Innovation, Social Connections, and the Boundary of the Firm*

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Abstract

In this paper, we propose and provide evidence that the existence of prior social connections between managers or board members of supplier (upstream) and customer (downstream) firms can encourage relation-specific investment and foster innovation by the upstream firms. We show that innovative activities by suppliers increase with the existence and strength of their social connections with customers. To establish causality, we exploit connection breaches due to manager/director retirements or deaths in the (much larger) customer firms and find that innovative activities drop for those suppliers connected to these customer members. Our work sheds light on how social connections can shape the boundary of the firm by mitigating contractual incompleteness and transactions costs, thereby allowing the upstream firms to remain as standalone entities instead of being vertically integrated with the downstream firms.

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1. Introduction

In manufacturing industries, many firms rely on their parts or materials suppliers for innovations that improve their products or processes. These suppliers often remain as standalone firms presumably because of the costs of complete (vertical) integration. For example, market-based incentives for innovators in the supplier firm could become less effective when the upstream supplier is integrated with the downstream firm. Moreover, post-integration, the corporate "headquarters" might expropriate the innovation done by a division, since the resulting patent would legally belong to the firm rather than the innovator. In smaller upstream firms, similar problems could be more easily resolved through the provision of equity ownership to the innovators, but this is much less likely to be effective if that firm becomes the division of a larger firm. As a result, the supplier's incentives to innovate would be dampened if it is merged with the downstream firm.[1]

The lack of integration, however, has some well-known costs of its own. When the relationship is "arms-length", the exchange relationship between the upstream and downstream firms has to be governed by a contract. However, the very nature of innovation is that it is difficult to specify the deliverables ex ante, so that contracts are likely to be incomplete. Such contractual incompleteness leads to opportunism and hold-up problems, which very likely lead to underinvestment, e.g. in R&D expenses, by the upstream firm supplying the innovative output. Since such relation-specific investment benefits the downstream firm as well, the inability of the later to commit not to behave opportunistically is a cost of non-integration. In an integrated firm, the "headquarters" makes the investment decision, and such problems can be avoided.

[1] For theoretical argument that the internal organization of the firm affects innovation, see Holmström (1989). For empirical evidence that firm boundary matters for innovative activity, see Seru (2014).

A question that naturally arises is whether there exist mechanisms that mitigate opportunism when the upstream firm remains independent. One such mechanism that has been emphasized in the literature is repeated interactions.[2] When parties interact repeatedly over time, implicit contracts that mitigate opportunistic behavior can be sustained by threats of non-cooperation, which are equilibrium outcomes in the one-stage version of the repeated game.[3] However, such cooperation only emerges if the relationship lasts for long periods. One database that provides information on upstream/downstream relationships and has been widely explored in the finance literature is derived from the Segment Files in Compustat. According to SFAS No. 131, firms are required to disclose the identities of customers that account for more than 10% of their total sales. This makes it possible to match suppliers with their principal customers. In this database, the average duration of a relationship between a supplier and a customer firm is only about 3 to 4 years (Fee, Hadlock, and Thomas, 2006; Banerjee, Dasgupta, and Kim, 2008) – not long enough, it would seem, to suggest that implicit agreements are sustainable.[4]

In this paper, we propose, and provide evidence for, an alternative mechanism that can sustain implicit agreements and mitigate opportunism, thereby encouraging relation-specific investment and more innovation by the upstream firms. This mechanism is the existence of prior social connections between senior managers and board members of upstream firms and downstream firms. Following prior literature[5], we argue that such social connections are more likely if the individuals were in the same educational institution or workplace at the same time.

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[2] Holmström and Roberts (1998) discuss that the pattern of relations between Japanese manufacturing firms and their suppliers is characterized by long-term, close relations that substitute for ownership stake in protecting specific assets.

[3] See Bull (1987), Baker et al. (1994), Baker et al. (2002), Schmidt and Schnitzer (1995), and Pearce and Stacchetti (1998), among many others.

[4] This would be true even ignoring the so-called "last period problem". For cooperation to be sustainable, the one-time profit from deviation must not exceed the lost discounted future profit from cooperation breaking down. If the relationships typically do not last long, this is unlikely to hold.

[5] A short and incomplete list includes Cohen, Frazzini, and Malloy (2008; 2010), Engelberg, Gao, and Parsons (2012), Fracassi and Tate (2012), and Ishii and Xuan (2014).

To distinguish connections that are pre-existing from those formed during the period over which the business relationship between the supplier and the customer continues, we require that such overlap occurs at least five years prior to the year in which the customer-supplier relationship is observed in the data. We do so not because relationships formed during the course of the business relationship are unimportant, but rather, to allow for variation in social connections across supplier-customer pairs, since all suppliers in business relationships with customers are a priori equally likely to develop connections.[6] Moreover, contemporaneous connections could be subject to reverse causality concerns – for example, performance of business relationships could lead to the formation of social connections (Engelberg, Gao and Parsons (2012)).

Social connections are expected to foster innovation by suppliers for several reasons. First, individuals who are socially connected are likely to interact repeatedly in many different spheres, and even outside the current business relationship. The value of cooperation through honoring implicit contracts is thus likely to be much more important than if these same individuals were to interact only during the course of the current business relationship.[7] Second, social networks are valuable to individuals, and connected individuals are more likely to have common third parties in their respective networks than unconnected individuals. Thus, individuals who breach implicit contracts with connected individuals are more likely to suffer reputational damage in their own social networks and face ostracism than if such breaches were to occur vis-à-vis unconnected individuals.[8] Finally, especially relevant in the our context of

[6] Our conclusions remain if we rely only on educational connections, which are typically formed much earlier.

[7] This notion of cooperation through repeated interaction comes very close to that of "trust" among socially connected individuals. One criticism of the "fully-rational" framework is that it cannot account for real-world behavioral patterns such as the evolution of trust. In the equilibrium path, trust is either always maintained or never formed. To generate the evolution of trust, models of bounded rationality have been proposed.

[8] In two-person experimental trust games played by Harvard undergraduates, Glaeser et al. (2000) find that the degree of social connections between players -- the number of common friends and the duration of acquaintance -- predicts trust and trustworthiness. Karlan et al. (2009) model the idea that indirect links between borrower and lender (for example) can determine the level of trust or social capital that would be breached and thus determine the

relatively smaller supplier firms and larger customer firms, access to key decision makers in the customer firm becomes much easier for the supplier firm if there are pre-existing social connections. This is likely to facilitate information flow and also mitigate hold-up.[9]

In contrast to these arguments as to why social connections between suppliers and customers may foster supplier innovation, an alternative hypothesis is that social connections can encourage favoritism and result in "sweetheart deals" for connected suppliers, who are not necessarily the best innovators. Ishii and Xuan (2014) study merger outcomes and find that the extent of cross-firm social connection between directors and senior executives at the acquiring and the target firms (a) has a significantly negative effect on the abnormal returns to the acquirer and to the combined entity upon merger announcement (b) a positive effect on the likelihood of target firm CEO and board member retention in the combined entity, and (c) a positive effect on the acquisitions being subsequently divested for performance-related reasons.

