Is Foreign Direct Investment a Channel of Knowledge Spillovers? Evidence from Japan's FDI in the United States*

Lee Branstetter**
Columbia Business School
and
NBER

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Abstract

Recent empirical work has examined the extent to which international trade fosters international "spillovers" of technological information. FDI is an alternate, potentially equally important channel for the mediation of such knowledge spillovers. I introduce a framework for measuring international knowledge spillovers at the *firm* level, and I use this framework to directly test the hypothesis that FDI is a channel of knowledge spillovers for Japanese multinationals undertaking direct investments in the United States. Using an original firm-level panel data set on Japanese firms' FDI and innovative activity, I find evidence that FDI increases the flow of knowledge spillovers both from and to the investing Japanese firms.

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** Lee Branstetter, Columbia Business School, Uris Hall 815, 3022 Broadway, New York, NY 10027; TEL 212-854-2722; FAX 212-854-9895; E-mail lgb2001@columbia.edu

I. Introduction

To what extent does technological knowledge flow across national borders, and by what means are these knowledge flows mediated? These questions have received an increasing amount of attention over the last decade, as leading scholars in international economics have focused considerable research effort on the topic of knowledge spillovers. Ethier (1982), Rivera-Batiz and Romer (1991), Feenstra (1996), and, perhaps most notably, Grossman and Helpman (1990, 1991), among others, helped place this general subject in the forefront of international economic research with their pathbreaking work on models of endogenous innovation-driven growth and trade.

Incorporating technological progress into trade models can make a real difference, at least in theory. Technological considerations can expand the gains from trade. Liberal trade policies provide domestic entrepreneurs with the possibility of exploiting global markets rather than merely national ones, inducing more R&D (or greater specialization), and generating higher levels of economic growth or welfare. Moreover, imported manufactured goods can -- in some of these models -- serve as channels of knowledge spillovers.[1] Domestic firms can "learn from" the foreign goods they purchase by reverse-engineering the technological innovations embodied in these goods. In this way, the "knowledge stock" on which domestic innovators can build is enlarged through liberal trade.[2] While less thoroughly explored in formal models, the literature also suggests the possibility of a "learning-by-exporting" effect in which firms learn to improve

[1] For empirical work on this possible channel of international knowledge spillovers, see Coe and Helpman (1995), and Keller (1998).

[2] Technological considerations can also complicate the gains from trade. If knowledge spillovers are national rather than international in scope, then comparative advantage itself can become path dependent, and an "accident of history" or a temporary policy that provides one country with a temporary advantage in an R&D-intensive sector can have long-lasting implications for trade. See Grossman and Helpman (1991).

the quality of their products and production processes through contact with more advanced foreign competitors in global export markets.[3]

The flow of goods is not the only means through which technological knowledge can flow across national boundaries. An obvious alternative is foreign direct investment. A number of countries have policies that encourage or even subsidize multinational investment. Often, as has been the case in Singapore and Malaysia, these policies are deliberately biased in favor of multinational firms in "technology intensive" industries. Such preferences are based on the view that production and/or research activities undertaken by multinational affiliates within national borders confer "spillover" benefits.[4]

In an effort to submit these views to careful statistical tests, a number of scholars have undertaken empirical studies of spillover benefits from FDI. The work of Harrison and her co-authors, which has been particularly influential, has used micro-level panel data drawn from Morocco and Venezuela.[5] While these papers do not explicitly model knowledge spillovers, their presence is inferred from changes in the productivity of "indigenous" manufacturing plants that are associated with the establishment of foreign manufacturing affiliates. These studies have generally failed to find robust evidence of positive knowledge spillovers from multinational investment.[6]

Following the basic methodology developed by Aitken and Harrison (1999), Keller and Yeaple (2002) and Haskel, Periera, and Slaughter (2002) have examined FDI in advanced

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[3] For empirical work on the "learning by exporting" channel, see Bernard and Jensen (1999), Clerides, Lach, and Tybout (1998), Aw, Chen, and Roberts (1997), and MacGarvie (2002). In general, these scholars have failed to find strong evidence of "learning by exporting."

[4] For examples of studies in the managerial literature on the importance of FDI as a channel for the international diffusion of technology and management practices, see McKinsey Global Institute (1993) and Porter (1990).

[5] See Aitken and Harrison (1999) and Haddad and Harrison (1993). A number of other studies, such as Eaton and Tamura (1996), use aggregate or industry-level data to examine these and related issues.

[6] Related work by Chung, Mitchell, and Yeung (1996) casts further doubt on the role of FDI as a channel of knowledge spillovers. However, see also Blomstrom et. al. (1995), who provide evidence for a more positive view of FDI as a channel of knowledge spillovers. Smarzynska (2002) finds evidence of positive spillovers through supplier linkages in Lithuania.

industrial economies.[7] Haskel et. al. (2002) find evidence of positive knowledge spillovers from FDI into the UK, but the estimated magnitudes are rather modest – so modest that the costs of the UK's FDI promotion policy plausibly exceed the benefits. Keller and Yeaple (2002), examining the impact of FDI in the United States, find evidence of statistically and economically significant knowledge spillovers to U.S. firms.[8]

This paper also examines the role FDI plays in mediating knowledge spillovers, but it takes a completely different methodological approach. First, in contrast to the aforementioned papers, I measure the impact of FDI not only on knowledge spillovers from the investing Japanese firms to "indigenous" American firms, but also the impact of Japanese investment on knowledge spillovers from American firms to the investing Japanese firms.[9] Second, I allow the impact of FDI on knowledge spillovers to depend upon the nature of the subsidiary – and I find differences in the spillover-enhancing impact of different types of subsidiaries that are reasonably consistent with recent theoretical work on multinational firms. Third, I do not follow the earlier convention of using measured changes in TFP or other revenue-based measures to infer the presence or absence of knowledge spillovers. As is well known, conventional measures of productivity can reflect market power as well as technical efficiency.[10] When technologically more advanced foreign affiliates first enter a market, their presence may erode the market power of indigenous incumbents while -- at the same time -- introducing new production techniques and

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[7] Note that most FDI consists of investment *from* advanced industrial economies *to* other advanced industrial economies.

[8] Keller and Yeaple also examine the impact of industry-level changes on imports as an alternative channel of knowledge spillovers. In general, the efficacy of trade as a channel of knowledge spillovers seems substantially weaker than that of FDI.

[9] Iwasa and Odagiri (2002) present results on the impact of Japanese research facilities in the U.S. on the innovative activity of the investing parent firm, but they do not consider the impact of knowledge flows in the opposite direction. Their inference is also limited by the fact that they essentially rely on cross-sectional evidence. It is quite likely that firms' (unmeasured) ability to receive knowledge spillovers even in the absence of U.S. R&D facilities is correlated with their investment in U.S. R&D and product engineering subsidiaries, but the absence of a panel dimension prevents these authors from using the conventional fixed effects machinery to get around this inference problem. Those concerns notwithstanding, these authors find evidence that the presence of R&D facilities in the U.S. contributes to the research productivity of the Japanese parent. My results are consistent with this finding.

[10] This point has been made by many others, including Bernard, Eaton, Jensen, and Kortum (2003).

technologies from which these same incumbents learn. Real knowledge spillovers can take place, yet their effects can be masked in the data by changes in "appropriability conditions." Alternatively, robust demand growth in a sector of the host country could lead to higher profits, which generates higher measured TFP growth for domestic firms while, at the same time, inducing investment by foreign firms. In other words, time-varying, industry-specific demand shocks, to which both indigenous firms and foreign firms respond, could create the appearance of knowledge spillovers from FDI where none actually exist.

This paper presents an alternative empirical framework for measuring the impact of foreign direct investment on knowledge spillovers using patent citations data. I then use this framework to measure the impact of foreign direct investment in the United States by a group of Japanese manufacturing firms on knowledge flows *from* American firms *to* these investing Japanese firms and *from* the investing Japanese firms *to* American inventors. To preview my empirical results, I find evidence that foreign direct investment enhances knowledge flows in both directions.[11] I also find that the direction and degree of spillover flow is related to the characteristics of Japanese firms' U.S. subsidiaries in plausible ways. Knowledge spillovers received *by* the investing Japanese firms tend to be strongest via R&D and product development facilities. On the other hand, spillovers *from* the investing Japanese firms to indigenous American inventors appear to flow most strongly through Japanese firms' greenfield affiliates.

