significantly different from average because of circumstances of external markets and other factors. This tends to happen to relatively small firms. For example, assume that there is a small firm that exports two goods – one product belongs to SITC 78 (Road vehicles) and the other product falls in SITC 61 (Leather manufactures). As we have shown in Fig. 2 in the main text, Japanese firms export a lot of products with SITC 78, but they do not export many products with SITC 61. Let us assume that proximity of the small firm in 1990 is 0.4. In 1991, there was a recall of the product with SITC 78. So, proximity of the small firm in 1991 became 0.1 because the

(*footnote continued*)
firm's sales from the product with SITC 78 decreased significantly in that year. In this case, based on the firm-year proximity measures, the firm's proximity in 1990 is four times bigger than 1991. Also, firms tend to invest R&D in the long run (at least longer than a year) – they do not change their strategies of their R&D every year. Hence, we consider that the overall proximity for the whole period would be more reasonable. (2) Second, related to the first shortcoming, using the firm-year (raw) proximity values makes us lose a number of observations – even relatively large firms do not report exports in some years especially early 1980s.

[53] The empirical results using the average share of exports using different periods, such as 1981–1985, 1981–1986 and 1981–1995, are qualitatively the same. Those results are available from the authors upon request.

[54] The rationales of the use of dummy variable of the export ratio are similar to the use of dummy variable of the proximity.

and export dummy ($ER_i$). The first interaction term ($YD$ and $PD_i$) captures the different impacts of exchange rate changes on R&D expenditures of firms with high proximity ($PD_i = 1$) and low proximity ($PD_i = 0$). This interaction term explains to what extent the South Korean manufacturing firms with similar exporting goods with Japanese manufacturing firms changed their R&D expenditures after the sharp appreciation of Japanese yen in 1986. In other words, this variable explicates how two groups of firms (above-median proximity and below-median proximity) in our sample responded differently to the sudden exchange rate changes in terms of their R&D expenditures.[55] Following the similar logic, we construct the second interaction term ($YD$ and $ER_i$) to measure the different impacts of Japanese yen's appreciation on R&D of firms with high exports share ($ER_i = 1$) and low exports share ($ER_i = 0$).

### 5.2. Alternative hypotheses

#### 5.2.1. Did patent law reform promote firms' R&D increase? - Patent law reform dummy & SITC5 dummy

As we discussed in the earlier section, there was a Korean patent law reform in 1987 (effective as of July 1, 1987). The reform could have had impacts on firms' R&D expenditure. Also, the Japanese yen's sharp appreciation and patent law reform occurred within a relatively short period so that it is hard to distinguish the impacts from each event.[56] We define a patent law reform dummy ($PR$) as follows:

$$PR = \begin{cases} 1 \text{ if } year \geq 1988 \\ 0 \text{ if } year < 1988 \end{cases} \tag{6}$$

The most significant changes of the reform include (i) the widened coverage of patent and (ii) the extended patent protection year. The extended patent protection year equally applies all firms. However, the widened coverage of patent benefits predominantly firms in *chemical and pharmaceutical industries* since new chemical and pharmaceutical products became patentable after this reform. Therefore, if the reform caused firms to raise R&D expenditure, then chemical/pharmaceutical firms would increase R&D more than the firms from other industries. We create a binary measure (*SICT5 dummy:* $SD_i$) to classify sample firms into two groups: (i) SITC5 and (ii) others.[57]

$$SD_i = \begin{cases} 1 \text{ if Firm } i \text{ belongs to SITC } 5 \\ 0 \text{ if Firm } i \text{ doesn't belong to SITC } 5 \end{cases} \tag{7}$$

If this patent law reform had a significant impact on firms' R&D expenditure, then the impact should be larger for firms in SITC5 industries. An interaction term is created by using $PR$ and $SD_i$.

#### 5.2.2. Does firm size matter? - Firm size dummy

Some people might think that big firms could have increased R&D investment since the late- 1980s because they have more flexible budget limits than small firms. In other words, this alternative hypothesis posits that big firms would have increased R&D investment even in the absence of a sharp appreciation by the Japanese yen. To evaluate this hypothesis, we will estimate our basic R&D function specification, but replace the proximity dummy ($PR_i$) with a measure of firm size. We calculated the average sales for each firm from 1981 to 1990.[58]

We define a *firm size dummy* ($FD_i$) as follows:

$$FD_i = \begin{cases} 1 \text{ if } Sales_i \geq Median\ (Sales) \\ 0 \text{ if } Sales_i < Median\ (Sales) \end{cases} \tag{8}$$

We interact $FD_i$ with $YD$ to create an interaction term.