We test these hypotheses using a large sample of supplier-customer pairs derived from the Compustat segment files. Consistent with the notion that pre-existing social connections foster supplier innovation, we find that firms in Compustat that disclose the presence of principal customers do more R&D when social connections exist between supplier and customer managers and board members. Moreover, supplier R&D is more sensitive to customer R&D in the presence of such social connections. These results hold even when we include supplier firm-fixed effects or supplier-customer pair fixed effects. We also find that suppliers are more likely to produce innovations that cite the customer's patent portfolio when the pairs are connected,

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amount of lending that is possible. They show that networks with high "closure", where connected individuals share many common friends, are more useful when parties exchange more valuable assets (or there is more information asymmetry), whereas those with low closure are more useful when flow of information is important. See also Allen and Babus (2009), who point out the monitoring effect of social networks.

[9] For example, a divisional manager or a procurement manager in the customer firm who deals with the supplier might be myopic and care only about keeping procurement costs low, which might discourage the supplier from making costly investment in R&D. Access to a senior manager at corporate headquarters who is more likely to take the perspective of long-term firm value maximization might remedy this type of hold-up.

suggesting that connections foster innovation more relevant for the customer. Moreover, connected suppliers are more innovative (as measured by the number of patents filed) and produce higher quality innovation (as measured by the number of citations the patents receive from other firms filing patents) when they are connected to principal customers. Again, all these results hold when we include firm or pair fixed effects.[10] Results also hold when we consider the number of connections, rather than a connection indicator variable.

The fact that our results hold when we include firm or relationship-pair fixed effects rules out an alternative explanation that the existence of connections captures other firm characteristics that could be correlated with the supplier's innovative potential vis-à-vis its customer. Essentially, these results imply that when the connection dummy switches from "on" to "off" (or conversely) during the course of a relationship as a result of departures (arrivals) of managers or board members of either firm, R&D and innovation go down (up). While this is consistent with our hypothesis, there could be concern that managerial or board member turnover in the smaller supplier firms could be in anticipation of future order flows from the customer, which in turn affects the R&D and innovation that the supplier engages in. In contrast, since the customer firms are much larger firms in our sample, it appears highly unlikely that the only function of customer senior managers or board members is to manage the relationship with a connected supplier. Thus, retirements of customer managers or board members are unlikely to be caused by anticipated changes in the business with connected suppliers. We examine the effect of retirements and deaths of customer managers and board members on the R&D and innovation of suppliers with whom these individuals are connected, compared to those of suppliers with whom the same individuals are not connected. Consistent with the notion that connections foster supplier innovation, we find that after such retirements and deaths, supplier R&D, the sensitivity

[10] We only report results for pair-fixed effects – those with firm-fixed effects are available from the authors.

of supplier R&D to customer R&D, supplier patent filings and patent citations all drop for those connected to these customer members, but not for those unconnected to the same members.[11]

Our results may potentially resolve a puzzle that has emerged in the literature on the finance and governance of firms in vertical relationships. Given that the standalone suppliers are small innovative firms and the customer firms are likely to benefit from such innovation, it might appear natural that issues of holdup and contractual incompleteness could be better resolved via some form of *partial integration*, such as equity ownership or board representation by the downstream customer firms in their upstream suppliers. However, several authors have documented that this is extremely uncommon in the customer-supplier data compiled from Compustat – in fact, less than 3 percent of the relationships involve equity ownership by the customer, and a similar percentage involve board representation.[12] Close to 85% of customer-supplier relationships in our sample involve at least one social connection. Thus, consistent with our arguments, it would appear that social connections effectively mitigate problems of contractual incompleteness, rendering partial integration unnecessary.[13,14]

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[11] Supplier innovation could drop in anticipation of a decline in business from the customer when a connected customer member departs from the firm. To rule out this possibility, we verify that our results hold when (i) the relationship lasts for at least three more years and the customer continues to be reported as contributing to more than 10% of sales, and (ii) the supplier belongs to the above-median group of suppliers in terms of citations of customer patents, suggesting a productive relationship that is expected to continue.

[12] Fee, Hadlock, and Thomas (2006) reports that only 3.31% of customers hold a 5% or above equity stake at their suppliers for a sample of supplier-customer relationships identified from Compustat Segment files from 1988 to 2001. Also using Segment files, Minnick and Raman (2014) finds that 4% (5%) of firms have directors/managers from customers (suppliers). Similarly, Dass et al. (2014) finds that only 1.2% of firms include an actual supplier or customer on the board when they identify actual supplier-customer relationships based on Segment files.

[13] Partial integration is likely to have its own costs. For example, a principal customer that holds equity stake or a board seat in the supplier may exert too much influence, which might impair the supplier's relationships with other (principal) customers.

[14] One caveat is that the customer-supplier data that is compiled from the Compustat Segment Files only identifies customers that are important for the suppliers, and not necessarily suppliers that are important for the customers. It is possible that partial integration with smaller suppliers is not observed as it is too costly to do so for numerous small suppliers, and social connections are an effective and less costly mechanism to mitigate problems associated with contractual incompleteness. It therefore remains an unanswered question whether firms rely on the same mechanism vis-à-vis important suppliers, or whether partial integration is more likely to be observed. We further discuss this issue in the concluding section.

Our paper is related to several strands of literature. While there has been a surge in recent interest on factors that spur corporate innovation,[15] with a few exceptions, the important issue of supplier innovation in vertical relationships has remained largely unaddressed. Using mutual fund flow-driven price pressure to identify exogenous negative shocks to stock prices, Williams and Xiao (2014) find that suppliers decrease subsequent R&D and produce fewer patents following declines in their key customers' market values. Chu, Tian, and Wang (2014) demonstrate that knowledge spillover from customer to supplier is a key determinant of supplier innovation. To do so, they examine customer relocation decisions and show that, in a difference-in-difference setting, the quality and quantity of supplier innovation drop (increase) after customers relocate their headquarters further (nearer) the supplier. Our paper also contributes to the growing literature on the economics and finance of the supply chain, based largely on firms' disclosure of the names of important customers in accordance with SFAS No. 131 that also forms the basis of this study.[16] Most importantly, our paper contributes to the literature on the boundary of the firm based on transactions cost economics (see for example, Suri (2014)), by providing evidence that social connections between contracting parties can mitigate contractual incompleteness and shape firm boundary.

[15] See, for example, Acharya, Baghai, and Subramanian (2009), Acharya and Subramanian (2009), Acharya, Subramanian and Baghai (2013), Aghion, Van Reenen, and Zingales (2013), Amore, Schneider, and Zaldokas (2012), Atanassov (2012), Bena and Li (2011), Bernstein (2012), Bradley, Kim, and Tian (2013), Brav, Jiang, and Tian (2014), Chang, Fu, Low, and Zhang (2012), Chava, Oettl, Subramanian and Subramanian (2013), Chemmanur, Tian, and Loutskina (2013), Cornaggia , Mao, Tian, and Wolfe (2015), Fang, Tian, and Tice (2013), Ferreira, Manso, and Silva (2012), Fulghieri and Sevilir (2009), He and Tian (2013), Hirshleifer, Teoh, and Low (2012), Hsu, Tian, and Xu (2014), Lerner, Sorensen, and Stromberg, (2011), Manso (2011), Nanda and Rhodes-Kropf (2012), Sevilir and Tian (2013), Tian and Wang (2014).