II. Empirical Methodology

Using Patent Citations Data to Infer Knowledge Spillovers

In describing the approach taken in this paper, I need to begin by carefully defining what I mean by the term "knowledge spillovers." When I use this term, I refer to the process by which one inventor learns from the research outcomes of others' research projects and is able to enhance her own research productivity with this knowledge without fully compensating the other

inventors for the value of this learning. A true knowledge spillover, by my definition, is something that generates further innovation. I make a conceptual distinction between knowledge spillovers *per se* and the related processes of "imitation" or "technology diffusion," though it is clear these phenomena overlap in practice.[12]

Patent documents provide a potentially rich source of information on knowledge spillovers. Every U.S. patent applicant is required to include appropriate citations to the "prior art" in his or her application. By explicitly identifying the prior art on which the inventor builds, these citations serve the important legal function of bounding the innovation protected by the patent document. Just as academic researchers are expected to explicitly acknowledge the ideas and findings of others that they use in their own research (or be open to charges of plagiarism), so patent applicants are expected to identify the prior art on which they build (or be open to charges of patent infringement).[13] By examining the citations in corporate patent documents, one can see the innovations the inventors consider to be the "technological antecedents" of their own inventions.[14]

The legal function citations play in delineating the scope of the intellectual property rights conferred by a patent creates strong incentives for inventors to get the number and nature of citations right. The cost of citing a friend in a scientific paper is minimal, so it may frequently take place even when little or no knowledge spillover has taken place. The cost of extraneous citations in a patent document can be substantial, because they narrow the scope of the patent by

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[11] This paper is certainly not the only recent study to use patent citation data to make inference about international knowledge spillovers. I discuss related work using patent citation data and explain its relationship to this paper in the next section.

[12] By restricting the focus of my paper to knowledge spillovers, I am necessarily taking a narrower approach than have some other papers in this literature, and I freely acknowledge that this narrower approach excludes much which is of economic interest.

[13] This analogy, while illustrative, is far from exact. Jaffe, Fogarty, and Banks (1998) and Fogarty, Jaffe, and Trajtenberg (2000) find that some patent citations are added by parties other than the inventor, such as patent attorneys or the patent examiner, for legal or procedural reasons that have nothing to do with "knowledge spillovers." Nevertheless, they found evidence that patent citations do indeed reflect patterns of knowledge spillovers.

[14] The points in this paragraph have been made and substantiated by Jaffe and his various co-authors, and some of the language here closely follows Jaffe, Fogarty, and Banks (1998).

explicitly placing related inventions *outside* the scope of the current patent application. As Jaffe, Trajtenberg, and Henderson (1993) put it, including extraneous citations is "leaving money on the table." Likewise, deliberately excluding appropriate citations can expose a patent applicant to patent infringement lawsuits or to sanctions by the U.S. Patent and Trademark Office.

The use of patent citations as an indicator of knowledge spillovers has been pioneered by Adam Jaffe, Manuel Trajtenberg, and Rebecca Henderson. In their 1993 paper, these three researchers used patent citations to measure the extent to which knowledge spillovers within the United States are geographically localized.[15] In a series of papers and a recent book, Jaffe and Trajtenberg have used patent citations to compare magnitudes of knowledge flows across countries and across technological fields.[16] *This* paper uses patent citations to measure the extent to which FDI aids or abets flows of knowledge across national borders.

Other recent work has used patent citation data to examine knowledge flows between domestic innovators and multinational *subsidiaries* in the United States, employing a variant of the methodology introduced in Jaffe, Trajtenberg, and Henderson (1993). Almeida (1996) compared the citation patterns in 114 patents assigned to the U.S. subsidiaries of foreign semiconductor firms to the citation patterns in an equivalent number of patents assigned to U.S. firms. Frost (2001) extended this basic methodology, comparing citations patterns in over 10,000 patents assigned to U.S. "greenfield" subsidiaries across a number of industries to a set of domestic control patents, with a focus on comparing knowledge flows between domestic entities to those from domestic entities to multinational subsidiaries. More recently, Singh (2002) has extended this approach even further, again using matched pairs of "foreign subsidiary" and

[15] Thompson and Fox-Kean (forthcoming) and Thompson (2003) have re-examined the work of Jaffe, Trajtenberg, and Henderson (1993), arguing that their measures of *intranational* localization of knowledge spillovers are too high. However, this recent work affirms the Jaffe et. al (1993) finding of *international* localization of knowledge spillovers. In the presence of barriers to the international diffusion of knowledge spillovers, multinational corporations may play an important role in mediating these knowledge flows.
[16] See Jaffe and Trajtenberg (1996, 2002).

"domestic" patents to examine citations from foreign subsidiaries to domestic entities, from domestic entities to foreign subsidiaries, and between foreign subsidiaries.

This paper differs from this earlier work in a number of respects. First, the paper links firm-level data on the expanding U.S. affiliate networks of a set of Japanese firms to data on the citations patterns contained in their U.S. patents in a panel data set. This allows me to examine the impact of changes in the U.S. "FDI presence" of individual firms on their citation patterns, controlling for other firm-level characteristics. Second, I examine patent citations not just to and from the patents of the U.S. subsidiaries of my sample firms, but also the patents of the parent companies. Belderbos (1999) shows that throughout the 1980s and 1990s, the innovative activity of Japanese firms' U.S. subsidiaries was very small compared to the R&D activity of the parent firm, and these subsidiaries accounted for only a small fraction of the parent system's total U.S. patents (on the order of 3%). Recent research by Khanna and Singh (2002) suggests that this is true more generally among OECD countries – the "internationalization" of R&D is much less advanced than the internationalization of production. These authors estimate that even in the 1990s, more than 80% of innovative activity in 30 leading countries was located in the home countries of multinationals.

The paper that comes closest to my approach is the study by MacGarvie (2003), who uses an empirical specification closely modeled on Branstetter (2000a) to measure the impact of French firms' trade flows on knowledge spillovers as measured by the patent citations in *European* patent documents. These citations differ substantively from those appearing in U.S. patent documents because essentially all of these citations are inserted into the patent documents by European patent examiners, not the inventors. However, MacGarvie finds that some of her results also hold when she conducts parallel analyses with the citations found in the U.S. patents of a subset of her sample of French firms.

Estimating the Impact of FDI on Knowledge Spillovers

Let C^J_{it} be the number of citations made by the patent applications Japanese firm i filed in year t to the cumulated stock of "indigenous" U.S.-invented patents granted as of year t.[17] I can then write the expectation of C^J_{it} as a function of several other observables

$$C^J_{it} = (N^J_{it})^{\beta_1} (N^A_t)^{\beta_2} [e^{\beta_3 FDI_{it}}][e^{\beta_4 PROX_i}] R_{it}^{\beta_5} \gamma_i \alpha_t \qquad (1)$$

C^J_{it} is a function of the number of patents Japanese firm i has taken out in the U.S. in year t (N^J_{it}), the number of potentially cited indigenous U.S. patents which exist as of year t (N^A_t), the level of firm i's "FDI presence" in the U.S. in year t (FDI_{it}), and the extent to which firm i is at a point in the technology space which is "densely populated" by other indigenous U.S. patents ($PROX_i$). Some Japanese firms might cite U.S. patents more frequently simply because they happen to be working on technologies in which a large number of indigenous U.S. inventors are active – I will need to control for this, and a method of doing so is outlined below. I also allow citations to be influenced by the firms' R&D spending (R_{it}) and by vectors of multiplicative fixed effects associated with the citing firm (γ_i) and the (application) year in which the citation takes place (α_t).

Including these fixed effects actually simplifies the equation, provided one is willing to make some assumptions. The stock of cumulated potentially citable indigenous U.S. patents will be the same for all Japanese citing firms in each year, so that the N^A_t terms are effectively absorbed into the time dummies. One may also want to assume that a firm's location in technology space relative to aggregate American inventive activity is relatively fixed over time.

[17] Inference will be based on citations to and from the U.S. patents of Japanese firms. For a discussion of why this is appropriate, and an explanation of how U.S. patents of Japanese firms are distinguished from the U.S. patents of "indigenous" firms, please see the Data Appendix. Note that the U.S. Patent and Trademark Office only makes available data on patent applications that are eventually *granted*. In this paper, patents are dated by year of application rather than year of grant, because it takes on average two years – sometimes much longer – for the patent office to grant a patent.

In that case, the effect of the *PROX* measure is absorbed into the firm fixed effects.[18] The fact that I cannot separately identify it from the firm effects is of little concern, as my primary focus is on the impact of changes in FDI on citations.