### 5.3. Econometric models for main hypothesis

We employ the following simple log-linear equations to estimate the impact of exchange rate changes on R&D expenditure.

$$rd_{it} = \beta_0 + \beta_1 s_{it} + \beta_2 s_{it-1} + \beta_3 YD + \beta_4 YD \times PD_i + \beta_5 YD \times ER_i + \sum_{t=1983}^{1995} \alpha_t dyear_t + u_i + \varepsilon_{it} \tag{9}$$

$rd_{it}$ denotes the natural log of R&D investment by firm $i$ in year $t$. $s_{it}$ indexes the natural log of sales of firm $i$ in year $t$. We also include the natural log of one-year lag sales (in year $t–1$). Japanese yen appreciation dummy is expressed as $YD$ whose value is 1 from 1986. $YD \times PD_i$ is the interaction term of the Japanese yen's appreciation dummy ($YD$) and proximity dummy ($PD_i$). $YD \times ER_i$ is the interaction term between Japanese yen's appreciation dummy ($YD$) and export dummy ($ER_i$). The impact of the proximity dummy and the export dummy are swept out in a linear model with firm fixed effects because they are time invariant, so they are omitted from Eq. (9). However, we can estimate the coefficients on the interaction terms. We expect the coefficient of these interaction terms (especially, $YD \times PD_i$) would be positive and statistically significant to support our main hypothesis. The $dyear_t$ terms represent year dummy variables. We assume that $u_i$ captures all unobserved, time-invariant firm-specific characteristics that affect R&D of the firm $i$. Finally, $\varepsilon_{it}$ stands for an $iid$ random disturbance. We use a typical firm fixed effect model. Furthermore, a cluster-robust covariance is estimated to relax the homoscedasticity assumption.[59]

### 5.4. Econometric models for alternative hypotheses

In this section, we present equations to test alternative hypotheses.

#### 5.4.1. Did patent law reform trigger firms' R&D increase? - Patent law reform dummy & SITC5 dummy

To test this hypothesis we alter Eq. (9) by replacing the yen appreciation dummy ($YD$) with the patent law reform dummy ($PR$) and the proximity dummy ($PD_i$) with the SICT5 dummy ($SD_i$). The rewritten equation as follows:

$$rd_{it} = \beta_0 + \beta_1 s_{it} + \beta_2 s_{it-1} + \beta_3 PR + \beta_4 PR \times SD_i + \sum_{t=1983}^{1995} \alpha_t dyear_t + u_i + \varepsilon_{it}. \tag{10}$$

We need to get a positive and statistically significant coefficient of the interaction term to accept this alternative hypothesis.

#### 5.4.2. Does firm size matter? – Firm Size dummy

In order to capture the different impacts of Japanese yen's sharp appreciation on R&D investment between big firms and small firms, we rewrite Eq. (9) by replacing the proximity dummy ($PD_i$) with the firm size dummy ($FS_i$), thus yielding:

$$rd_{it} = \beta_0 + \beta_1 s_{it} + \beta_2 s_{it-1} + \beta_3 YD + \beta_4 YD \times FS_i + \sum_{t=1983}^{1995} \alpha_t dyear_t + u_i + \varepsilon_{it}. \tag{11}$$

We would reject this alternative hypothesis if the coefficient of the interaction term were negative or statistically insignificant.

[55] This is a typical format of the difference-in-difference analysis using two categorical variables.

[56] The period is about two years between two events. Because Japanese yen started being appreciated in late 1985 and the reform was effective since July 1, 1987.

[57] SITC 5 (Chemicals and related products): See the appendix for more details on SITC.

[58] The empirical results using the average share of exports using different periods, such as 1981–1985, 1981–1986 and 1981–1995, are qualitatively the same. Those results are available from the authors upon request.

[59] This allows the error terms to be heteroscedastic and correlated within clusters.

