

Role of Foreign Direct Investment in Knowledge Spillovers: Firm-Level Evidence from Korean Firms' Patent and Patent Citations

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This study investigates firm-level evidence that Foreign Direct Investment (FDI) through multinational corporations plays a significant role, particularly in knowledge diffusion from U.S. firms to Korean firms. By using micro-level data for Korean firms' U.S. patents and their citations, I explore the patterns of knowledge diffusion from U.S. firms to Korean firms, and identify the role of FDI in enhancing knowledge spillovers between two countries. I find evidence that Korean firms with FDI obtain more knowledge spillovers from U.S. than do Korean firms without FDI. The results provide an answer to the question of whether FDI enhances technology transfer and thus contributes to recent sustainable growth in Korean economy.

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1. INTRODUCTION

To what extent and through what channels does knowledge flow across national borders? This question has received a lot of attention in recent theoretical and empirical economic literature on knowledge spillovers (e.g., technology diffusion¹). Most of these studies focus on technology diffusion

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embodied in traded goods. Since the theoretical work by Grossman and Helpman (1990) emphasizing the potential importance of international R&D spillovers in models of trade and growth, a number of researchers have attempted to quantify its importance (e.g., Coe and Helpman, 1995; Eaton and Kortum, 1996; Keller, 1998; Connolly, 1998). Their main finding is that international technology spillovers are trade-related. In an open economy, however, knowledge diffusion can take place through various channels. In addition to trade, Foreign Direct Investment (FDI) by multinational corporations (MNCs) is often considered to be another important channel for the spread of advanced technologies. FDI is one of the main avenues for the movement of knowledge, technology and modern business methods across national borders.

Despite its obvious potential importance as a means of knowledge spillovers, comparatively little empirical analysis has been conducted on the role of FDI as a channel of knowledge diffusion. Moreover, the results from previous works are inconsistent (e.g., Lichtenberg and la Potterie 1998; Borensztein *et al.*, 1998; Connolly 1998). This might be due largely to the poor quality of the FDI data at the aggregate level, as most of previous works have examined the role of FDI at the country level. FDI data at the aggregate level might not appropriately represent the real business activity of MNCs that actually serve as a channel for knowledge diffusion. For instance, aggregate data does not distinguish FDI by strategic business partners engaged in real business activity from FDI by financial partners for financial investment.²⁾ To refine this matter, more works need to be done at the firm level. However, few work has analyzed the impact of FDI on knowledge diffusion at the firm level due to a lack of micro-level data for both FDI and knowledge spillovers. It is still an open empirical question whether FDI

¹⁾ In general, technology diffusion is one example of knowledge spillovers. Knowledge spillovers might be a more accurate expression for this study, but in this paper I use both terms to be interchangeable.

²⁾ By the OECD definition, FDI refers to the investment by foreign affiliates of domestic enterprises in which domestic residents hold ownership or control of more than 10 percent of an enterprise's voting securities. FDI data by this definition does not distinguish FDI by strategic business partners from FDI by simple stock-holders for financial investment.

increases the ability of firms to learn from the research activity and technological innovation of firms in the host country. This paper has asked whether firms could obtain useful knowledge spillovers from the host country through FDI, and FDI could play a significant role in the spillovers process.

1.1. Background and Motivation

This paper attempts to fill the gap in the previous literature mentioned above by proposing an alternative empirical framework using micro-level data to examine the role of FDI at the firm level in knowledge diffusion.³⁾ In particular, by using data for Korean firms' U.S. patents and their citations from the U.S. Patent and Trademark Office, I explore the patterns of technology flows from U.S. firms to Korean firms, and attempt to identify the role of FDI in enhancing technology spillovers between two countries. Korea is one of the newly industrializing economies that have achieved tremendous technological progress and high economic growth. Korea has graduated from imitation to innovation within a few decades, by building their indigenous technological capabilities and moving up the technology ladder. Knowledge diffusion from advanced economies such as U.S. and Japan has played an important part in the economy's transition. However, the channels for this diffusion process are not well understood. Partly, it takes the form of technology transfer embodied in imported goods or through brought through FDI by MNCs. Technology diffusion can also take place via knowledge diffusion, where by researchers and inventors benefit from their knowledge of research in more advanced economies. In this paper, I investigate the patterns of knowledge diffusion from U.S. firms to Korean firms, and identify the role of FDI in enhancing knowledge spillovers between two countries.