[16] A short and incomplete list of studies on economics and finance of the supply chain using Segment files include Banerjee, Dasgupta, and Kim (2008), Fee, Hadlock, and Thomas (2006), Kale and Shahrur (2007), Hertzel, Li, Officer, and Rodgers (2008), and Brown, Fee and, Thomas (2009).

The rest of the paper is organized as follows. Section 2 describes sample and variable construction and reports the summary statistics. Section 3 discusses the empirical strategy and results. We conclude in Section 4.

2. Sample Construction and Summary Statistics

2.1 Sample Construction

Our sample construction starts from Compustat Segment files and covers firm years from 2000 to 2012[17]. According to SFAS No. 131, firms are required to disclose the identities of customers that account for more than 10% of their total sales, though some firms voluntarily report customers below this threshold. We treat all disclosed customers as principal customers but exclude government buyers or generic customers reported as “Foreign Sales”, “Major Customer”, “Vendor”, or “Not Reported”.

One complexity in segment disclosures is that only customer names or name abbreviations are reported. In order to get customers’ financial and management information, we match the disclosed customer names or name abbreviations to CRSP head files following the procedure adopted in Fee, Hadlock, and Thomas (2006). Specifically, we first use phonetic matching algorithms based on the spelling distances to identify several CRSP companies as potential matches for each disclosed customer. Then we manually check and confirm each match based on corporate names, industry classification, additional information from Corporate Library database, and news releases from Factiva. In case that no matches are found, we search Bloomberg Businessweek to decide whether the disclosed customer is one subsidiary of any public company and assign the parent company’s CRSP identifications to the disclosed customer

[17] We start our sample periods from 2000 because the social network information in BoardEx is incomplete before 2000. See Engelberg, Gao, and Parsons (2013) for a detailed description of the BoardEx data.

if it is. In the whole matching process, we tend to be careful and conservative to ensure that our matched CRSP firms are in fact the customers disclosed by the suppliers. The above matching procedures result in a total of 5,212 unique supplier-customer pairs (1,984 unique suppliers and 1,098 unique customers) and 17,261 pair-year observations.

The social network information is obtained from BoardEx, which provides detailed biographic information for directors as well as senior managers. We match each firm in our supplier-customer sample to BoardEx following the procedures used in Engelberg, Gao, and Parsons (2013). The match is mainly based on Cusip and CIK[18]. When the two identifiers are not available from BoardEx, we match the two databases based on company names using the string matching scheme similar to the one used when we match segment files to the CRSP universe. To maintain accuracy, we also visually investigate each match and ensure that the two firms are referring to the same one. Applying the matching procedure to BoardEx leaves us with 4,366 unique supplier-customer pairs and 14,844 pair-year observations that both parties could be identified in BoardEx.

Finally, we require both supplier/customer firms to have relevant financial information to be included in our sample. Firm-level characteristics are obtained from the Compustat/CRSP merged database. Following the previous literature, we further exclude supplier or customers that are in utility industry (SIC codes 4900-4999) and financial industry (SIC codes 6000-6999) since these firms are highly regulated. The final sample consists of 12,892 pair-year observations with 1,627 unique suppliers and 796 unique customers.

[18] For firms covered by the BoardEx database between 2000 and 2012, about 86% of them have CIK and 64% have Cusip.

2.2 Innovation Measures

Because we are interested in how social connections along the supply chain affect suppliers' engagement in innovative activities, especially those specific to key customers, we follow the literature and construct two sets of innovativeness proxies, namely innovation input measured by R&D expenses (and R&D sensitivity), and innovation output measured by patent-based measures (cross citations, number of patents, and citations per patent).

R&D expenses have been widely used in the literature as a proxy for innovation input and relation-specific investment (Allen and Phillips, 2000; Griffith, Redding, and Reenen, 2004). Specifically, we scale the research and development expenses by the firm's book value of total assets and treat the ratio as zero if R&D is missing. A limitation of the R&D measure is that it is only firm-level proxy and may not capture the level of innovation input for a specific business relationship. To overcome this, we also look at the sensitivity of R&D investments between the supplier and customer.

The second set of innovativeness proxies we use is constructed based on a firm's patenting activities. The patent data is kindly provided by Kogan, Papanikolaou, Seru, and Stoffman (2012), who download the entire history of U.S. patent documents from Google Patents and carefully match them to CRSP firm identifiers. The dataset contains the entire universe of patents and citations from 1926 to 2010.[19] Several variables are constructed using the data. First, we alternatively measure RSI by identifying whether the supplier has produced any patent that cites the existing patent portfolio of its customer, i.e. cross citations. The presence of cross citation activity along the supply chain indicates that suppliers tailor their research and development based on the customer firms' technology and that knowledge flows are transferring between the two firms (Jaffe, Trajtenberg, and Fogarty, 2000). Besides this pair-level measure,

[19] The data can be found at https://iu.app.box.com/patents.

we also follow the existing literature and develop two proxies for firm-wide innovation outcomes. To measure the quantity of innovation output, we count the number of patents that suppliers file to US Patent and Trademark Office and that are eventually granted at the application year. We choose application year instead of grant year because application year is more relevant to when firms develop the patents (Hall, Jaffe, and Trajtenberg, 2001). To measure the quality of innovation output, we calculate the number of non-self-citations each patent receives in subsequent years.

We follow the innovation literature and adjust the patent-based measures to deal with the truncation problem associated with the patent data. The first issue is that we can only observe the patents that are finally granted. Therefore, towards the end of our sample period, firms whose patents are still in process do not show to have patents application in the dataset. We follow Hall et al. (2001) and use the empirical application-grant time gap distribution to adjust the truncation bias in patent counts. The second truncation problem is related to patent citations. A patent would keep receiving citations over a long period of time but we can only observe patent citations until 2010. Following Hall et al. (2001), we estimate the citation-lag distribution and adjust the citation data accordingly.

2.3 Social Connections Measures

BoardEx provides detailed biographic information (work experience, educational background, social activities such as club memberships and charity participation) of directors and senior managers. One issue with the constructions of social connection measure is that they might be subject to a reverse causality concern. For example, it is plausible that the business relationship between the supplier and customer leads to formation of social relation rather than the causal effect of social connection on RSI as we argue. In order to mitigate this reverse causality concern, we restrict our attention to *pre-existing* connections in the spirit of Engelberg, Gao, and Parsons (2012). Particularly, we only focus on two types of social connections: (1) school ties, where two persons study at the same program of the same institution for an overlapped time[20]; (2) pre-existing third-party employment connections, where two persons work at the same firm other than the focal supplier firm or customer firm at least 5 years before the current supplier-customer relationship. This requirement ensures that the social connections we try to identify are pre-determined at a distant place and time from the supplier-customer business relationship we are interested in.