Taking the log of (1) and implementing these assumptions gives us a simple, log-linear estimation equation

$$c_{it}^{J} = \beta_0 + \beta_1 p_{it} + \beta_2 FDI_{it} + \beta_3 r_{it} + \gamma_i + \alpha_t + \varepsilon_{it} \qquad (2)$$

where c^J_{it} is the log of the number of citations made by the U.S. patent applications of Japanese firm *i* in year *t* to indigenous U.S. patents, *p* is the log of the count of U.S. patent applications of Japanese firm *i* in year *t*, FDI is one of a number of alternative measures of the FDI stock of firm *i* in year *t*, *r* is the log of R&D spending of firm *i* in year *t*, the α_t's are time dummies, and γ_i is a "firm effect," reflecting firm-specific research productivity and, perhaps, firm-specific but time invariant differences in the "connectedness" of the Japanese firm's research team to current developments in U.S. research that might affect its tendency to cite U.S. patents.

The assumption that the technological proximity of a Japanese firm to U.S. inventive activity stays fixed over a long period is a strong one. If one wishes to control directly for this "technological proximity," and allow it to vary within firms over time, the existing literature suggests a way in which this could be done.[19] The typical Japanese firm in this data set conducts R&D in a number of technological fields simultaneously. One could obtain a measure of a firm's location in "technology space" at a point in time by measuring the cumulative distribution of its R&D effort across various technological fields. Let firm *i*'s R&D program at time t be described by the vector F_{it}, where

$$F_{it} = (f_{1t}, \ldots, f_{kt}) \qquad (3)$$

[18] "Industry effects" will also be absorbed into the firm effects, because firms in my sample do not change their primary industry affiliation over time.

[19] The construction of the technological proximity coefficient used here closely follows Jaffe (1986).

and each of the k elements of F represent the firm's cumulative research resources and expertise in the kth technological area as of time t.[20] From the number of patents taken out in different technological areas over a period of time, I can infer what the distribution of R&D investment and technological expertise across different technical fields has been.

In the same way, I can also compute a vector of location in technology space for the aggregate of all U.S. inventors, treating them as though they belonged to a single giant enterprise, and denoting that F_{USt}. This suggests that $PROX_{it}$ might be measured as:

$$PROX_{it} = \frac{F_{it} F_{USt}'}{[(F_{it} F_{it}')(F_{USt} F_{USt}')]^{1/2}} \tag{4}$$

If firms are simultaneously increasing their FDI in the U.S. and moving "closer" to U.S. firms in technology space, inclusion of this variable allows me to control for the latter effect, picking up only the partial effect of an increase in FDI on spillovers as measured by citations. This imposes a more stringent statistical test of the impact of FDI on knowledge spillovers. After all, it is possible some of the movement of Japanese firms in technology space is *induced* by spillovers from American firms, which they receive through their network of subsidiaries. My specification would not attribute any of this effect to changes in Japanese firms' subsidiary networks.[21] However, if a positive effect of FDI remains even after controlling for this movement, this is stronger evidence in favor of the view that FDI is a channel of knowledge spillovers. The specification suggested by this line of thinking would be:

$$c_{it}^{J} = \beta_0 + \beta_1 p_{it} + \beta_2 FDI_{it} + \beta_3 r_{it} + \beta_4 PROX_{it} + \gamma_i + \alpha_t + \varepsilon_{it} \tag{5}$$

[20] The k different technological clusters are constructed by aggregating the hundreds of patent classes in the U.S. Patent and Trademark Office classification system into 50 distinct categories of technology. I then count the number of patents taken out by firm i in each of these 50 categories as of year t.

[21] It is also true that, to the extent that spillovers obtained through FDI networks lead to higher levels of patenting, these effects will be attributed in my specification to my patent control variable rather than to the FDI variable. I only measure the impact of changes in Japanese firms' FDI networks on the citations within their patents.

Plausibly, it will take some time for changes in a firm's FDI network in the U.S. to yield measurable changes in flows of knowledge spillovers, so in empirical estimation of (5) I will experiment with lags of various lengths.

The focus of interest will be on the coefficient β_2. Do firms that increase their levels of FDI in the United States experience an increased tendency to cite U.S. patents? A positive, significant coefficient would suggest the answer is yes. The reason why one might expect a positive coefficient is straightforward. To monitor and understand other firms' R&D can be a difficult task – particularly when the other firms' R&D activities are located on the opposite side of the Pacific Ocean. It may be facilitated enormously by the geographical proximity attained through FDI, through which the cost of accessing foreign firms' knowledge assets is reduced. This effect may occur regardless of whether the FDI by the Japanese firm takes the form of an R&D subsidiary, a greenfield factory, or the acquisition of an existing U.S. firm.[22]

However, there are also both theoretical and empirical reasons for thinking the spillover-enhancing effects of FDI differ depending on its type. The "internalization" theory of FDI suggests firms establish operations abroad in order to exploit firm-specific intangible assets not possessed by their foreign competitors.[23] The highly specialized nature of these assets – for which no well-developed external market exists – inhibits their deployment abroad through arm's-length relationships with local firms. Joint ventures may also be problematic, as the foreign firm and the local partner may not be able to agree on the value of the intangible asset (for instance, a proprietary technology) without its contents first being thoroughly disclosed. These

[22] To the extent that Japanese firms are deliberately undertaking investments in order to receive knowledge spillovers, they are "paying for them." In a strict sense, only a component of the knowledge flows generated by these kinds of investments can be considered a pure spillover – those knowledge flows which provide value in excess of the costs incurred in generating them. In practice, it is extremely difficult to compute what component of the knowledge flow generated by investment in the U.S. is a pure spillover. While I will continue to refer to these knowledge flows going back to the investing Japanese parent as spillovers, I concede that this characterization properly only applies to some subset of the flows.

[23] This basic idea is an old one, going back at least as far as Dunning (1956). Recent theoretical work formalizing this notion includes Markusen (2001), Carr, Markusen, and Maskus (2001), and Helpman, Melitz, and Yeaple (2002).

issues have been thoroughly explored in the transactions cost literature in industrial organization, and a large body of theoretical and empirical work has applied this thinking to the problem of the "optimal mode of entry" for a foreign firm.[24] Important contributions to this literature include Anderson and Gatignon (1986, 1988), Asiedu and Esfahani (2001), Blomstrom and Zejan (1991), Gomes-Casseres (1989, 1990, 1996), Javorcik and Saggi (2003), and Smarzynska (2002). This literature has established a strong connection between the degree of importance of firm-specific intangible assets and the tendency of a multinational to expand in a foreign market through the establishment of new subsidiaries that are majority-owned or wholly-owned by the foreign entrant.[25]

In line with the prediction of this literature, the vast majority of new affiliates established by Japanese manufacturing firms in the United States are majority-owned or wholly-owned by the Japanese investor.[26] This literature further implies that Japanese firms establishing new production facilities in the United States may have relatively little to learn from their less technologically advanced American counterparts. As a consequence, greenfield investments may yield little or no measurable spillover benefit to the investing Japanese firm. Of course, direct contact with greenfield foreign affiliates employing advanced technologies and management practices may be quite beneficial for indigenous American firms – thus greenfield FDI could be a significant channel of spillover to local firms.[27]

While the establishment of greenfield affiliates is arguably motivated by the desire to exploit technological advantages over domestic incumbents, acquisition FDI may be driven by

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[24] See Williamson (1979, 1985) for an influential exposition of transactions costs and the constraints they impose. I thank an anonymous referee for stressing the importance of the related literature on entry mode.

[25] In regressions not reported in the paper, I also find a positive, statistically significant relationship between numbers of greenfield affiliates and levels of R&D spending for the firms in my data set.