³⁾ We can distinguish between types of technology diffusion, in terms of innovations in products and processes. In this paper, I focus on innovation in processes, which is more appropriate for technology transfer involved in patent.

The use of patents and patent citations as a direct measure of knowledge spillovers has been pioneered by Jaffe *et al.* (1993). They indicated the usefulness of patent citations for exploring knowledge spillovers. Knowledge flows are unobservable. But knowledge flows do sometimes leave a paper trail, in the form of citations in patents. As argued by Jaffe *et al.*, “In principle, a citation of Patent X by Patent Y means that X represents a piece of previously existing knowledge upon which Y builds, and so knowledge flows from X to Y , . . . , we looked at citations made by patents to previous patents as a window on the process of knowledge flow” (Jaffe *et al.* 1993, p.580). Because U.S. patent data from the U.S. Patent & Trademark Office contains detailed information about patent inventors (firms) and original inventors of cited patents, this allows us to examine the extent of knowledge spillovers at the firm level across countries. Jaffe *et al.* (1993, 1998)⁴⁾ also found the evidence for significant geographic localization of knowledge spillovers to the extent that citations to domestic patents are more likely to be domestic.⁵⁾ Subsequently, Hu and Jaffe (2001) investigated

⁴⁾ Jaffe *et al.* (1993, 1998) used different approaches in their first (1993) and second (1998) works mainly due to the limitation of patent data available. To examine geographical location of knowledge spillovers in their first paper (1993), they compared directly the patterns of raw citation frequency between domestic and foreign citations, instead of using estimation approach. This is mainly due to the limitation of their first data set (i.e. data for other covariate are not available). I adapt their first approach due to the limitation of my data set. I examine directly the patterns of Korean firms’ raw citation frequency of U.S. patent in 1995 and compare them between firms with FDI and firms without FDI to explore the role of FDI at the firm level. Their second work (1998) is an extension of their first work with more detailed data collection for patent citation. They estimated citation functions using a Probit-type model. Regressor variables include the dummy variables for sectors and other covariates mostly related to characteristics of patent citation (e.g. technological proximity, country dummy, and citing time period). However, they did not include “demand” or “cost” factors, due to lack of those data for citation. As they mentioned, the limitations make it difficult to go much further with such questions. While their first work indicates the usefulness of patent citations for exploring geographic location of knowledge flows, the second work highlights the need for careful attention to the details of the patenting and citation process. Overall, their second results confirm their earlier findings that there is significant geographic localization of knowledge flows. As I mentioned in conclusion, one particular useful extension of my current work would be to adapt their second approach for estimating citation function of firms with FDI and without FDI to explore the details of the role of FDI in knowledge flow. This requires collecting longer spans and more detailed data for Korean firms’ patent citation.

⁵⁾ They explored the patterns of citations among patents taken out by inventors in the U.S., the U.K., France, Germany and Japan, and found that knowledge spillovers are geographically

patterns of knowledge diffusion from advanced economies to Korea and Taiwan. While these previous works have concentrated on examining patterns of knowledge flows among countries, there has been little work to identify the channels for knowledge diffusion process such as FDI. In this work, I try to identify the role of FDI in knowledge diffusion process. The existence of FDI can lessen the localization of and make difference in the pattern of knowledge spillovers. MNCs have access to the technology of local firms in hosting countries through their foreign affiliates. This, in turn, makes MNC's citations less likely to be domestic, because MNCs are more likely to have an access to foreign patents than are domestic firms. In other words, foreign affiliates of MNCs act as a bridgehead for knowledge flows across countries. FDI by MNCs enhances knowledge spillovers beyond national borders between hosting and hosted countries. This implication allows us to identify the role of FDI in knowledge diffusion by examining patterns of firms' patents and their citations. If FDI plays a role as a bridge for technology spillovers between countries, there should be a significant difference in the patterns of patents and citations between firms with FDI and without FDI. Specifically, we would expect firms with FDI to cite the patents of firms in its hosting country more frequently than those without FDI do. Also, firms cite the patents of foreign firms with a substantial FDI presence more frequently than those of foreign firms without FDI. I examine these hypotheses by using a data set of U.S. patents assigned to Korean firms (assignees) during 1995. I look at citations made by Korean firms to previous U.S. patents as a window of the technology flows from U.S. firms to Korean firms, and compare the patterns between Korean firms with FDI and those without FDI.