Specifically, two proxies are constructed to measure the social connectedness between the suppliers and customers. The first one is a dummy indicator, denoted as *Connected*, which equals one if at least one school tie or employment connection exists between senior managers/directors in the supplier firm and those in the customer firm.[21] In other words, as long as one senior manager/director in the supplier firm is socially connected to any senior managers/directors in the customer firm, through either education channel or previous employment channel, the supplier is considered to be connected to that particular customer.

We also construct a continuous measure, denoted as *Log(connections),* which is calculated as the natural logarithm of one plus the number of pair-wise interpersonal connections between all the senior managers/directors in the suppliers and their counterparties in the customers. To construct this variable, we first count the number of social connections each senior manager/director in the supplier firm has with senior managers/directors in the customer firm.

[20] Following Engelberg et al. (2013), we divide all education programs into undergraduate, master, MBA, law degree, and others.

[21] We include all directors (both independent directors and executive directors) and senior managers in the calculation of social connectedness. Senior managers refer to CEO, CFO, COO and VP. We exclude division managers or regional managers or group managers based on the job title in BoardEx. Our coverage of senior managers is larger than that in ExecuComp.

Then we sum over all senior managers/directors in the supplier firm to get the total number of pair-wise interpersonal connections. For example, if 15 senior managers/directors work in the supplier firm and 20 senior managers/directors work in the customer firm, at most there would be 300 (=15*20) pair-wise interpersonal connections if everyone in the supplier firm is connected to everyone in the customer firm. To avoid double-counting, we only count once if the two persons have both a school tie and an employment connection.

2.4 Summary statistics

Panel A of Table 1 presents the summary statistics for dependent variables used in our empirical analysis. An average supplier in our sample spends 7.4% of total assets on R&D expenses. Among all the supplier-customer pairs, about 7.6% of suppliers engage in cross-citation activity with their customer and produce an average of 2.02 patents that have cited the existing patent portfolios of their customers. A typical supplier produces 11.59 patents per year and these patents receive an average of 4.65 citations in subsequent years.

Pair-level characteristics for supplier-customer relationships are summarized in Panel B of Table 1. A typical supplier in our sample has 2.6 principle customers while a typical customers has 18.49 suppliers. Sales to each customer accounts for 17.5% of suppliers' total sales, which is not surprising since suppliers are only mandated to report their customers above the 10% threshold. The geographic distance between the supplier and customer is 981 miles, similar to the 939 miles found in Chu et al. (2014). Consistent with previous studies such as Fee et al. (2006) and Chu et al. (2014), customers are much larger than suppliers. The average (median) ratio of supplier size to customer size is 0.107 (0.016) in our sample, indicating that the average (median) customer is almost 10 (63) times as large as a supplier. In terms of connectedness between suppliers and customers, 84.3% of pairs have at least one school tie or employment connection. For the continuous measure, they have on average 5.59 pair-wise personal connections between senior managers/directors on both sides.

We also account for a battery of firm-level characteristics whose summary statistics are presented in Panel C and D of Table 1. On average, suppliers have 2,548 million total assets, spend 4.7% of total assets in capital expenditures and 7.4% of assets in R&D, and have a leverage ratio of 0.194. Moreover, customers are generally large and mature companies which spend 2.5% of total assets in R&D and have a leverage of 0.229.

3. Empirical strategy and results

In this section, we empirically examine the impact of social network on supplier innovation. Specifically, we examine whether supplier R&D expenses and innovation outcomes (cross citations, patent count and citation count) vary with the presence and strength of social connections with principal customers. In order to address the endogeneity concern that some unobservable forces drive social connection and supplier innovation at the same time, we not only explore "within" variation of connection status by incorporating relationship pair fixed effects, but also use a subsample of supplier-customer pairs in which social connections are subject to exogenous changes due to retirements or deaths of managers/directors in customers.

3.1 Empirical strategy

To study how social connections between suppliers and customers affect innovation, we conduct regression analysis using the following model specification.

$$Innovation_{ijt} = \beta_0 + \beta_1 SC_{ijt} + \gamma' W_{ijt} + Year_t + Ind_i/Pair_{ij} + \epsilon_{ijt} \quad (1)$$

where *i* denotes suppliers, *j* denotes customers and *t* denotes year. We conduct our analysis at supplier-customer pair level. In case when a supplier discloses multiple customers in segment files in a particular year, the same supplier-year observation may repeat. Partially for this reason, we cluster standard errors at supplier firm level to correct for the repetition of supplier-years across different supplier-customer pairs. Clustering in this way can also adjust for within-supplier serial correlation of the residuals (Petersen, 2009).

The dependent variable, *Innovation*, is proxied by R&D expenditure, and innovation outcomes such as cross-citations, number of patents, and number of non-self-citations.[22] For R&D, we also explore the sensitivity of supplier R&D to customer R&D, and how that sensitivity is affected by pre-existing social connections. The main independent variable of interest, social connections (denoted as *SC*), is measured in two ways as discussed in details in Section 2.3: (1) a dummy indicator, *Connected*, which is equal to one when at least one director or manager in the supplier firm is socially connected to at least one director or manager in the customer firm; (2) a continuous measure, *Log(connections)*, which is the natural logarithm of one plus the number of pairwise social connections between all directors and managers in the supplier firm and its customer firm.

Following prior research (e.g., Fee, Hadlock, and Thomas, 2006; Banerjee et al., 2009; Dass et al., 2014), we include a large set of control variables to capture the influence of supplier firm characteristics on innovation outcomes, including supplier firm size (natural logarithm of book value of total assets), market leverage (total debt divided by market value of total assets), market to book ratio (market value of total assets divided by book value of total assets), proportion of tangible assets (net PPE divided by book value of total assets), ROA (income before extraordinary items divided by total assets), capital expenditure (capital expenditure

[22] In unreported results, we also use the establishment of strategic alliance as an additional proxy for the engagement in innovation-based projects since strategic alliance is usually associated with intensive relation-specific investments (Fee, Hadlock, and Thomas, 2006; Kale and Shahrur, 2007; Robinson, 2008). Consistently, we find that social connections significantly increase the propensity to establish a strategic alliance between the supplier and customer.

divided by total assets), industry competition (Herfindahl–Hirschman Index measured at 2-digit SIC industry classification). We also control for customer characteristics, namely customer firm leverage and customer R&D. Moreover, in order to control for the closeness of supplier-customer relationships, we add supplier sales to customer within suppler-customer pairs and geographic distance between the headquarters of suppliers and their customers (Chu, Tian, and Wang, 2014).