[26] Various data sets measuring Japanese FDI in the U.S., such as that compiled by the International Trade Administration of the U.S. Department of Commerce, indicate that the fraction of Japanese subsidiaries with substantial equity ownership by the U.S. partner is quite small. Estimates based on *Toyou Keizai* (Oriental Economist) data suggest that the fraction of total U.S. subsidiaries in which the U.S. side has more than 40% ownership is only about 4.5%

[27] Smarzynska (2002) and Blalock and Gertler (2004) report evidence of such spillovers to the local suppliers of foreign multinationals.

quite different motives. Kogut and Chang (1991, 1996), Yamawaki (1993), and Blonigen (1997) have all found evidence suggesting that Japanese acquisitions in the United States are motivated -- at least in part -- by the desire to "access" American technological strengths.[28] If this is correct, then acquisition FDI may have an impact on knowledge spillovers *to* the investing Japanese firms, but little impact on measures of spillovers *from* these firms to indigenous American inventors. In light of this, I will present results based on total FDI activity, as well as separate specifications measuring only greenfield FDI and acquisition, respectively.[29]

In addition, my data source is sufficiently detailed regarding the "business purpose" of the individual affiliates to allow me to identify affiliates whose purpose is R&D, product development, or the gathering of "market intelligence" for the parent firm.[30] Japanese multinationals have been particularly aggressive about building up research centers in the United States over the last fifteen years, and many of these centers are set up with the express purpose of tracking and learning from U.S. technological innovations. I can thus estimate the impact of these affiliates, which are deliberately focused on "spillover augmentation," separately from that of other affiliates that do not share this explicit mission.[31]

Of course, for Americans, the question of greater interest may be not what the Japanese firms have learned through their investments, but what indigenous American inventors have gained from a greater Japanese presence in the United States. I can use a variant of the approach developed in the previous paragraphs to examine this. I begin by defining a new dependent

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[28] Wesson (1998) also finds evidence for "asset-seeking" FDI.

[29] This discussion raises the question of how I should treat Japanese firms' citations of the U.S. patents of their acquired subsidiaries and, conversely, the citations by the acquired subsidiaries to the U.S. patents of the Japanese parents. It would hardly be surprising to see such citations – in both directions – increase after an acquisition. However, this would *not* be evidence of a "spillover" in the sense that unaffiliated U.S. firms are receiving and providing greater technological externalities vis-à-vis the Japanese parent firms as a consequence of an increase in the "FDI presence" of those parent firms. In recognition of this, the results presented in this paper deliberately exclude citations to and from acquired subsidiaries. I thank Jim Rauch for discussions on this point.

[30] I note that some affiliates combine R&D activity with production, distribution, or administrative activity. For purposes of this analysis, these affiliates are classified as R&D affiliates.

[31] See Kuemmerle (1997, 1999) for a review of recent developments in the establishment of R&D subsidiaries by multinationals.

variable, C^A_{it}, as the number of citations made *to* the cumulated stock of U.S. patents of Japanese firm *i* in year *t by* the universe of indigenous U.S.-invented patents applied for in year *t*. I can then consider C^A_{it} to be a function of cited firm characteristics:

$$C^A_{it} = (N^J_{it})^{\beta_1} (N^A_t)^{\beta_2} [e^{\beta_3 FDI_{it}}][e^{\beta_4 PROX_{it}}][e^{\beta_5 Age_{it}}] R_{it}^{\beta_6} \gamma_i \alpha_t \qquad (6)$$

where the variables have the same definitions as in (1), except for N^J_{it} and N^A_t. Here N^J_{it} stands, not for the number of patents applied for by Japanese firm *i* in year *t*, but rather the cumulative *stock* of patents held by Japanese firm *i* as of year *t*. This is because the number of citations a Japanese firm receives in a given year is likely to be a function of its cumulative *stock* of U.S. patents rather than the number of applications taken out in a particular year. N^A_t stands for the number of potentially citing indigenous U.S. patents generated in year t, which will be the same for all sample firms in a given year. I have also added a variable, *Age*, which is described below.

In their detailed studies of patent citations, Adam Jaffe and his co-authors have found that it takes time for the knowledge contained in patents to diffuse, such that patent citations initially increase over time. As time passes, the knowledge contained within patents becomes obsolete, so that patent citations have a tendency to *decrease* over longer lengths of time. Since I want to control for differences in the "citedness" of different Japanese firms that are driven by differences in the age distribution of their patent stocks rather than FDI, I will include for each Japanese firm in each year for which I have sufficient data a summary statistic of the age distribution of their U.S. patent stocks, denoted *Age*.[32] This additional control is not needed in specification (5), because in that specification I am looking at citations made by a "new" cohort of patents generated by a Japanese firm at a point in time to a pre-existing stock of potentially cited American inventions.

[32] Work by Jaffe and his coauthors suggests that the frequency of citation for a given patent peaks on average 4-6 years after the granting of the patent. This summary statistic measures the fraction of the U.S. patent stock for Japanese firm *i* in year *t* which is at this "prime" age.

As in equation (4), one could begin by assuming the relative technological proximity of firm *i* to aggregate American inventive activity is fixed over time, take the logs, and generate a log-linear estimating equation:

$$c_{it}^{A} = \beta_0 + \beta_1 p_{it} + \beta_2 FDI_{it} + \beta_3 r_{it} + \gamma_i + \alpha_t + \varepsilon_{it} \qquad (7)$$

where the variables have the same definitions as in (4), with the exception that p_{it} now stands for the cumulative stock of patents of firm *i* as of year *t*. Relaxing the (problematic) assumption of "fixed" technological proximity and controlling for changes in the age distribution of Japanese firms' patent stocks suggests a slightly more complicated specification:

$$c_{it}^{A} = \beta_0 + \beta_1 p_{it} + \beta_2 FDI_{it} + \beta_3 r_{it} + \beta_4 Age_{it} + \beta_5 PROX_{it} + \gamma_i + \alpha_t + \varepsilon_{it} \qquad (8)$$

Again, my interest will focus on β_2. Do U.S. inventors' citations to the patents of a Japanese firm increase as the FDI presence of that firm increases? A positive, significant β_2 would indicate this. As in earlier specifications, I measure FDI in four different ways: total cumulative counts of affiliates, cumulative counts of acquired affiliates, cumulative counts of R&D/product development facilities, and cumulative counts of greenfield affiliates. Specifications (5) and (8) are analogous, but not the same, and the estimates obtained from these specifications are not directly comparable.[33] Because (8) measures spillovers from investing Japanese firms to indigenous American inventors, the relative impact of different kinds of FDI on measured spillover flows may be quite different.

As a statistical matter, when one attempts to estimate (5) or (8), one finds there are a large number of observations for which the dependent variable is 0, and hence, the log of the dependent variable is undefined. I deal with this issue by using an econometric model especially

[33] The earlier caveat raised about spillovers back to the Japanese parent does not apply here. The knowledge which flows to American inventors as a function of the proximity of Japanese affiliates is properly regarded as a true spillover in the stricter sense of the word.

designed for count data, in which 0 is a natural outcome -- the fixed effects negative binomial model developed by Hausman, Hall, and Griliches (1984).[34]

III. Empirical Results: The Impact of FDI on International Knowledge Spillovers

Data on Japanese firms' industrial affiliation were taken from the Japan Development Bank Corporate Finance Database. Data on R&D spending were collected from various issues of the *Kaisha Shiki Ho (Japan Company Handbook)* series, published by *Toyou Keizai (Oriental Economist*) and from various issues of the *Nikkei Kaishai Jouhou (Japan Company Information*) Series, published by the *Nihon Keizai Shimposha (Japanese Economy Publishing)*. Data on FDI were taken from the *Kaigai Shinshutsu Kigyou Souran (Firm Overseas Investment)*, 1997 and 1999 editions, both published by *Toyou Keizai* (*Oriental Economist*). Patent data were obtained from the U.S. Patent and Trademark Office and the NBER Patent Citation database, which is described in Hall et. al. (2000). Further details on data sources and construction are provided in the Data Appendix. Some sample statistics are provided in Table 1. Regressions are based on an unbalanced panel data set for 189 Japanese firms for the years 1980-1997. Note that data on FDI consist of *counts* of affiliates acquired or established in the U.S. Unfortunately, the nature of the data prevent me from weighting these counts by measures of the size of the relevant affiliates.[35] This will inevitably introduce error into the measurement of an individual firm's FDI presence in the U.S., potentially leading to a downward bias in estimates of the impact of FDI on knowledge spillovers.