I chose Korean data for two main reasons. First, Korea has had an interesting experience with direct investment. Korea was a recipient of foreign direct investment (inward FDI) through 1980, but since 1990, it has recorded more outward (i.e. net outward flow) FDI on a flow basis (exporter of direct investment). Over that time span, its outward FDI has increased at

localized.

a rapid rate. In the 1990s, both inward and outward FDI have coexisted significantly in the Korean economy. Second, this rapid increase of recent FDI makes it a hot topic of discussion in Korea. What role has FDI played in Korea's economic performance? Did FDI raise productivity through the transfer of technology? I use data from 1995, a period when both inward and outward FDI were the largest in 1990s before the currency crisis of 1997.⁶⁾ Thus, as an issue of economic development, this work would provide an answer to the question of whether FDI enhances technology transfer and thus contributes to recent sustainable growth in Korean economy.

By using micro-level data for Korean firms' U.S. patents and their citations during 1995, I explore the patterns of knowledge flows from U.S. firms to Korean firms, and identify the role of FDI in enhancing knowledge spillovers between countries. I find evidence that Korean firms with FDI in the United States obtain more knowledge spillovers from U.S. firms than do Korean firms without FDI. I also find that Korean firms obtain more knowledge spillovers from U.S. firms with FDI in Korea than from those without FDI. These empirical results suggest that FDI through MNCs enhances knowledge transfer and thus contributes to recent sustainable growth in Korean economy.

This paper is organized as follows. In section 2, I specify the methodology and the hypothesis that guide the empirical tests. I describe the sources, description and basic statistics for data in section 3. I present and discuss empirical results and their implications in section 4. Concluding remarks are in section 5.

2. THE METHODOLOGY

To identify the role of FDI, we first need to separate U.S. patents assigned to Korean firms into two groups according to firms with FDI and those

⁶⁾ I exclude the period of the currency crisis, as an exceptional event not reflecting regular patterns of FDI movements.

without FDI.⁷⁾ The FDI group and non-FDI group are created for individual firms as follows. The FDI group consists of Korean firms with FDI in the United States and the non-FDI group consists of Korean firms with no FDI in the United States. I also separate Korean firm's citation into patents held by U.S. firm with FDI in Korea and those without FDI. Then, I examine patterns of patents and their citations between the two groups of firms. If FDI plays a role in the technology spillovers, there should be a significant difference in citation patterns between the two groups. Similarly, Korean firms' citations of patents held by U.S. firms with FDI in Korea are compared with those of U.S. firms without FDI in Korea. If we find that Korean firms with a substantial FDI presence in the United States cite patents of U.S. firms more frequently, this would be direct evidence of spillover augmented by Korean FDI in the United States (outward FDI of Korea). On the other hand, if we find that Korean firms cite the patents of U.S. firms with a substantial FDI presence in Korea more frequently than those of U.S. firms without FDI, this would be direct evidence of spillover augmentation through U.S. FDI in Korea (inward FDI in Korea).

2.1. Model and Hypothesis

This logic is summarized into a simple model and hypothesis illustrated in Figure 1 and Table 1. The model in Figure 1 shows how technology flows from U.S. firms to Korean firms. This model considers only one direction of technology flows, from an advanced country (the United States) to a less advanced country (Korea).⁸⁾ In each country, there are two types of firms, firms with FDI (K^{FDI} : Korean firms with FDI, and U^{FDI} : U.S. firms with FDI) and firms without FDI (K^{NO} : Korean firms without FDI, and U^{NO} : U.S. firms without FDI), and their foreign affiliates (K_{US} : U.S. affiliates of Korean firms,

⁷⁾ A detailed description of patent data from the U.S. Patent and Trademark Office is in section 3.3.

⁸⁾ With more data available, this analysis could be extended for two directional technology spillovers. However, technology spillovers from Korea to U.S. are less likely to happen.

Table 1 The Hypotheses

Test	Null Hypothesis (H ₀)	Alternative Hypothesis (H _a)
Role of K_{US}	No role of K_{US} : $H_0: [U^{NO} \dashrightarrow K^{FDI}] = [U^{NO} \dashrightarrow K^{NO}]$	Significant role of K_{US} : $H_a: [U^{NO} \dashrightarrow K^{FDI}] > [U^{NO} \dashrightarrow K^{NO}]$
Role of U_{KR}	No role of U_{KR} : $H_0: [U^{FDI} \dashrightarrow K^{NO}] = [U^{NO} \dashrightarrow K^{NO}]$	Significant role of U_{KR} : $H_a: [U^{FDI} \dashrightarrow K^{NO}] > [U^{NO} \dashrightarrow K^{NO}]$