In all regressions, we add year fixed effects to control for the impact of the macro economy and the business cycle. In baseline regressions, SIC 2-digit industry fixed effects are added to account for the fact that certain industry is more R&D intensive and hence engages in more innovation activities. A potential concern with industry fixed effects is that some unobservable firm characteristics may vary across firms within the same industry and correlate with social connections and innovation at the same time. For example, firms with substantial innovative potential may be more attractive to directors with large social networks. More generally, customers that have more social connections with certain suppliers may share characteristics that foster innovation – e.g., creative individuals. In order to address such concerns, we include supplier firm fixed effects or supplier-customer pair fixed effects.[23]

While firm or relationship level fixed effects address the issue that unobserved firm or relationship level characteristics explain our results, this strategy may not completely address potential reverse causality concerns. The most important reverse causality issue is that connections with the customer bring more business to the supplier, and either that innovation is mechanically related to the volume of orders from the customer, or that innovative projects are more profitable for the supplier and customers favor suppliers to whom they are connected by

[23] To save space, we do not report our baseline results that incorporate supplier firm fixed effects, but focus on supplier-customer relationship pair fixed effects. All our results are robust to the inclusion of firm fixed effects.

allocating such projects to them. While the former concern is addressed by controlling for the level of sales to the customer, the latter is more challenging to deal with. If the "within variation" in connectedness were completely exogenous, the fixed-effect strategy would mitigate such a reverse causality concern, but it is possible that not all such variation is exogenous. For example, a connected supplier may be informed by the customer that the latter plans to switch to a new supplier. This might lead to a decline in its innovation stemming from customer orders; at the same time, a manager who was the source of the link with the customer and responsible for bringing orders to the supplier may now become dispensable and leave the company. This causes a change in the connected dummy to be associated with a decline in the supplier innovation, but the causality is in the opposite direction to what we want to establish. To establish that an increase (decrease) in customer-supplier connections facilitates (hinders) supplier innovation, we examine a sample of departures from customer boards and managerial positions due to deaths or retirements. Such departures are plausibly exogenous to a supplier because customer firms are much larger firms than the supplier firms in our sample (the mean ratio of supplier size to customer size is 10%, and the median is 1%, as reported in Panel B of Table 1) and it is very unlikely that a customer manager or board member's only role would be to manage the relationship with a particular supplier, and that the member's death or departure could be triggered by expected discontinuation of the relationship.[24] Specifically, for each connected departure, we find a set of suppliers to the same customer firm whose connectedness to the customer is not affected by the same departure, and examine whether, relative to this latter group, innovation (including the sensitivity of supplier R&D to customer R&D) drops after the departure in the former group.

[24] Our results hold if we only consider deaths of customer members, as reported below.

3.2 Main Results

A. R&D Expenses

We start testing the role of social network in innovation by examining the effect of social connections on R&D expenses within supplier-customer relationships. R&D expenses are considered as an important input of innovation process and are highly correlated with innovation outcomes in subsequent periods (e.g., Griffith, Redding, and Reenen, 2004).

Our regression model is specified in Equation 1, and we report the results in Table 2. The dependent variable is defined as R&D expenses scalded by total assets. In cases where R&D expenses are missing in Compustat, we replace them with zero. The main explanatory variables of interest are measures of social connections, which are measured as a dummy variable, *Connected*, in the first four columns and a continuous variable, *Log(connections)*, in the last four columns.

In addition to the test on the level of supplier R&D expenses reported in columns (1)-(2) and (5)-(6), we examine whether supplier R&D becomes more sensitive to customer R&D when social connections exist between supplier and customer in columns (3)-(4) and (7)-(8). To do so, we add an interaction term between customer R&D and the connection dummy (columns (3)-(4)) or the customer R&D and *Log(connections)* (columns (7)-(8)).

The results show that social connections lead to more R&D activity by the supplier, and supplier R&D becomes more sensitive to customer R&D when the supplier and customer are socially connected. In column (1), connected suppliers' R&D spending within the same industry is higher by 2.5% of assets than that of unconnected suppliers. Not surprisingly, the economic magnitude drops (but remains statistically significant at the 10% level) in column (2) when we control for relationship level fixed effects. Nonetheless, the magnitude is still large. Since we do not observe supplier R&D at the relationship level (but only at the firm level), we cannot directly compare the change in R&D spending as a percentage of the relationship level mean or median. However, relative to a firm level sample mean (median) level of R&D spending of 7.4% of assets (2.5% of assets), R&D spending drops by 0.4% of assets, representing a 5% (16%) decline relative to sample mean (median), when a connected supplier loses connections with its customer.

When we control for relationship fixed effects, supplier R&D is sensitive to customer R&D only when the supplier and the customer are connected (columns (4) and (8)). One concern that one might have about the regressions involving interactions between the connection dummy and customer R&D is that this interaction term is highly correlated with customer R&D, since for 84% of the sample relationships, the connection dummy takes a value of 1. In Table 3, we report several tests exploring the robustness of our results. In Panels A and B, we split the sample based on whether both the supplier and customer operate in manufacturing or non-manufacturing industries.[25] If contractual incompleteness associated with relationship-specific investment is what makes connections facilitate innovation, we would expect the effect to be stronger in manufacturing industries. This is exactly what we find. Importantly, in both samples, the correlation between *Customer R&D* and *Customer R&D*Connection* is high and of a similar magnitude [0.8]. Yet, our results are only present for the manufacturing sample, suggesting that the correlation is not somehow spuriously driving our results. Second, in Panel C, we partition the overall sample based on whether the connection dummy is 1 or 0. The results are more pronounced in connected pairs (columns (1) and (3)) than unconnected pairs (columns (2) and (4)). Moreover, the coefficient of customer R&D is significantly different between the two subsamples.

[25] Manufacturing industries are those with primary SIC code between 2,000 and 3,990.

B. Innovation Outcome

In this subsection, we examine how social connections affect innovation outcomes. We first measure innovation outcomes by cross citations, which capture the extent to which suppliers tailor innovation to customers' needs and produce patents that are more relevant to customers. We compute cross citation in two ways: a dummy variable, which indicates whether supplier has produced any patent that cites the customer's patents in year t+1, and a continuous variable, which is defined as natural logarithm of one plus the total number of citations of customers' patents by suppliers in year t+1.

The results are reported in Table 4. Columns 1 and 2 present the results of probit regressions of cross citation dummy and the remaining four columns present the results of OLS regressions of cross citation count. The probit marginal effects imply that connected suppliers are 5% (five percentage points) more likely to cross-cite customer patents than unconnected ones. The OLS results (with or without pair fixed effects) indicate that the number of cross-citations increases by 4% when a social connection exists between supplier and customer. These are economically large magnitudes given that in the overall sample, only 7.6% of the relationships involve a cross-citation.[26]

The second measure of innovation outcomes is patent count. This measure is widely used to capture the quantity of innovation. It is computed as the natural logarithm of one plus the number of patents that suppliers file to US Patent and Trademark Office and that are eventually granted. Following the innovation literature, we use the application year instead of the grant year since the application year is closer to the time of the actual innovation activities. We also

[26] An alternative explanation for the cross-citation results is that some supplier members might cite the patents of their friends' company which could have nothing to do with relation-specific investment. However, Gomes-Casseres, Hagedoorn, and Jaffe (2006, JFE) argue that "patent citations have the advantage that they perform a legal function related to the validity of the patent and the technology to which it applies, so that they are not contaminated by unnecessary citations to friends, colleagues, or famous people".

measure the patent counts in year t+1 since it takes considerable time and effort for innovative projects to materialize. In robustness checks, we also examine the impact of social connections on patent numbers in year t+2 and t+3.

The results are reported in Panel A of Table 5. The connection dummy and the logarithm of one plus the number of connections are both positive and significant at 1% or 5% level. The economic magnitude corresponds to a 6% higher level of patent filing in the following year for connected firms, or an elasticity of 13.5% (6%) for the rate of patent filing with respect to the number of connections in column 3 (column 4).