The electronics industry, broadly defined, is the largest single industry in the data set, accounting for roughly 33% of all firm-year observations. Other significant industries include chemicals (26%), general machinery (13%), and transportation equipment (14%). The remaining

[34] For some observations, the number of U.S. patent applications in a given year is also zero. Inclusion of a dummy variable to designate these observations did not qualitatively change the results. I thank an anonymous referee for raising this issue. In addition, I note that the conclusions of this paper do not change if one uses the fixed effects Poisson estimator with robust standard errors developed by Wooldridge (1999). As Wooldridge has shown, this estimator is consistent and standard errors are robust even in the case of substantial violations of the usual distributional assumptions imposed by Poisson or similar models.

firms come from a wide range of industries, including beverage manufacturing, steel, and textiles. Focusing on a particular industry dramatically lowers the sample size, making the kind of empirical analysis conducted in this paper difficult. However, the main results of this paper remain unchanged if one drops any of the four largest industry categories from the data set, suggesting that the kind of spillover-enhancing effects of FDI found here are not driven by a single industry.[36]

The Impact of FDI on Knowledge Spillovers ***to*** *Investing Firms*

Results for citations *by* the patents of Japanese firms *to* the stock of "indigenous" U.S. patents are given in Table 2. These can be viewed as indicators of knowledge spillovers *to* Japanese firms *from* U.S. inventors. The designation of columns as (1), (2), (3), and (4) refers to the use of four alternative measures of FDI. Column (1) counts the cumulative sum of total affiliates, regardless of the means of establishment or the purpose of the affiliate. Column (2) counts only the cumulative sum of affiliates obtained through total or partial acquisition of pre-existing U.S. firms. Column (3) counts only the cumulative sum of affiliates whose "statement of business purpose" in the FDI database explicitly identifies it as an overseas R&D facility. Column (4) counts only "greenfield" affiliates whose business purpose is unrelated to R&D. In all cases, the measures of FDI are lagged by two periods. As the table indicates, the measured impact of FDI is positive and statistically significant for total counts and for counts of R&D facilities. The impact of acquisitions is statistically indistinguishable from zero, as is the impact of "greenfield" affiliates with no connection to R&D. This pattern of results suggests that the positive results for total counts may be driven by R&D facilities.

The coefficient on the FDI term has a "semi-elasticity" interpretation. For example, the coefficient on R&D affiliates provided in the third column suggests that setting up an additional R&D lab in the U.S. leads to a roughly 2% increase in annual flows of spillovers from U.S.

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[35] For a discussion of these measurement issues, see the Data Appendix.
[36] Regression results establishing this are available from the author upon request.

inventors. While this would seem to be a rather modest effect, one has to keep in mind that some firms in my database had built up a rather extensive network of R&D and product engineering facilities in the U.S. by the end of my sample period. One firm had as many as 18 such facilities by the end of my sample period. Multiplying the estimated marginal effect of an increase in R&D affiliates by the magnitude of the increase in such affiliates that I actually observe for some firms in my sample implies cumulative effects on annual spillover flows that are quite large.[37]

Given that greenfield FDI is often motivated in the first instance by the investing firms' possession of a technological advantage over domestic incumbents, it is not surprising that this kind of FDI has little measurable impact on spillovers back to the investing Japanese firm – there may be relatively little to learn from less advanced local firms. On the other hand, the lack of impact of acquisition seems to be inconsistent with the work of Blonigen (1997), which suggested that Japanese FDI was motivated by the desire to acquire firm-specific assets. Conversations with U.S.-based managers of Japanese affiliates and a careful review of the data on individual acquisitions suggest some possible explanations.[38] First, the number of recorded acquisitions by the manufacturing firms in my data set is small relative to the number of total subsidiaries. This may lower the estimated impact of acquisition. Second, while Japanese firms' acquisition of U.S. enterprises was sometimes motivated by the desire to obtain intangible knowledge assets, interviews with expatriate Japanese managers indicates that the Japanese acquirers often found – to their frustration – that many of the key American individuals in whom these knowledge assets were quite literally "embodied," would leave the firm shortly after acquisition. Both the direct knowledge and the entrée into local technological networks through personal connections that the Japanese acquirers hoped to obtain were not difficult to purchase, but extremely hard to retain

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[37] These enhanced spillover flows may contribute to, among other things, the *quality* of Japanese inventions. In exploratory regressions, I find a positive, substantial, and statistically significant relationship between measures of "spillovers" from indigenous U.S inventions, as measured by citations to U.S. prior art, and the quality of Japanese patents, as measured by the citations they subsequently receive.

over time.[39] Third, a review of the identities of acquired firms suggests that Japanese acquirers were often more interested in obtaining a brand name or access to distribution channels than technology *per se*.[40]

There is a clear and obvious relationship between the number of citations made by a firm's cohort of patents to prior U.S. invention and the number of patents in that cohort. The coefficient on the log of the patent count is statistically indistinguishable from unity. The coefficient on the technological proximity term is of the expected sign, but it is not statistically significant at conventional levels. This result is partly a function of the fixed effects specification employed in this table. There is substantial variance *across* firms in the level of measured technological proximity, but less variation *within* firms over time, and it is clear that the measure of contemporaneous patent counts is absorbing a large fraction of the "within variance" in the dependent variable. Although not shown here to conserve space, the results of an alternative random effects specification, which exploits the cross-sectional variance, show the technological proximity variable to be statistically significant at conventional levels. The possibility of a correlation between FDI and other unmeasured firm characteristics, however, argues for a more conservative fixed effects approach.

The coefficient on R&D is small in magnitude and statistically indistinguishable from zero. As many others have found in similar data sets, I find a substantial correlation between levels of R&D spending and contemporaneous patent counts.[41] This is particularly true in a fixed effects specification, where inference is based on changes within firms over time. Once patent counts are controlled for, the inclusion of R&D spending adds little additional information, and

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[38] The discussion here was substantially improved by the comments of an anonymous referee. See the Data Appendix for further discussion of the results of interviews with U.S.-based managers of Japanese affiliates as well as discussions with managers in the parent firms.

[39] These hard lessons learned by Japanese acquirers may help explain why the dramatic appreciation of the yen in the mid-1990s was *not* accompanied by a surge of Japanese acquisition of U.S. firms, as the model in Blonigen (1997) would have predicted.

[40] Even in cases where access to technology was part of the motivation, conversations with managers suggest that Japanese acquirers were sometimes less interested in purchasing entrée into a technological network than they were in acquiring a discrete, specific product or process technology.

the multicollinearity between R&D and contemporaneous patent counts appears to generate an implausible negative coefficient on the former, although I emphasize that the coefficients are statistically indistinguishable from zero.[42] The results presented in Table 2 and subsequent tables do not qualitatively change if the R&D variable is dropped altogether.

Table 3 extends the results in Table 2 by exploring alternative lag structures for measures of R&D affiliates. As can be readily seen from the table, the estimated effects do not vary much for different lags. The estimated impact is slightly higher for the two-period and three-period lagged measures than for the contemporaneous or one-period lagged measures, but these differences are small relative to the magnitudes of the standard errors. While the robustness is reassuring, this also reflects the fact that the alternative lags are highly multicollinear.

*The Impact of FDI on Spillovers **from** Investing Firms*

Having presented some evidence on the impact of Japanese FDI on knowledge spillovers from the U.S. to Japan, I now examine its impact on knowledge spillovers in the other direction. Table 4 measures spillovers *from* Japanese firms to indigenous American inventors. Following specification (8), I use as controls measures of time-varying technological proximity, the evolving cumulated sum of U.S. patents (i.e., the patent stock) held by these investing Japanese firms, real R&D spending, and the changing age distribution of their U.S. patent stocks. To facilitate a comparison with Table 2, I use two-period lagged measures of FDI stocks in the regressions reported here.[43] Column (1) shows that (total) FDI has a positive and statistically significant effect on spillovers to American inventors. In column (2), however, the estimated coefficients suggest that the impact of acquisition FDI is statistically indistinguishable from zero. In column

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[41] See, among others, Hall, Hausman, and Griliches (1986).

[42] See the useful discussion of multicollinearity in Greene (1990). Dropping the contemporaneous patent count causes the coefficient on R&D spending to become positive, large, and statistically significant. The measured impact of R&D affiliates also rises substantially. However, the obvious relationship between the number of citations made in a patent cohort and the number of patents in that cohort requires controlling from the latter.

[43] The fixed effects negative binomial estimation routine in STATA automatically drops firms for whom the dependent variable is zero in all periods. Five of my 189 firms, which have low levels of U.S.

(3), the impact of U.S. R&D affiliates is positive and significant at conventional levels, and the estimated coefficient appears only slightly smaller in magnitude than that estimated in the "spillovers to" regressions.[44]

One might think that spillovers from investing Japanese firms to American inventors would be strongest where the Japanese firm possessed a technological advantage vis-à-vis its American competitors. In that context, the establishment of greenfield production facilities and distribution centers incorporating the parent firms' technology and management practices might be expected to have the strongest impact on spillover flows to local firms. Evidence supporting this view is provided by the results of column (4), in which I use a measure of greenfield production and distribution centers.[45] I note that the measured coefficient on this FDI term is considerably larger than on the "total count" term employed in column (1), suggesting that leakage of technology from greenfield establishments is contributing significantly to the results shown in column (1).[46]

As in earlier specifications, I include a full set of time dummies, although the coefficients are not reported to conserve space. The other control variables generally have the expected sign and are statistically significant at conventional levels.[47] The exception to this is R&D spending, which is statistically indistinguishable from zero in all regressions. Again, the strong correlation in the data between patent stocks and R&D may be partially responsible for this result.