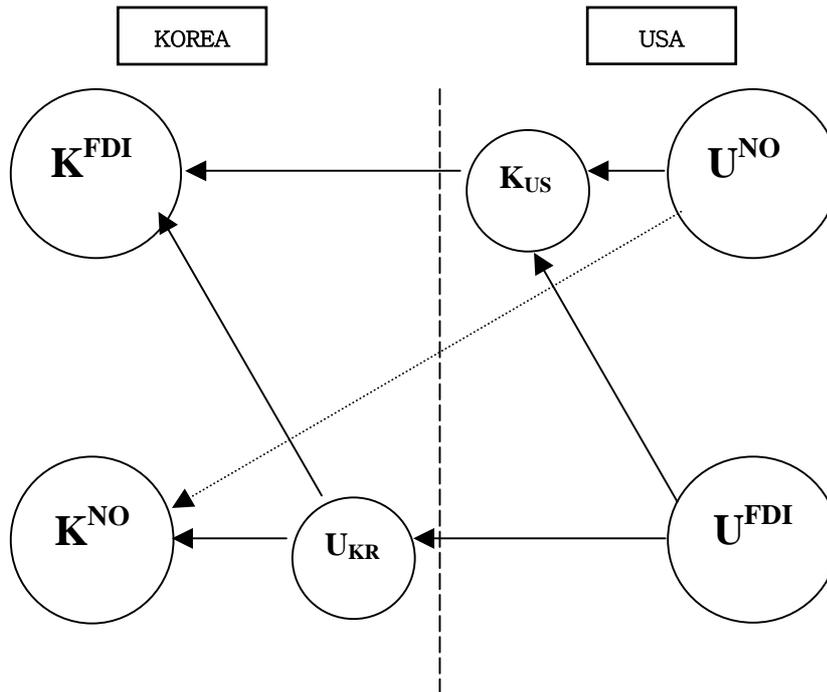
Note: $[X \rightarrow Y]$ implies technology flows from X to Y and $[X \dashrightarrow Y]$ implies technology does not flow from X to Y .

and U_{KR} : Korean affiliates of U.S. firms).⁹⁾ Without FDI, it is difficult for technology to spillover between two countries, due to the geographic localization of knowledge spillovers. With FDI as a bridge for technology spillovers between two countries, technology flows from the United States to Korea. In particular, as showed in Figure1, Korean firms with FDI in the United States (K^{FDI}) can have access to advanced technology of U.S. firms (both U^{NO} and U^{FDI}) through their affiliates in the United States (K_{US}). However, Korean firms without FDI (K^{NO}) can access only advanced technology from U.S. firms with FDI in Korea (U^{FDI}) through U.S. firms' affiliates in Korea (U_{KR}). In other words, Korean firms without FDI have no way to access the technology of U.S. firms without FDI in Korea (U^{NO}). This case with no FDI can be used as a benchmark to compare with other cases with FDI effects. Next, I discuss this implication in detail to examine the role of FDI in this process of technology flows.

First, I examine the role of Korean FDI in the United States. If such FDI plays a significant role in technology spillovers from the United States to Korea, there should be a significant difference in technology flows to Korea between FDI group and non-FDI group in Korea. That is, since technology flows from U.S. to Korean firms are measured by patent citations in both

⁹⁾ By "U.S. firms with (without) FDI," I mean in this context U.S. firms with (no) FDI in Korea.

Figure 1 Technology Flow between Korea (recipient) and the United States (sender):

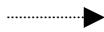


Notes:

Technology Flow:



Potential Technology Flow:



K^{FDI} : Korean Firm with FDI in the U.S., K^{NO} : Korean Firms with No FDI in the U.S.

U^{FDI} : U.S. Firms with FDI in Korea, U^{NO} : U.S. Firms with No FDI in Korea

K_{US} : U.S. affiliates of K^{FDI} .