The third measure of innovation outcomes is citation count. The number of citation could reflect the quality of innovation output (Hall, Jaffe, and Trajtenberg, 2001). We construct this variable by counting the total number of non-self-citations received on the firm's patents filed (and eventually granted), scaled by the number of the patents filed (and eventually granted) in year t+1. We exclude self-citations to better quantify the quality of patents.

The results are reported in Panel B of Table 5. Once again, both the connected dummy and the logarithm of one plus the number of connections are significant, at least at the 5% level, in their respective specifications. The magnitudes are economically important: connected firms receive 3% more citations per patent than suppliers without social connections with their customers.

In Table 6, we do a number of robustness checks. In Panel A, we examine whether the effect of social connections on innovations persist. They do: the economic magnitudes of the coefficients of the connection dummy and the logarithm of one plus the number of connections become larger in years t+2 and t+3. In panel B, we drop all observations with zero patents and citations because there is a clustering around zero, which could bias the coefficient estimates.

Our results hold. Finally, in Panel C, we estimate a negative binomial model which arguably is better suited to our setting where the dependent variables (number of patents and citations) correspond to count data. Our results remain qualitatively unchanged.

3.3 Identification

So far, we have demonstrated that social connections between suppliers and customers play an important role in fostering supplier innovation. However, our results may be spurious due to the selection of well-connected managers or directors by suppliers. For example, suppliers may try to cultivate social connections with their customers by hiring managers or directors that are connected to customers when they anticipate that their customers have considerable growth opportunities and innovative potentials, which in turn affect R&D and innovation by the suppliers. To address such concerns, we use retirement or death of managers and directors in customer firms as an exogenous change in the social network within supplier-customer relationships. Our identification relies on an important feature of our data, that is, customers identified from segment files are almost 100 times as large as suppliers (Fee et al, 2006; Chu et al., 2014).[27] Such stark difference in firm size makes it unlikely that manager and director turnovers in customers are caused by (anticipated) changes in the relationship with (or the innovativeness of) a particular small supplier. Moreover, we focus on retirements or deaths because they are less likely to correlate with customers' financial performance and future prospects, which could affect the supplier's incentive to innovate.

Following Fracassi and Tate (2012), we use a generalized difference-in-difference framework to identify the causal inference of social connections on innovation. We first identify 946 events in our sample, including 838 retirements (managers or directors leave customer firms

[27] See Panel B of Table 1. Chu, Tian, and Wang (2014) find that the customers are more than 100 times larger than the suppliers based on the entire Compustat segment file.

at the age of 65 or above) and 108 deaths (managers or directors die at the job in customer firms). We further require that the leaving manager or director has at least one connected supplier and one unconnected supplier so that we can compare innovation in connected suppliers to unconnected suppliers while keeping customers the same. The event window contains 5 years centered on the event and only suppliers that have at least one year before and after the event are included. The above sample filtering leaves us 94 events (73 retirements and 21 deaths) in the end.[28] The regression specification is as follows.

$$Innovation_{ijt} = \alpha_0 + \alpha_1 After_{jt} + \alpha_2 After_{jt} * Connected\ Departure_{ij} + \alpha_3 Connected\ Departure_{ij} + \gamma' W_{ijt} + Year_t + Ind_i/Supp_i + \epsilon_{ijt} \quad (2)$$

The dependent variables, supplier R&D expenses and patenting activities, are defined as before. *After* is a dummy indicating years after retirements or deaths. *Connected Departure* is equal to one if the manager or director leaving the customer is socially connected with at least one manager or director of the supplier. Otherwise, it is set to zero. We interact *After* with *Connected Departure* in all regressions to identify the difference-in-difference effect. Thus, the coefficient on *After* captures the average effect of exogenous departures of managers or directors of customers on unconnected suppliers' innovation. The coefficient on the interaction term captures the incremental effect of these events on connected suppliers' innovation. We control for the same set of supplier and customer characteristics as before. Year and supplier fixed effects are also included to control for macro economy cycles and unobservable firms characteristics, respectively.

The event study results are reported in Table 7. Panel A reveals that R&D tapers off for connected suppliers after the departure of the customer member; when supplier fixed effects are

[28] As seen from Panel B in Table 1, each customer on average has 16 suppliers identified in the database, hence we could potentially have approximately 94*16*5=7520 observations. We actually have 3461 due to missing variables or missing observation in the 5 year window around the event.

included, there is no effect on the suppliers who are not connected to the same member. Similarly, the sensitivity of supplier R&D to customer R&D drops for connected suppliers. Interestingly, in column (1), R&D spending of suppliers not connected to the departing member increases after the departure, and in both columns (3) and (4), the sensitivity of these suppliers to customer R&D increases. These results could be due to the fact that these other suppliers (some of whom could still be connected to other customer members) benefit at the expense of the suppliers that lose connections and step up their R&D activity. In Panel B, we examine patent activity and citations. Both decline for suppliers that lose connections after the departure of the customer member, but here, there is no effect on the other suppliers who are not connected to the departing customer member.[29]

One concern about reverse causality that may still remain is that perhaps the suppliers that lose connections reduce innovation because connections bring more business, and now they expect less business in the future. We address this issue in two ways. First, we restrict attention to those cases where the supplier continues to identify the customer as important for its business for three years after the departure. The results, reported in Panel A of Table 8, remain qualitatively and quantitatively similar to Table 7. Second, we argue that if a relationship has been productive, then it is likely to continue even after the supplier loses connections (for example, the supplier may have developed some know-how that is difficult to replace). We define a relationship as productive if the supplier has produced at least one patent citing the customer's patents within 3 years prior to the event. The results are presented in Panel B and key implications continue to hold.

[29] All the above results hold when we control for the logarithm of one plus the number of other connections that the supplier has with the customer. These results are not reported here but available on request.

Finally, in Panel C, we report our results on the sample of connection breaches that occur due only to deaths of customer managers or board members. This sample is much smaller and has a tenth of the firm-year observations than the one in Table 7. Even though this sample is much smaller, our results continue to hold.

4. Conclusion

In this paper, we demonstrate how the prevalence of social connections between upstream and downstream firms shapes the boundary of the firm. Existing literature focused on transactions cost economics has explained firm boundary in terms of the costs and benefits of integration. Contractual incompleteness between parties at arms-length creates integration incentives. However, integration has its own costs, which probably explains why many upstream firms remain as standalone entities.

In this paper, we offer another explanation why innovative upstream firms can remain independent even though contracts may be incomplete. We find that pre-existing social connections between upstream suppliers and their downstream customers is extremely common. We show that innovative activity by suppliers increases when they have (more) social connections with their customers, suggesting that such connections mitigate the problems associated with contractual incompleteness.

One caveat of our study is that our data does not identify the full set of suppliers for the customer firms, but only those for whom the customer contributes a major part of their sales. It would be interesting in future work to examine whether social connections play a similar role for relationships with "important suppliers", or other mechanisms such as partial integration (e.g., equity ownership or board representation in the supplier firms) are more common ways to mitigate problems stemming from contractual incompleteness. Such mechanisms are very uncommon in our data, possibly because the suppliers that we are able to identify are among many small suppliers (including private upstream firms) to the customer who are individually too costly to partially integrate with.