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patenting, are never cited in any year by indigenous U.S. inventors. As a consequence, inference in the "spillovers from" regressions of Tables 4, 5, and 6 are based on a cross-section of 184 firms.

[44] The numbers of observations in the columns of Tables 2 and 4 differ slightly, because the negative binomial fixed effects estimator automatically disregards firms which register zero citations in all periods. Because the dependent variable differs in the "spillovers to" and "spillovers from" specifications, the number of dropped observations also varies. However, restricting these specifications to a common subset of observations yielded results that are qualitatively similar to those shown in the paper.

[45] Also included in this total are a handful of greenfield affiliates whose function is purely administrative – they coordinate the activities of other affiliates.

[46] When measures of greenfield affiliates and R&D affiliates are both used in the same specification, the coefficient on the former is more than twice as large as that of the latter, and hypothesis of equality can be rejected at the 10% level (p-value of .07).

[47] The technological proximity measure is consistently statistically significant in the "spillovers from" regressions. This difference with the "spillovers to" regressions may exist because the measure of patent

If firms with more valuable technology tend to be the firms that most aggressively invest in greenfield affiliates, then one might worry that the pattern of results described above is simply reflecting the fact that firms with more valuable technology tend to receive more citations to their U.S. patents, rather than providing evidence on the relative importance of greenfield establishments as a channel of knowledge spillover to U.S. firms.[48] Fortunately, the panel structure of the data and the employment practices of Japanese firms during my sample period allow me to conduct a limited test of this alternative interpretation.

Let me assume for the sake of argument that FDI confers no advantage whatsoever in terms of the propagation of knowledge spillovers in either direction. In this case, the quality of a firm's technology will be a function of the quality of its researchers and the level of its investment in R&D. Throughout my sample period, the employment of Japanese R&D personnel was governed by the "lifetime employment system." Under this system, scientists and engineers would typically enter a company directly after obtaining an undergraduate or master's degree and stay with that company throughout their careers. Interfirm labor mobility was much more limited than in the U.S., and movement of university faculty into full-time corporate research positions was rare. Under this system, the composition of a firm's internal research team evolved slowly. Over short periods of time, it would not be unreasonable to think of a firm's unmeasured "research quality" as being an attribute that would be plausibly absorbed into a firm fixed effect.

Given this reality, I can re-estimate equation (8) over subperiods of my data set. Statistical inference would be based on changes within firms over that subperiod. The quality of technology possessed by the firm prior to the onset of that subperiod could be thought of as predetermined. The evolution of unmeasured "research quality", particularly when one controls for the level of R&D effort, is plausibly slow enough that it changes little over periods on the order of five to eight years in length. Even in subperiods of that limited length, re-estimation of

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stocks used here seems to absorb less of the "within firm" variance in the dependent variable in these regressions than the measure of contemporaneous patent counts absorbed in the "spillovers to" regressions.

equation (8) generated results qualitatively similar to those shown in Table 4. These results strengthen my initial interpretation of the greenfield FDI term.

Table 5 explores the use of different lags for the "greenfield" FDI term. As in Table 3, I find that the estimated impact does not vary much. The impact increases slightly for one-period lags relative to the others, but this difference is not large relative to the magnitudes of the standard errors. According to these regression results, the estimated marginal impact of an additional U.S. affiliate on spillover flows is approximately 2-3%. Again, this appears to be a modest effect, but the cumulative impact of a large increase in a firm's U.S. "FDI presence" could be substantial. Some sample firms establish a significant number of U.S. affiliates over the course of the sample period. Multiplying this level of increase in a firm's FDI stock by my estimated marginal effects implies a potentially large increase in knowledge spillover flows from these firms.

IV. Extending the Empirical Analysis – FDI and Interfirm Technology Alliances

In addition to aggressive FDI in the U.S., many Japanese firms in my sample have also exported substantial quantities of goods to the U.S. market and engaged in numerous technology licensing relationships and even cooperative R&D alliances with U.S. firms. It would obviously be of interest to measure the impact of FDI on international flows of knowledge spillovers, controlling for these alternative categories of international contact between Japanese and U.S. firms. Unfortunately, there is little publicly available data on firm's exports to the U.S. At this point, I am unable to control simultaneously for the effects of trade.

However, much more extensive data are available for the firms in my sample on their technological cooperation, broadly defined, with U.S. firms. Despite the marked increase in interfirm technological collaboration over recent decades, the received literature in international economics dealing with the subject of knowledge spillovers has generally ignored deliberate

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[48] I thank an anonymous referee for raising this point.

attempts by firms based in different countries to foster spillovers across firm boundaries.[49] This is a potentially significant oversight, as many firms which engage in international trade and investment are also avid participants in these international interfirm technology alliances. Japanese firms, in particular, have quite aggressively pursued technological collaboration with U.S. firms over the years.

John Hagedoorn and his co-researchers at the University of Maastricht have constructed a comprehensive database of international technological cooperative activity which is based on publicly announced R&D alliances, cooperative product development efforts, and major technology licensing and cross-licensing initiatives, known as the Cooperative Agreements and Technology Indicators (CATI) database.[50] There are obvious problems with data based on contemporary press accounts, but this database is the most comprehensive publicly available data source on international technology collaboration. Using this CATI database, I have constructed, for each Japanese firm, a cumulative count of technology alliances with U.S. firms and institutions in force in that year.

Limitations in the CATI database prevent me from weighting these alliances by the amount of money invested in them. Nevertheless, these measures provide a firm-specific, time-varying measure of the intensity of a Japanese firms' collaborative R&D activity with U.S. firms and other U.S.-based research organizations. The existing literature on research alliances strongly suggests that formal R&D alliances between firms increase the level of cross-citation between participants.[51] Given that FDI and collaborative R&D activity are likely to be highly correlated, controlling for contemporaneous R&D collaboration would be an important robustness check on the impact of FDI on international knowledge spillovers. Table 5 presents results of regressions of equations (5) and (8) with this alliance measure incorporated in a manner

[49] See Gomes-Casseres (1996) for a book-length treatment of this topic.
[50] See the description of this data base in Gomes-Casseres, Jaffe, and Hagedoorn (2003).

similar to that of the counts of foreign affiliates. Column (1) presents a version of (5) with only technology alliances, while column (2) includes measures of both technology alliances and counts of foreign (R&D) affiliates. Likewise, column (3) presents a version of (8), measuring spillovers to indigenous American inventors, while incorporating a measure of technology alliances. Column (4) re-runs this specification, using counts of both greenfield affiliates and technology alliances. The coefficients on the technology alliance and FDI terms have a semi-elasticity interpretation – they yield the percentage increase in annual spillover flows that result from an additional affiliate or alliance.

As can be clearly seen from column (2), R&D affiliates continue to have a positive, statistically significant impact on international knowledge spillovers *to* investing Japanese firms. The coefficient estimate on the alliance term – .001 – appears modest, but some firms in the sample maintain several dozen alliances at a given point in time. Similar results are shown in column (4) for spillovers *from* investing Japanese firms. The measured impact of "greenfield" FDI on knowledge spillovers to American inventors remains positive and statistically significant, even with the inclusion of the alliance counts.

Conversations with Japanese R&D managers based in the United States confirmed that R&D affiliates in the U.S. are often closely involved in the selection of partners for technology alliances involving the parent firm. In fact, the site for R&D affiliates in the U.S. is often chosen in part on the basis of proximity of potential partners for R&D or product development alliances. Further exploration of the potential complementarity between R&D affiliates and technology alliances is the focus of ongoing research.

V. Conclusions and Next Steps

In this paper, I have used patent citations data to measure the importance of foreign direct investment in mediating flows of knowledge spillovers across national borders. I find evidence

[51] On this point, see, among other studies, Gomes-Casseres, Jaffe, and Hagedoorn (2003) and Mowery, Oxley, and Silverman (1996). For other studies of the impact of technology alliances on firm performance,

that FDI is a channel of knowledge spillovers, both *from* investing firms *to* indigenous firms and *from* indigenous firms *to* investing firms. Strategy experts have long asserted that investing abroad can be a useful way of tapping into foreign technology networks. My study upholds this belief with quantitative data, emphasizing the potential importance of multinational corporations as channels of knowledge spillovers between advanced economies.