U_{KR} : Korean affiliates of U^{FDI} .

$$H_0: [U^{NO} \dashrightarrow K^{FDI}] = [U^{NO} \dashrightarrow K^{NO}]$$

$$H_a: [U^{NO} \rightarrow K^{FDI}] > [U^{NO} \dashrightarrow K^{NO}].$$

groups, I specify the null and alternative hypothesis to test the role of Korean FDI in the U.S. (K^{FDI}) as follows:¹⁰⁾

By omitting U.S. firms with FDI (testing the patents of U^{NO} rather than U^{FDI}), the first hypothesis avoids confounding effects to Korean firms from U.S. firms. The null hypothesis states that technology spillovers from U.S. firms to Korean firms with FDI are equal to those from U.S. firms to Korean firms without FDI. The alternative implies that the former is larger than the latter, because the existence of Korean FDI in the U.S. enhances technology spillovers from U.S. firms to Korean firms. Using patent citations as a proxy to measure technology flow, the above hypothesis can be rewritten in a testable form as:

H_0 : {Patent citation of Korean firm with FDI to patents of U.S. firm without FDI}

= {Patent citation of Korean firm without FDI to patents of U.S. firm without FDI}

H_a : {Patent citation of Korean firm with FDI to patents of U.S. firm without FDI}

> {Patent citation of Korean firm without FDI to patents of U.S. firm without FDI}.

Second, I examine the role of U.S. FDI in Korea (inward FDI of Korea). If U.S. FDI in Korea plays a significant role in technology spillovers from U.S. to Korea, there should be a significant difference in technology flows to

¹⁰⁾ Note: [$X \rightarrow Y$] implies technology flows from X to Y and [$X \dashrightarrow Y$] implies technology does not flow from X to Y . Technology flow from X to Y is measured by patent citations of X firm to patents of Y firm.

non-FDI Korean firms between U.S. firms with FDI and those without FDI in Korea. That is, I specify the null and alternative hypothesis to test the role of U.S. FDI in Korea (U^{FDI}) as follows:

$$H_0: [U^{FDI} \dashrightarrow K^{NO}] = [U^{NO} \dashrightarrow K^{NO}]$$

$$H_a: [U^{FDI} \rightarrow K^{NO}] > [U^{NO} \dashrightarrow K^{NO}]$$

The null hypothesis states that technology spillovers from U.S. firms with FDI to Korean firms is equal to those from U.S. firms without FDI to Korean firms. The alternative implies that the former is larger than the latter, because U.S. FDI in Korea enhances technology spillovers from U.S. firms to Korean firms. This second hypothesis can be rewritten in a testable form as:

$$H_0: \{ \text{Patent citation of Korean firm } \underline{\text{without FDI}} \text{ to patents of U.S. firm } \underline{\text{with FDI}} \} \\ = \{ \text{Patent citation of Korean firm } \underline{\text{without FDI}} \text{ to patents of U.S. firm } \underline{\text{without FDI}} \}$$

$$H_a: \{ \text{Patent citation of Korean firm } \underline{\text{without FDI}} \text{ to patents of U.S. firm } \underline{\text{with FDI}} \} \\ > \{ \text{Patent citation of Korean firm } \underline{\text{without FDI}} \text{ to patents of U.S. firm } \underline{\text{without FDI}} \}.$$

This hypothesis is similar to the first, but with a focus on U.S. FDI. By omitting Korean firms with FDI (testing the citations of K^{NO} rather than K^{FDI}), the second hypothesis avoids confounding effects from the first hypothesis (and vice versa).

3. DATA AND BASIC STATISTICS

3.1. On-line Search and Retrieval of Patent Data

The technology Assessment and Forecast Branch of the U.S. Patent and Trademark Office provides large on-line databases for U.S. patents granted. They include data for each patent, indicating the nature of the organization to which the patent property right was assigned, the names of the inventors and the organization to which the patent right was assigned, the date of the patent application and the patent grant, a detailed technological classification for the patent, references cited by the patent (referenced by U.S. patent documents and foreign patent documents), and miscellaneous other information. The Boolean search-query-method in the databases allows us to search U.S. patents according to various categories. First, I searched and retrieved 1995 patents assigned to Korean firms, yielding total 1,159 patents. Next, I separated the data set into two groups of Korean firms those with FDI and those without FDI in the U.S. A listing of Korean multinational firms with FDI in the United States is available in the *Directory of foreign firms operating in the United States* (1995). This procedure resulted in 820 U.S. patents for Korean firms with FDI and 339 patents for Korean firms without FDI. With these data sets, I examined detailed information of their patent citations, the U.S. patents cited, the U.S. patents of U.S. firms with FDI, the U.S. patents of U.S. firms without FDI, the U.S. patents of foreign firms, the U.S. patents of Korean firms, and the foreign patents by foreign patent office. A listing of U.S. firms with FDI in Korea is based on the *Directory of Multinationals* (1995).