**Table 2**
R&D regression: Japanese yen's appreciation, proximity, and export (Firm Fixed Effects, 1981–1995) – Proximity and Export in the Same Models.

| Dependent variable | ln (R&D) | | | | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| ln (Sales) | 0.635*** | | 0.720*** | 0.672*** | | 0.798*** |
| | (0.194) | | (0.229) | (0.242) | | (0.304) |
| ln (Sales): one year lag | | 0.381** | −0.083 | | 0.438* | −0.086 |
| | | (0.190) | (0.197) | | (0.229) | (0.235) |
| Yen appreciation dummy | 1.447*** | 1.665*** | 1.318*** | 1.133*** | 1.251*** | 0.941** |
| | (0.365) | (0.376) | (0.400) | (0.393) | (0.397) | (0.423) |
| **Yen Appreciation Dummy * Proximity Dummy** | | | | **0.809*** ** | **0.907*** ** | **0.782** ** |
| | | | | **(0.305)** | **(0.295)** | **(0.308)** |
| **Yen Appreciation Dummy * Export Dummy** | | | | **−0.079** | **−0.037** | **−0.076** |
| | | | | **(0.284)** | **(0.300)** | **(0.305)** |
| Constant | −0.361 | 4.283 | −0.280 | −1.026 | 3.312 | −1.586 |
| | (3.450) | (3.352) | (3.971) | (4.339) | (4.081) | (5.027) |
| Year dummies | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |
| Number of observations | 1494 | 1455 | 1455 | 1155 | 1121 | 1121 |
| Adj. *R* squared | 0.296 | 0.282 | 0.290 | 0.327 | 0.316 | 0.324 |

The firm-level data for regression estimations presented in this table were obtained from the Korea Listed Companies Association. Regression specifications are estimated in STATA using the fixed-effects model with cluster–robust standard errors for firms. The yen appreciation dummy equals 1 if year is 1986 and after. The proximity dummy equals 1 if the firm's proximity value is greater than the median. The export dummy equals 1 if the firm's share of exports is greater than the median. Standard errors are reported in brackets. For detailed information about the specification, sample selection, and variable construction, consult the text. Statistical significance at ***0.01, **0.05, and *0.1. Detailed estimation results are available from the authors upon requests.

**Table 3**
R&D regression: Japanese yen's appreciation, proximity, and export (Firm Fixed Effects, 1981–1995) – Proximity and Export in Separate Models.

| Dependent Variable | ln (R&D) | | | | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| ln (Sales) | 0.667*** | | 0.747** | 0.757*** | | 0.945*** |
| | (0.223) | | (0.294) | (0.245) | | (0.301) |
| ln (Sales): One year lag | | 0.440** | −0.0351 | | 0.452* | −0.171 |
| | | (0.206) | (0.220) | | (0.241) | (0.240) |
| Yen appreciation dummy | 1.148*** | 1.265*** | 0.949** | 1.164*** | 1.366*** | 0.980** |
| | (0.366) | (0.387) | (0.417) | (0.403) | (0.400) | (0.429) |
| **Yen Appreciation Dummy * Proximity Dummy** | **0.778** ** | **0.891*** ** | **0.758** ** | | | |
| | **(0.317)** | **(0.309)** | **(0.324)** | | | |
| **Yen Appreciation Dummy * Export Dummy** | | | | **0.221** | **0.324** | **0.218** |
| | | | | **(0.328)** | **(0.345)** | **(0.351)** |
| Constant | −0.931 | 3.273 | −1.580 | −2.471 | 3.161 | −2.617 |
| | (3.995) | (3.668) | (4.642) | (4.397) | (4.293) | (5.109) |
| Year dummies (1982–1995) | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |
| Number of observations | 1206 | 1171 | 1171 | 1155 | 1121 | 1121 |
| Adj. *R* squared | 0.331 | 0.321 | 0.328 | 0.316 | 0.303 | 0.315 |

The firm-level data for regression estimations presented in this table were obtained from the Korea Listed Companies Association. Regression specifications are estimated in STATA using the fixed-effects model with cluster–robust standard errors for firms. The yen appreciation dummy equals 1 if year is 1986 and after. The proximity dummy equals 1 if the firm's proximity value is greater than the median. The export dummy equals 1 if the firm's share of exports is greater than the median. Standard errors are reported in brackets. For detailed information about the specification, sample selection, and variable construction, consult the text. Statistical significance at ***0.01, **0.05, and *0.1. Detailed estimation results are available from the authors upon requests.