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Table 1. Summary statistics

The table presents the summary statistics for variables used in the paper. Panel A, B, C, and D presents the summary statistics for the dependent variables, social connection measures, supplier, and customer characteristics, respectively. Variable definitions are in Appendix A.

Panel A: Dependent variables

	N	Mean	Std	Q1	Median	Q3
Supplier R&D	12892	0.074	0.116	0	0.025	0.102
Alliance	12892	0.043	0.202	0	0	0
Cross citation dummy	9566	0.076	0.265	0	0	0
Number of cross citations	9566	2.015	19.517	0	0	0
Log(cross citations)	9566	0.162	0.675	0	0	0
Number of patents	9566	11.589	88.967	0	0	1.535
Log(patents)	9566	0.685	1.259	0	0	0.93
Number of citations per patent	9566	4.652	12.56	0	0	2.152
Log(citations)	9566	0.674	1.211	0	0	1.148

Panel B: Pair-level characteristics

	N	Mean	Std	Q1	Median	Q3
Connected	12892	0.843	0.363	1	1	1
Number of connections	12892	5.59	7.291	1	3	7
Log(connections)	12892	1.461	0.927	0.693	1.386	2.079
Sales to customer	12892	0.175	0.188	0.067	0.117	0.208
Distance (miles)	12892	981	795	335	763	1523
Supplier size/Customer size ratio	12892	0.107	0.229	0.004	0.016	0.075
Number of customers per supplier	12892	2.606	2.140	1.000	2.000	3.000
Number of suppliers per customer	12892	18.490	26.497	3.000	9.000	22.000

Panel C: Supplier characteristics

	N	Mean	Std	Q1	Median	Q3
Supplier size ($ mil)	12892	2548	12549	106	354	1341
Supplier leverage	12892	0.194	0.211	0.004	0.142	0.312
Supplier MB ratio	12892	1.966	1.431	1.133	1.507	2.209
Supplier tangibility	12892	0.212	0.213	0.064	0.138	0.272
Supplier ROA	12892	-0.044	0.248	-0.062	0.03	0.072
Supplier Capex	12892	0.047	0.059	0.015	0.028	0.053
HIndex	12892	0.057	0.051	0.03	0.039	0.066

Panel D: Customer characteristics

	N	Mean	Std	Q1	Median	Q3
Customer R&D	12892	0.025	0.042	0	0.001	0.032
Customer leverage	12892	0.229	0.159	0.11	0.216	0.298

Table 2. Social connections with customers and supplier RSI: R&D

The table presents the results from regressions of supplier R&D on the social connections between the supplier and customer. The dependent variable is the supplier's R&D expenses (XRD) over book value of total assets (AT). Other variable definitions are in Appendix A. In parentheses are p-values based on standard errors adjusted for heteroskedasticity (White, 1980) and firm clustering (Petersen, 2009). ***, **, and * stand for statistical significance based on two-sided tests at the 1%, 5%, and 10% level, respectively. We control for year and industry fixed effects in columns (1), (3), (5), and (7) and year and supplier-customer pair fixed effects in columns (2), (4), (6), and (8).

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dependent variable	Supplier R&D	Supplier R&D	Supplier R&D	Supplier R&D	Supplier R&D	Supplier R&D	Supplier R&D	Supplier R&D
Connected	0.025***	0.004*	0.018***	0.000				
	(0.000)	(0.059)	(0.000)	(0.988)				
Connected*Customer R&D			0.359***	0.183***				
			(0.000)	(0.007)				
Log(connections)					0.017***	0.002*	0.014***	-0.001
					(0.000)	(0.090)	(0.000)	(0.374)
Log(connections)*Customer R&D							0.121**	0.105**
							(0.022)	(0.018)
Supplier size	-0.006***	-0.043***	-0.006***	-0.043***	-0.009***	-0.043***	-0.009***	-0.043***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Supplier leverage	-0.038**	0.023	-0.038**	0.023	-0.039**	0.023	-0.039**	0.022
	(0.029)	(0.261)	(0.029)	(0.267)	(0.027)	(0.265)	(0.027)	(0.275)
Supplier MB ratio	0.029***	0.007***	0.029***	0.007***	0.028***	0.007***	0.028***	0.007***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Supplier tangibility	-0.009	0.148***	-0.007	0.147***	-0.009	0.147***	-0.007	0.146***
	(0.683)	(0.000)	(0.736)	(0.000)	(0.662)	(0.000)	(0.751)	(0.000)
Supplier ROA	-0.299***	-0.143***	-0.299***	-0.143***	-0.295***	-0.143***	-0.295***	-0.143***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Supplier Capex	-0.078*	0.004	-0.080*	0.005	-0.074*	0.004	-0.077*	0.006
	(0.061)	(0.853)	(0.057)	(0.822)	(0.073)	(0.845)	(0.065)	(0.770)
HIndex	-0.140**	0.000	-0.136**	0.001	-0.143**	0.001	-0.138**	0.005
	(0.021)	(0.995)	(0.025)	(0.975)	(0.021)	(0.977)	(0.024)	(0.912)
HIndex squared	0.159**	-0.064	0.155**	-0.066	0.168**	-0.064	0.163**	-0.069
	(0.023)	(0.147)	(0.026)	(0.134)	(0.020)	(0.147)	(0.023)	(0.120)
Customer R&D	0.442***	0.132*	0.131*	-0.024	0.387***	0.131*	0.204***	-0.024
	(0.000)	(0.090)	(0.094)	(0.746)	(0.000)	(0.093)	(0.009)	(0.693)
Customer leverage	0.024**	0.010	0.024**	0.010	0.021*	0.010	0.022**	0.010
	(0.027)	(0.181)	(0.027)	(0.198)	(0.053)	(0.178)	(0.044)	(0.217)
Sales to customer	0.014	0.026**	0.014	0.026**	0.010	0.026**	0.010	0.026**
	(0.411)	(0.017)	(0.412)	(0.016)	(0.541)	(0.018)	(0.538)	(0.017)
Log(distance)	0.002**	-0.001*	0.002**	-0.001*	0.003***	-0.001	0.003***	-0.001
	(0.049)	(0.076)	(0.039)	(0.080)	(0.002)	(0.129)	(0.001)	(0.234)
Year FE	X	X	X	X	X	X	X	X
Industry FE	X		X		X		X	

Pair FE		X		X		X		X
Observations	12,892	12,892	12,892	12,892	12,892	12,892	12,892	12,892
Adjusted R-squared	0.439	0.776	0.440	0.776	0.443	0.776	0.443	0.776

Table 3. Social connections with customers and supplier R&D: robustness checks

The table presents the results from regressions of supplier R&D on the social connections between the supplier and customer. The dependent variable is the supplier's R&D expenses (XRD) over book value of total assets (AT). Other variable definitions are in Appendix A. Panel A presents the results on subsamples where both supplier and customer come from manufacturing industries (SIC between 2000 and 3999) and Panel B on subsamples where neither supplier nor customer come from manufacturing industries. Panel C presents the subsample results where supplier R&D is regressed on customer R&D on socially connected pairs and unconnected pairs, separately. We control for the same set of variables as those used in Table 2. The coefficients of these control variables are suppressed for brevity.