3.2. Description of Basic Statistics

As a prelude to the hypothesis tests, Table 2 presents some descriptive statistics about the patents and their citations by category. The first to fourth columns report data for U.S. patents cited according to the origins of the cited assignees: U.S. firms (with FDI and without FDI), non-U.S. firms

Table 2 Descriptive Statistics
2-A Assignee: All Korean Firms (1,159 patents)

Assignee	U.S. Patent Cited				Non-U.S. Patent Cited
	U.S. firms with FDI	U.S. firms with No FDI	Non-U.S. Firms	Korean firms	
Mean	0.9456	1.7075	2.9184	0.3878	1.0068
Median	0.0000	1.0000	2.0000	0.0000	0.0000
Variance	2.6272	5.1399	8.9796	0.8871	3.8424
Minimum	0	0	0	0	0
Maximum	10	12	15	7	11
Total	1,096	1,979	3,382	450	1,168

2-B Assignee: Korean Firms with FDI in the U.S. (820 patents)

Assignee	U.S. Patent Cited				Non-U.S. Patent Cited
	U.S. firms with FDI	U.S. firms with No FDI	Non-U.S. Firms	Korean firms	
Mean	0.6346	2.1923	3.1250	0.2788	1.0769
Median	0.0000	1.0000	2.0000	0.0000	0.0000
Variance	1.7478	6.1374	9.9551	0.4166	4.3630
Minimum	0	0	0	0	0
Maximum	10	12	15	3	1
Total	520	1,798	2,562	229	884

2-C Assignee: Korean Firms with No FDI in the U.S. (339 patents)

Assignee	U.S. Patent Cited				Non-U.S. Patent Cited
	U.S. firms with FDI	U.S. firms with No FDI	Non-U.S. Firms	Korean firms	
Mean	1.6977	0.5349	2.4186	0.6512	0.8372
Median	1.0000	0.0000	2.0000	0.0000	0.0000
Variance	4.0255	0.8261	6.4396	1.6135	2.6157
Minimum	0	0	0	0	0
Maximum	9	4	10	7	7
Total	576	181	820	221	284

and Korean firms. The fifth column reports data for non-U.S. patents cited by Korean firms. Table 2-A gives detailed citation data for 1,159 U.S.

patents that were assigned to Korean firms during 1995. It shows that Korean firms cited U.S. patents more frequently than non-U.S. patents; they cited on average $5.9593(=0.9456+1.7075+2.9184+0.3878)$ U.S. patents, while they cited an average of 1.0068 non-U.S. patents. Citations range from 0 to 15 for U.S. patents and from 0 to 11 for non-U.S. patents.

Table 2-B and 2-C provide additional detail on two sub-groups, Korean firms with FDI in the United States & those without FDI. These tables provide more interesting data required to compare patent citations between firms with and without FDI. Tables B and C show that Korean firms with FDI in the United States had received more U.S. patents than those without FDI — 820 patents compared to 339 patents. Korean firms with FDI had on average more citations than those without FDI in respect to both U.S. and non-U.S. patents. Korean firms without FDI cited on average 5.3017 U.S. patents and 0.8372 non-U.S. patents, while Korean firms with FDI cited 6.2307 U.S. patents and 1.0769 non-U.S. patents. First, Korean firms with FDI cited more U.S. patents of U.S. firms without FDI in Korea than those without FDI did (on average 2.1923 vs. 0.5349). This fact is consistent with hypothesis 1. Second, Korean firms without FDI cited patents of U.S. firms with FDI more than patents of U.S. firms without FDI (1.6977 vs. 0.5349), consistent with hypothesis 2.

Furthermore, with respect to citations to Korean patents, we can see that Korean firms without FDI cited Korean patents more frequently than those with FDI did. The average number of citations to FDI-firms is 0.2718, while that of non-FDI firms is 0.6512. In other words, non-FDI-Korean firms' citations are more likely to be domestic than are FDI-Korean firms. This is consistent with the fact that firm without FDI can't have access to foreign technology. It also implies that there is a significant difference in the pattern of localization of knowledge between domestic firms and MNCs. This data shows that the existence of FDI can lessen the patterns of localization of knowledge spillovers found in Jaffe et al (1993).

Overall, the basic descriptive data show that there is a different pattern of

citation of U.S. patents between Korean firms with FDI and those without FDI. Next, I conduct hypothesis tests regarding these differences.