In addition to establishing the basic result that foreign subsidiaries can serve as channels of knowledge spillovers, I find that the direction and degree of spillover flow is related to the characteristics of Japanese firms' U.S. subsidiaries in plausible ways. Knowledge spillovers received *by* the investing Japanese firms tend to be strongest via R&D and product development facilities. Given that these facilities are often explicitly designed to augment the ability of the investing Japanese firms to track and learn from research developments in the U.S., these results seem reasonable. On the other hand, spillovers from investing Japanese firms to indigenous American investors appear to flow most strongly through greenfield affiliates in which Japanese firms, often possessing a productivity advantage over American incumbents, are deploying superior technology and or managerial practices. These results are also plausible, particularly when viewed through the lens of recent work on the theory of the multinational firm, in which "greenfield" FDI arises due to the technological advantages possessed by foreign investors.

I also demonstrate that my basic results are robust to the inclusion of a measure of technological alliances between U.S. and Japanese firms – a potential channel of international knowledge spillovers that much of the received literature in international economics has largely ignored. I have noted how the framework presented in this paper could be extended to analyze the impact of Japanese *exports* to the United States on the ability of the exporting firms to "learn from" U.S. technological developments (the focus of the "learning by exporting" literature). While publicly available data detailing the breakdown of Japanese firms' exports by destination market are limited, the Japanese Ministry of Economy, Trade, and Industry, has conducted

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see Stuart (2000) and Branstetter and Sakakibara (2002).

surveys of Japanese multinationals which include these data for several years. I am currently seeking to obtain access to these data for the firms in my sample. In a similar fashion, the framework could be extended to measure the impact of Japanese exports to the United States (that is, *imports* of Japanese goods by American inventors) on the propensity of *U.S.* innovators to cite Japanese inventions.

Although Japanese firms are collectively the most important foreign users of the U.S. patent system, large numbers of European firms also patent and invest heavily in the U.S. The framework presented in this paper could be utilized to measure the impact of FDI or trade on knowledge spillovers between the U.S. and Europe.[52] Finally, the framework used in this paper could potentially serve as the nucleus for a more complete model of the R&D-intensive multinational firm that links information on knowledge spillovers derived from patent citations to other "innovative output" measures. Creating such a model is the focus of current research.

[52] MacGarvie (2002) presents some results along these lines.

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Table 1A Sample Statistics for Japanese Firms

Variable	Mean	St. Dev.	Min	Max	Observations
Patents	62.93	173.19	0	2,006	2,485
R&D	21,917.03	53,111.07	46	546,000	2,485
Citations to U.S.-invented patents	134.77	408.24	0	4,465	2,485
Citations by U.S.-invented patents	124.04	455.69	0	6,895	2,485
U.S. affiliates	2.49	3.66	0	24	2,485
R&D affiliates	.497	1.39	0	18	2,485
Acquired affiliates	.314	.673	0	5	2,485
Greenfield affiliates	1.69	2.55	0	19	2,485

Units of R&D figures are millions of Japanese yen.

Table 1B Firms with one or more affiliates in 1990

Total affiliates	147
R&D affiliates	50
Acquired affiliates	53
Greenfield affiliates	120

Table 1C Distribution of Firm-Year Observations Across Major Industry Groups

Electronics	33%
Chemicals and Pharmaceuticals	26%
Transportation Equipment	14%
General Machinery	13%
Other Industries	14%

Table 2 Spillovers *to* Japanese Firms

	(1) Total	(2) Acquisition	(3) R&D	(4) Greenfield
U.S. FDI (total) lagged 2 periods	**.007** **(.002)**			
U.S. FDI (acquisition) lagged 2 periods		**- .007** **(.010)**		
U.S. FDI (R&D) lagged 2 periods			**.016** **(.003)**	
U.S. FDI (greenfield) lagged 2 periods				**.003** **(.003)**
Proximity	.188 (.116)	.192 (.117)	.166 (.116)	.197 (.116)
log U.S. patents	.996 (.012)	1.01 (.012)	.989 (.012)	1.00 (.011)
log R&D	-.020 (.011)	-.020 (.011)	-.013 (.011)	-.020 (.011)
Log Likelihood	-7,234.10	-7,242.17	-7,227.64	-7,242.03
Firms	189	189	189	189
Observations	2,389	2,389	2,389	2,389

All columns present results of fixed effects negative binomial regressions. Standard errors are given in parentheses.
(1) Indicates FDI measured as cumulative counts of all U.S. subsidiaries.
(2) Indicates FDI measured as cumulative counts of acquired U.S. subsidiaries.
(3) Indicates FDI measured as cumulative counts of U.S. R&D/product development facilities.
(4) Indicates FDI measured as cumulative counts of greenfield non-R&D affiliates.
All specifications include a full set of year dummies.

Table 3 Spillovers *to* Japanese Firms

	(1)	*(2)*	*(3)*	*(4)*
U.S. FDI (R&D) (Contemporaneous)	**.014** **(.003)**			
1-pd. Lagged FDI (R&D)		**.014** **(.003)**		
2-pd. Lagged FDI (R&D)			**.016** **(.003)**	
3-pd Lagged FDI (R&D)				**.016** **(.003)**
Proximity	.176 (.110)	.179 (.110)	.166 (.116)	.170 (.127)
log U.S. patents	.994 (.011)	.993 (.011)	.989 (.012)	.990 (.012)
log R&D	-.020 (.011)	-.019 (.011)	-.013 (.011)	-.018 (.011)
Log Likelihood	-7,566.25	-7,544.57	-7,227.64	-6,897.76
Firms	189	189	189	189
Observations	2,485	2,478	2,389	2,296

Columns (1)-(4) present the results of negative binomial fixed effects regressions with various lags of counts of R&D affiliates. Standard errors are given in parentheses. The use of lagged terms reduces the number of observations in columns (2)-(4). All specifications include a full set of year dummies.

Table 4 Spillovers *from* Japanese Firms

	(1) Total	(2) Acquisition	(3) R&D	(4) Greenfield
U.S. FDI (total)	**.014**			
	(.002)			
U.S. FDI (acquisition)		**.008**		
		(.012)		
U.S. FDI (R&D)			**.015**	
			(.004)	
U.S. FDI (greenfield)				**.024**
				(.004)
Proximity	.609	.624	.587	.646
	(.151)	(.152)	(.152)	(.150)
log U.S. patents	.712	.729	.717	.719
	(.023)	(.023)	(.023)	(.023)
Age	.790	.770	.799	.757
	(.073)	(.074)	(.074)	(.073)
log R&D	-.014	-.011	-.009	-.011
	(.014)	(.015)	(.014)	(.014)
Log Likelihood	-6,913.94	-6,932.15	-6,924.78	-6,915.90
Firms	184	184	184	184
Observations	2,362	2,362	2,362	2,362

All columns present results of fixed effects negative binomial regressions. Standard errors are given in parentheses.
(1) Indicates FDI measured as cumulative counts of all U.S. subsidiaries.
(2) Indicates FDI measured as cumulative counts of acquired U.S. subsidiaries.
(3) Indicates FDI measured as cumulative counts of U.S. R&D/product development facilities.
(4) Indicates FDI measured as cumulative counts of U.S. greenfield non-R&D affiliates.
All specifications include a full set of year dummies. Five firms in the sample are automatically dropped because they receive zero citations from indigenous American inventors in all years. This reduces the cross-section from 189 firms to 184 firms.

Table 5 Spillovers *from* Japanese Firms

	(1)	(2)	(3)	(4)
U.S. FDI (Contemporaneous)	**.022**			
	(.004)			
1-pd. Lagged FDI		**.026**		
		(.004)		
2-pd. Lagged FDI			**.024**	
			(.004)	
3-pd. Lagged FDI				**.022**
				(.004)
Proximity	.566	.576	.646	.705
	(.143)	(.143)	(.150)	(.159)
log U.S. patents	.725	.728	.719	.712
	(.023)	(.023)	(.023)	(.023)
Age	.760	.760	.757	.734
	(.072)	(.072)	(.073)	(.074)
log R&D	-.004	-.010	-.011	-.017
	(.014)	(.014)	(.014)	(.014)
Log Likelihood	-7,215.35	-7,189.69	-6,915.90	-6,608.47
Firms	184	184	184	184
Observations	2,458	2,451	2,362	2,269

Columns (1)-(4) present the results of negative binomial fixed effects regressions with various lags of counts of greenfield affiliates. Standard errors are given in parentheses. The use of lagged terms reduces the number of observations in column (2)-(4). All specifications include a full set of year dummies.