## 6. Estimation results

### 6.1. Results based on main hypothesis

The firms with the above-median proximity ($PD_i = 1$) are supposed to have a larger impact of Japanese yen's sharp appreciation on R&D spending than the firms with the below-median proximity ($PD_i = 0$) if our main hypothesis is valid. We expect the coefficients of the interaction term ($YD \times PD_i$) in Eq. (9) to be positive and statistically significant. Table 2 reports the results.[60]

Most of the coefficients on our key variables are statistically significant at the 1% level. We can generally interpret that there could be a positive relationship between Japanese yen's appreciation and South Korean manufacturing firms' R&D spending since the coefficient of the yen's appreciation dummy is positive and statistically significant. More importantly, as we have expected, the coefficients of the interaction term between yen appreciation dummy and proximity dummy are positive and statistically significant through all the models (columns (4)–(6)). These coefficients indicate that firms that had similar exports to Japanese firms increased R&D investment after the exchange rate changes more than the other firms with dissimilar export goods. The coefficients in column (6) are consistent with the hypothesis that the firms with close proximity increased their R&D after yen's appreciation by 119% more than the firms with distant proximity.[61] This result strongly supports our main hypothesis that exogenous movement in the exchange rate of Japan can encourage South Korean firms' R&D investment.

[60] The models in Table 2 include both proximity and export dummy variables. Table 3 reports the regression results from the models including one of each dummy variable. The results are consistent with Table 2.

[61] $e^{0.782} - 1 = 1.186$

**Table 4**
R&D regression: SITC5 and Patent Law Reform & Firm size and Japanese yen's appreciation (Firm Fixed Effects, 1981–1995).

| Dependent variable | ln (R&D) | | | | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| ln (Sales) | 0.656*** | | 0.730*** | 0.632*** | | 0.716*** |
| | (0.196) | | (0.231) | (0.198) | | (0.236) |
| ln (Sales): One year lag | | 0.389** | −0.0787 | | 0.387* | −0.0937 |
| | | (0.195) | (0.199) | | (0.200) | (0.219) |
| Patent Law Reform dummy | 1.321*** | 1.609*** | 1.236*** | | | |
| | (0.395) | (0.409) | (0.432) | | | |
| **Patent Law Reform Dummy * SITC5 Dummy** | **0.191** | **0.0840** | **0.116** | | | |
| | **(0.225)** | **(0.229)** | **(0.227)** | | | |
| Yen appreciation dummy | | | | 1.336*** | 1.453*** | 1.152*** |
| | | | | (0.385) | (0.394) | (0.404) |
| **Yen Appreciation Dummy * Firm Size Dummy** | | | | **0.175** | **0.371** | **0.326** |
| | | | | **(0.300)** | **(0.322)** | **(0.320)** |
| Constant | −0.719 | 4.156 | −0.520 | −0.298 | 4.205 | −0.00503 |
| | (3.479) | (3.420) | (4.035) | (3.526) | (3.521) | (4.005) |
| Year dummies | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |
| Number of observations | 1494 | 1455 | 1455 | 1475 | 1438 | 1438 |
| Adj. *R* squared | 0.297 | 0.282 | 0.290 | 0.295 | 0.284 | 0.292 |

The firm-level data for regression estimations presented in this table were obtained from the Korea Listed Companies Association. Regression specifications are estimated in STATA using the fixed-effects model with cluster–robust standard errors for firms. The patent law reform dummy equals 1 if year is 1988 and after. The SITC5 dummy equals 1 if the firm's industry belongs to SITC5. The yen appreciation dummy equals 1 if year is 1986 and after. The firm size dummy equals 1 if the firm's sales (the average from 1981 to 1990) are greater than the median. Standard errors are reported in brackets. For detailed information about the specification, sample selection, and variable construction, consult the text. Statistical significance at ***0.01, **0.05, and *0.1. Detailed estimation results are available from the authors upon requests.

The coefficients of the interaction term between yen appreciation dummy and export dummy, however, are close to zero and not statistically significant. These results suggest that there is no evidence that export-oriented firms increased R&D expenditure more than domestic-oriented firms after Japanese yen's sharp appreciation, once we have controlled for proximity (in the export market) with Japanese firms. This result would be reasonable if there were a significant number of export-oriented firms whose exporting goods are dissimilar to Japanese exporting goods. In this case, these firms should compete with firms with similar exporting goods from other countries, not with Japanese manufacturing firms with dissimilar exporting goods. As a consequence of this logic, this firm should not regard Japanese yen's sharp appreciation as a significant opportunity.[62] It suggests that when firms decided R&D investment in the late- 1980s and early- 1990s because of sharp Japanese yen's appreciation, the proximity of their export goods to Japanese export goods was a more important factor than the share of total exports.