4. HYPOTHESIS TESTS AND DISCUSSION

This section tests statistically the hypotheses with the citation data discussed in section 3. Table 3 presents the results of testing hypotheses 1 and 2 specified in section 2. To measure Korean firms' citations to U.S. patents held by U.S. firms, I first use the raw number of citations from the original data set. However, comparing the raw frequency may not be appropriate when the groups are different sizes. Accordingly, I next use a relative frequency measure: I calculate the ratios of patents in each category to all U.S. patents, and compare the ratios between groups. The first row presents the result of the test using raw frequency of citations, and the second row presents the results of the test using the ratio to all U.S. patent citations. Columns 3 and 4 report the results of testing equality of variance to conduct t-test for the hypothesis. Columns 5 to 7 report the results of testing for equality in the hypotheses. I report the results with and without the assumption of equal variances.

Table 3-A shows the result of testing hypothesis 1 to examine the role of Korean FDI in the United States. The result indicates rejecting the null hypothesis at 1% significance level ($p\text{-value} < 0.01$ for all four cases). This implies that Korean firms with FDI cited patents held by U.S. firms without FDI significantly more than did Korean firms without FDI. More specifically, Korean firms with FDI cited on average about 2 patents (0.43 in the ratio) more than did Korean firms without FDI. In other words, this evidence implies that Korean FDI in the U.S. plays a significant role in technology spillovers from U.S. to Korea.

Next, I test hypothesis 2 to examine the role of U.S. FDI in Korea. Table 3-B shows the results of testing hypothesis 2. Like part A, I use both an absolute measure and a ratio. Again, the statistics indicate rejecting the null hypothesis at 1% significance level ($p\text{-value} < 0.01$ for all four cases),

Table 3 Hypothesis Tests
3-A Hypothesis I

	Assumption of equal variances	Levene's test for Equality of Variance		t-test for Equality		
		F-value	p-value	Difference	t-value	p-value
1.Using Raw Value	yes	20.547	0.000*	1.6574	4.263	0.000*
	no			1.6574	5.926	0.000*
2.Using Relative Ratio	yes	23.830	0.000*	0.4264	6.175	0.000*
	no			0.4264	7.379	0.000*

3-B Hypothesis II

	Assumption of equal variances	Levene's test for Equality of Variance		t-test for Equality		
		F-value	p-value	Difference	t-value	p-value
1.Using Raw Value	yes	15.963	0.000*	1.1628	3.362	0.001*
	no			1.1628	3.493	0.001*
2.Using Relative Ratio	yes	6.978	0.010*	0.1765	3.294	0.001*
	no			0.1765	3.401	0.001*

3-C Hypothesis III

	Assumption of equal variances	Levene's test for Equality of Variance		t-test for Equality		
		F-value	p-value	Difference	t-value	p-value
1.Using Raw Value	yes	1.271	0.261	0.4946	1.161	0.248
	no			0.4946	1.266	0.209
2.Using Relative Ratio	yes	0.091	0.763	0.2499	0.723	0.471
	no			0.2499	0.714	0.477

Notes: Raw value implies raw frequency of patent citations and relative ratio is calculated as ratio of total patents of U.S. firms. * Indicates rejecting the null hypothesis at 1% significance level.

implying that there exists a significant difference in technology flows from U.S.-FDI firms and those from non-FDI-U.S. firms. Non-FDI Korean firms

cited U.S. patents of U.S. FDI firms on average 1 patent (0.18 in the ratio) more than U.S. patents of non-FDI U.S. firms. That is, the evidence supports the role of U.S. FDI in Korea in technology spillovers from the United States to Korea. Overall, I find evidence that both Korean FDI in United States and U.S. FDI in Korea play a significant role in technology diffusion from the United States to Korea.

These results raise another question about the relative roles of Korean FDI in the United States and U.S. FDI in Korea. From the perspective of the Korean economy, the former indicates outward FDI, and the latter indicates inward FDI. Since we found significant evidence for the role of both inward and outward FDI, this part asks if there is a quantitatively significant different pattern in the role each play in technology diffusion from the United States to Korea. In general, knowledge transfer to Korean firms engaging in FDI may only lead to gains for this specific Korean firm. On the other hand US FDI in Korea could lead to a wider dissemination amongst more Korean companies. Thus, we would expect that U.S. FDI in Korea provides broader dissemination of knowledge spillovers to Korea. In other words, the evidence from the previous part implies that $H(1)_a: [U^{NO} \rightarrow K^{FDI}]$ and $H(2)_a: [U^{FDI} \rightarrow K^{NO}]$ holds, and so we ask if there is a difference between $H(1)_a$ and $H(2)_a$. That is, the null and alternative hypothesis are specified as follows:

$$H_0: [U^{NO} \rightarrow K^{FDI}; \text{outward FDI}] = [U^{FDI} \rightarrow K^{NO}; \text{inward FDI}],$$

$$H_a: [U^{NO} \rightarrow K^{FDI}; \text{outward FDI}] \neq [U^{FDI} \rightarrow K^{NO}; \text{inward FDI}].$$