Table 6 Impact of Technology Alliances on Knowledge Spillovers

	(1)	(2)	(3)	(4)
	Spillovers to Japanese firms		Spillovers from Japanese firms	
Technology alliances (counts)	**.002**	**.001**	**.005**	**.004**
	(.0005)	**(.0006)**	**(.0006)**	**(.0007)**
U.S. FDI (R&D affiliates)		**.011**		
		(.003)		
U.S. FDI (greenfield affiliates)				**.015**
				(.005)
Proximity	.332	.250	.713	.716
	(.119)	(.121)	(.149)	(.150)
log U.S. patents (annual flow)	.994	.990		
	(.012)	(.012)		
log U.S. patents (stock)			.719	.715
			(.023)	(.023)
Age			.790	.778
			(.073)	(.073)
log R&D	-.020	-.018	-.011	-.011
	(.011)	(.011)	(.014)	(.014)
Log Likelihood	-7,233.01	-7,227.71	-6,908.78	-6,903.70
Firms	189	189	184	184
Observations	2,389	2,389	2,362	2,362

All columns report results from a fixed effects negative binomial specification. Standard errors are given in parentheses. Columns (1) and (2) incorporate measures of technology alliances into versions of specification (5), measuring spillovers to investing Japanese firms. Columns (3) and (4) incorporate measures of technology alliances into versions of specification (8), measuring spillovers from investing Japanese firms to indigenous firms. All specifications include a full set of year dummies.

Data Appendix

In order to keep the text of the paper reasonably short, I have omitted a number of details about data sources, data construction, and the empirical methodology. This Data Appendix describes the basic data sources in greater detail. It also reviews some of the key learnings from interviews conducted by the author with managers of Japanese firms investing in the United States.

Data Sources and Measurement Issues

The primary source of data on the U.S. FDI of Japanese firms is *Kaigai Shinshutsu Kigyou Souran (Firm Overseas Investment)*, published in Japanese by the *Toyou Keizai (Oriental Economist)* publishing company of Japan. This source provides detailed data on FDI activity at the firm level. Japanese FDI in the U.S. (as opposed to FDI from other significant source countries) is of particular interest, because it changed so dramatically over the course of the 1980s and 1990s. A large number of Japanese multinationals shifted from a position of very limited direct investment (or no direct investment) in the U.S. at the beginning of my sample period to a position of "substantial" direct investment by the end. This large change may help identify the parameters of interest. The unit of analysis in the *Kaigai Shinshutsu Kigyou Souran* data source is that of the enterprise or business. In principle, one might want to weight counts of acquired or established enterprises by the size of these enterprises. In practice that is difficult, as the data on employment or sales of U.S. affiliates of Japanese firms are not recorded in this source with consistency.

Data on parent firms' industry affiliation were taken from the Japan Development Bank Corporate Finance database. Data on the R&D spending of Japanese firms were taken primarily from survey data published (in Japanese) in the *Kaisha Shiki Ho* (*Japan Company Handbook*) and *Nikkei Kaisha Jouhou* (*Japan Company Information*) quarterly series of reports on Japanese publicly traded firms. Data on the U.S. patenting of Japanese firms were taken from the NBER Patent Citation Database, described in Hall, Jaffe, and Trajtenberg (2001), which, in turn, draws upon the electronic records of the U.S. Patent and Trademark Office. The years of my sample period are 1980 through 1997, although only a handful of Japanese firms report R&D spending in 1980.[53]

[53] Data are available on the U.S. patents of Japanese firms granted as late as 1999. However, because of the (average) two-year lag between patent application and patent grant, only a fraction of the patents

This study uses data on the U.S. patents of 189 Japanese firms and the universe of "American" inventors. All U.S. patents assigned to these Japanese firms or their foreign subsidiaries were considered to be "Japanese," even if the patented invention was created in the United States. The set of "indigenous" American patents was defined as all U.S. patents, not assigned to the Japanese firms in my sample or their subsidiaries, which list a U.S. address for the first inventor. "American" inventors working for non-U.S. multinationals are considered "American" for the purposes of this study.[54] Conversely, foreign inventors (that is, inventors with a non-U.S. address) working for U.S. firms are not counted as part of the body of "American" inventors. This is intentional, in that the purpose of this study is to examine the impact of the geographic proximity conferred by FDI *in the U.S.* on spillovers to and from inventive activity *physically located in that country*. It is also worth noting that the vast majority of R&D activity conducted by U.S. multinationals is undertaken within the boundaries of the United States.

For this study, there was really no alternative to the use of data on Japanese firms' U.S. patents, as Japanese patent law does not require inventors to disclose citations to the prior art. Nevertheless, interviews with leading Japanese firm executives and empirical studies such as Branstetter and Sakakibara (1998) and Sakakibara and Branstetter (2001) suggest that Japanese firms seek to patent all their valuable ideas in both the U.S. and Japan, so that trends in their U.S. patents should be reflective of their total innovative activity. Note that Japanese firms are by far the most important foreign users of the U.S. patent system, accounting for roughly one quarter of all patents granted by the U.S. during the latter 1980s and early 1990s.

Qualitative Evidence from Practitioner Interviews

In order to obtain a "practitioner's perspective" on the extent to which FDI functions as a channel of knowledge spillovers, I conducted a series of interviews with Japanese industry observers, government officials at the Ministry of Economy, Trade and Industry (the government agency charged with overseeing the foreign direct investment activities of Japanese firms, formerly known as MITI), Japanese managers of

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applied for in the years 1997-1999 would have been granted by 1999. As a consequence of this truncation problem, the results reported in this paper are based on data through 1997.

[54] To be more precise, "American" inventors who produce patents assigned to the investing Japanese parent company are always considered to be "Japanese." Americans working for "native" enterprises that are subsequently acquired by Japanese firms are effectively removed from the analysis undertaken in this paper, because all of the patents produced by these firms are excluded from the regressions reported herein.

high-tech corporations, and Japanese managers of affiliates based in the United States. These interviews were conducted in the fall of 2000.

All interviewees agreed with the view that foreign direct investment in the United States facilitates knowledge spillovers, as I have defined that term in this paper. It was also clear from discussions with the managers of Japanese research facilities in the U.S. that a major priority of at least some of these facilities is "tracking" U.S. technological developments in universities and among the leading firms.[55] However, the interviewees also suggested that useful technology is sometimes absorbed by U.S. affiliates that are not "pure" research organizations. They also agreed with the view that Japanese technology "leaks out" through their U.S. subsidiaries. In fact, this "leakage" is sometimes deliberately *fostered* by the Japanese firms. One example of this is attempts by Japanese firms to educate their local suppliers concerning Japanese technology and management practices.

Japanese firms make an effort to maintain a reasonably high degree of communication and coordination between their central R&D operations and their U.S. R&D facilities. One manager of such a facility claimed to communicate on a *daily* basis with the parent company and to physically travel to Japan several times per year for conferences with central R&D managers. The same manager claimed that his firm sends large numbers of engineers from the Japanese parent company to U.S. facilities each year on short term visits, essentially to promote knowledge spillovers. As mentioned in the text, conversations with managers of Japanese firms' U.S. R&D facilities indicated a strong connection between these facilities and formal research alliances between the parent and U.S. firms. The location of U.S. R&D facilities was often chosen because of the proximity of potential American research partners. Engineers dispatched to U.S. R&D facilities often play an important role in managing interfirm research collaboration with American firms and universities.

Finally, as mentioned in the text, the interviewed managers noted the difficulty of absorbing the knowledge assets contained in firms they had acquired in the U.S., particularly entrepreneurial high-tech firms in areas like Silicon Valley. In many instances, the most valuable individuals in the acquired firm, in

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[55] A particularly effective method of "tapping into" U.S. technological developments is to hire engineers, technology managers, and research scientists away from leading American firms and universities. This is a high priority for many Japanese research facilities, but also a continuing challenge. Many traditional Japanese labor market practices, such as lifetime employment, seniority based wages, slow promotion

terms of their engineering skill and personal connections to the local technology network, tended to leave the firm shortly after acquisition, leaving the Japanese acquirers, in effect, holding an expensive shell. While many firms were still willing to consider such acquisitions in the late 1990s, they were, in their own estimation, taking a much more cautious approach to this than was the case in the late 1980s.

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tracks, and consensus-style decisionmaking, do not fit well with the more entrepreneurial culture of such U.S. technology centers as Silicon Valley.