### 6.2. Results based on alternative hypotheses

#### 6.2.1. Did patent law reform promote firms' R&D increase? - Patent law reform dummy & SITC5 dummy

We acknowledge the potential influence of stronger IPR on R&D investment in the previous section. If patent law reform were an important driver in R&D expenditure increase, then firms in SITC 5 should increase the level of R&D more than firms in other industries after the reform. The results obtained from estimating Eq. (10) presented in Table 4 (columns (1)–(3)) do not support this alternative hypothesis. The positive and statistically significant coefficients of the patent law reform dummy are not sufficient to confirm this alternative hypothesis. More importantly, the coefficients of the interaction term are not statistically significant, which suggests that the widened coverage of patentable materials did not encourage firms to increase their R&D investment. This empirical result is consistent with Kortum and Lerner (1999), who note that biotech and software patents accounted for only five percentage of the surge in U.S. patents from 1983 to 1991.[63]

Besides, the positive and statistically significant coefficients of the patent law reform dummy could have been caused by other factors that occurred around the same time such as the Japanese yen's sudden shifts. This is important as it invalidates a key alternative hypothesis for our results – namely, that firms increased R&D investment in the late 1980s because of patent law reform, not because of Japanese yen's sharp appreciation.

#### 6.2.2. Does firm size matter? - Firm size dummy

The results obtained from estimating Eq. (11) are reported in Table 4 (columns (4)–(6)). The coefficients of the interaction term measure the different impacts of Japanese yen's sharp appreciation on R&D investment between big firms ($FS_i = 1$) and small firms ($FS_i = 0$). The interaction term does not show any significant results, suggesting that the firm size did not drive the increase in R&D in the late 1980s.

## 7. Conclusion

Can exogenous movement in exchange rates encourage R&D and innovation? In this paper, we document empirical results that show how exchange rate changes motivate firms to invest more in R&D. It should be highlighted that we focus on another country's exchange rate (yen to the U.S. dollar), rather than our sample firms' home country's exchange rate (won to the U.S. dollar).[64] We find that South Korean manufacturing firms, especially those with close proximity to Japanese manufacturing firms in terms of exporting products, increased R&D investments to take advantage of the opportunity driven by the Japanese yen's huge appreciation. Not all firms, however, responded to the opportunity in the same manner. The firms with close proximity to Japanese firms' export portfolios increased their R&D spending more than the other firms with distant proximity. The empirical analyses suggest that yen's sharp appreciation served as a significant inducement (or momentum) for South Korean manufacturing firms to increase R&D

[62] For example, you can think of a firm whose main product is coffee. This firm should probably be more sensitive to exchange rates of other countries such as Brazil, Vietnam and Columbia.

[63] The scope of patentable patents in the biotech and software was widened during the period.

[64] It does not mean that we do not care about won to yen exchange rate. See appendix for more details.

investment in the late 1980s and early 1990s, especially for the firms primarily competing with Japanese firms in large external markets. Our findings contribute to the literature by demonstrating the role of exchange rate shifts in driving firms' R&D investment choices.

To our best of our knowledge, this is one of the few papers to test the impact of exchange rate changes on firm-level R&D expenditure. Our paper may also provide a useful complement to the growing literature that emphasizes the relationship between market size and innovation.[65] Acemoglu and Linn (2004) show there is a large positive effect of potential market size on the entry of new drugs and molecular entities. It means that pharmaceutical firms invest more R&D in drug categories with larger numbers of (potential) patients. The size of the potential market of each drug category is measured by using the U.S. demographic trends. Unlike this gradual change in demand driven by demographic evolution, the Japanese yen's sharp appreciation in the 1980s happened relatively quickly, and the appreciation persisted throughout the period of our analysis. South Korean manufacturing firms, especially the ones who were competing with Japanese firms in external market, would probably perceive an increase in demand for their products because of improved price competitiveness driven by the sharp exchange rate change.

We conduct this research as part of a broader inquiry into the role of exchange rates (home country and other countries' exchange rates) on firms' behavior related to their innovation. The study needs to be interpreted with caution even if the evidence in this article strongly supports our hypothesis. Evidence from two countries, South Korea and Japan, may not be representative because of the unique and close economic, political and cultural relationships between the two countries. We also lack evidence on small and medium-sized firms because of data limitations. In this context, future research with detailed data drawn from different countries is required to substantiate the results of this study.

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## Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.jjie.2018.01.004.

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[65] For more papers on the market size and innovation in pharmaceutical industry, see Blume-Kohout and Sood (2013), Dubois et al (2015), Lichtenberg and Duflos (2008), Finkelstein (2004) and Duggan and Morton (2010).