Table 3-C presents the result of testing hypothesis 3. Like hypotheses 1 & 2, I report the results using both an absolute measure and a ratio. The statistics fail to reject the null hypothesis under the assumptions of both variance; p-values to reject the null are 0.248, 0.209, 0.471 and 0.477 for each case. This evidence implies that even though there exist a significant role of Korean inward FDI and outward FDI in technology diffusion from

U.S. to Korea, I find no evidence of a quantitatively significant difference between them.

Summing up, this evidence of patent citation have found a role for FDI at the firm level, particularly in explaining technological diffusion from U.S. firms to Korean firms. Although I believe that these results provide a persuasive firm-level evidence for the role of FDI, issues related to causality are still somewhat open. For instance, it is possible that firms' FDI decision is not completely exogenous and might relate to technological links before their FDI activities. In other words, previous technological links might be one of determinants for firms' FDI (e.g., firms are investing internationally as a consequence of the possible spillovers). Although Borensztein *et al* (1998) found the role of FDI in enhancing the transfer of technology by using the instrumental variables estimation of a cross-country regression, the causality issue at firm level is still somewhat unclear. As I mentioned in conclusions and extensions, further understanding on causality between firms' FDI and spillovers will require additional detailed time-series analysis at the firm level to be adequately addressed (e.g., difference in time-series patterns between before-FDI and after-FDI periods in a specific firm). This also requires collecting longer spans of data for patent.

5. CONCLUSIONS

Corporate strategy experts strongly support the view that tapping foreign sources of technological advance through FDI could be a profitable strategy (Porter 1990). It is still an open empirical question whether FDI increases the ability of firms to learn from the research activity and technological innovation of firms in the host country. This paper has asked whether Korean firms could obtain useful knowledge spillovers from the innovation activities of U.S. firms through FDI in Korea and in the U.S. This paper presents a straightforward empirical framework to examine the role of FDI of Korean firms and U.S. firms in knowledge diffusion. I use firm level data on Korean firms' U.S. patents and their citations to explore knowledge flows

from U.S. firms to Korean firms.

This paper has presented firm-level evidence that FDI plays a significant role, especially in knowledge diffusion from U.S. firms to Korean firms. I find evidence that Korean firms with FDI in the United States obtain more knowledge spillovers from U.S. firms than do Korean firms without FDI. I also find that Korean firms obtain more knowledge spillovers from U.S. firms with FDI in Korea than from those without FDI. Furthermore, even though it is generally believed that U.S. FDI in Korea might lead stronger knowledge diffusion to Korea than Korea FDI in U.S. does, there is no quantitatively significant difference between them. In the perspective of economic development, this result would provide the empirical evidence for an answer to the question of whether FDI enhances technology transfer and thus contributes to recent sustainable growth in Korean economy.

I have carefully constructed a data set of Korean firms' U.S. patents and their citations, which itself can be considered a useful contribution of this work. A number of extensions could be made to the work presented here with this data set. Databases from U.S. Patent and Trademark Office contain detailed information about U.S. patents and citations such as the issue date and international classification. One particular useful extension would be to use the dates to explore the timing of knowledge spillovers. For instance, it is reasonable to think that the knowledge does not spillover instantly but with lags.¹¹⁾ If this is the case, then there may be a difference in the timing of citations between firms with FDI and those without FDI. Also, data on the classification of patents would provide additional information to investigate intra- and inter-sector technology spillovers. Collecting such data would be extremely time-consuming, but might improve our understanding of knowledge spillovers and the role of FDI. Another interesting issue could be a consideration of commercial viability and market value for knowledge spillovers in patent citation. Hall, Jaffe and Trajtenberg (2000) recently explored the economic meaning of citation-based patent measures using market valuation of the firm that own the patents. A future study for the role

¹¹⁾ Jaffe *et al.* (1993) found that localization of technology spillovers fades over time.

of FDI with application of their work on market valuation of patent might provide a more interesting problem regarding the quality and commercial viability of knowledge diffusion and technology transfer.

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