Panel A: Manufacturing relationships

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dependent variable	Supplier R&D	Supplier R&D	Supplier R&D	Supplier R&D	Supplier R&D	Supplier R&D	Supplier R&D	Supplier R&D
Connected	0.035***	0.004*	0.011	-0.010				
	(0.000)	(0.064)	(0.306)	(0.191)				
Connected*Customer R&D			0.282*	0.253**				
			(0.057)	(0.017)				
Log(connections)					0.026***	0.009*	0.019***	-0.019
					(0.000)	(0.060)	(0.000)	(0.276)
Log(connections)*Customer R&D							0.099*	0.442*
							(0.097)	(0.085)
Control variables	X	X	X	X	X	X	X	X
Year FE	X	X	X	X	X	X	X	X
Industry FE	X		X		X		X	
Pair FE		X		X		X		X
Observations	3,930	3,930	3,930	3,930	3,930	3,930	3,930	3,930
Adjusted R-squared	0.508	0.773	0.525	0.782	0.514	0.756	0.475	0.758

Panel B: Non-manufacturing relationships

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dependent variable	Supplier R&D	Supplier R&D	Supplier R&D	Supplier R&D	Supplier R&D	Supplier R&D	Supplier R&D	Supplier R&D
Connected	0.004	-0.005	0.002	-0.004				
	(0.384)	(0.451)	(0.661)	(0.619)				
Connected*Customer R&D			0.281	-0.231				
			(0.295)	(0.407)				
Log(connections)					0.001	-0.005	0.001	-0.004
					(0.689)	(0.159)	(0.659)	(0.279)
Log(connections)*Customer R&D							-0.011	-0.099
							(0.903)	(0.386)
Control variables	X	X	X	X	X	X	X	X
Year FE	X	X	X	X	X	X	X	X
Industry FE	X		X		X		X	
Pair FE		X		X		X		X
Observations	2,983	2,983	2,983	2,983	2,983	2,983	2,983	2,983
Adjusted R-squared	0.392	0.895	0.392	0.895	0.392	0.895	0.391	0.895

Panel C: Subsample analysis on R&D sensitivity

	(1)	(2)	(3)	(4)
	Connected pairs	Unconnected pairs	Connected pairs	Unconnected pairs
Dependent variable	Supplier R&D	Supplier R&D	Supplier R&D	Supplier R&D
Customer R&D	0.372***	0.167**	0.154*	-0.029
	(0.000)	(0.033)	(0.083)	(0.675)
Control variables	X	X	X	X
Year FE	X	X	X	X
Industry FE	X	X		
Pair FE			X	X
Observations	10,874	2,018	10,874	2,018
Adjusted R-squared	0.452	0.353	0.788	0.666
p-value for test of difference in coefficient of (*Customer R&D*) between the two subsamples	H0: (1)=(2) 0.037		H0: (3)=(4) 0.066	

Table 4. Social connections with customers and supplier RSI: Cross citations

The table presents the results from regressions of supplier-customer cross citations on the social connections between the supplier and customer. The dependent variable in columns (1) and (2) is a dummy indicator, which equals to 1 if the supplier has produced any patent that cites the customer's patent in year t+1 and 0 otherwise. The dependent variable in columns (3) to (6) is the natural logarithm of one plus the total number of citations made by supplier's patents toward customer's patents in year t+1. Other variable definitions are in Appendix A. In parentheses are p-values based on standard errors adjusted for heteroskedasticity (White, 1980) and supplier-customer-pair clustering (Petersen, 2009). ***, **, and * stand for statistical significance based on two-sided tests at the 1%, 5%, and 10% level, respectively. We control for year and industry fixed effects in columns (1), (2), (3) and (5) and year and supplier-customer pair fixed effects in columns (4) and (6).

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable	Cross citation (1/0)	Cross citation (1/0)	Log(cross citations)	Log(cross citations)	Log(cross citations)	Log(cross citations)
Connected	0.050***		0.043**	0.040**		
	(0.000)		(0.014)	(0.049)		
Log(connections)		0.043***			0.116***	0.045***
		(0.000)			(0.000)	(0.005)
Supplier size	0.024***	0.015***	0.090***	0.105***	0.064***	0.103***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Supplier leverage	-0.086***	-0.090***	-0.175***	0.046	-0.174***	0.045
	(0.001)	(0.000)	(0.000)	(0.214)	(0.000)	(0.216)
Supplier MB ratio	0.004**	0.004**	0.017***	0.003	0.015***	0.004
	(0.010)	(0.017)	(0.002)	(0.606)	(0.005)	(0.582)
Supplier tangibility	0.022	0.032	0.068	-0.018	0.068	-0.026
	(0.489)	(0.314)	(0.515)	(0.866)	(0.516)	(0.804)
Supplier ROA	-0.004	-0.002	-0.042*	-0.014	-0.025	-0.013
	(0.460)	(0.642)	(0.095)	(0.300)	(0.211)	(0.318)
Supplier Capex	0.160**	0.146**	0.432***	0.091	0.467***	0.097
	(0.011)	(0.022)	(0.001)	(0.431)	(0.001)	(0.401)
HIndex	-0.839***	-0.643**	1.529***	2.222***	1.429***	2.255***
	(0.005)	(0.027)	(0.001)	(0.000)	(0.002)	(0.000)
HIndex squared	2.375***	2.003***	-1.342***	-1.756***	-1.220***	-1.764***
	(0.003)	(0.007)	(0.003)	(0.000)	(0.005)	(0.000)
Customer R&D	0.547***	0.484***	1.938***	-0.039	1.606***	-0.047
	(0.000)	(0.000)	(0.000)	(0.879)	(0.000)	(0.853)
Customer leverage	0.022	0.020	0.001	0.011	-0.015	0.015
	(0.334)	(0.364)	(0.992)	(0.891)	(0.832)	(0.850)
Sales to customer	-0.032	-0.043*	-0.011	0.141***	-0.025	0.139***
	(0.241)	(0.097)	(0.795)	(0.001)	(0.560)	(0.001)
Log(distance)	-0.003	0.001	-0.013	0.038	-0.003	0.032
	(0.171)	(0.486)	(0.157)	(0.508)	(0.727)	(0.587)
Year FE	X	X	X	X	X	X
Industry FE	X	X	X		X	
Pair FE				X		X
Observations	9,566	9,566	9,566	9,566	9,566	9,566
Pseudo (Adjusted) R-squared	0.316	0.352	0.143	0.706	0.161	0.707

Table 5. Social connections with customers and supplier innovation outcomes

The table presents the results from regressions of supplier's innovation outcomes on the social connections between the supplier and customer. The dependent variable in Panel A is the natural logarithm of one plus a firm's total number of patents filed (and eventually granted) in year t+1. The dependent variable in Panel B is the natural logarithm of one plus a firm's total number of non-self-citations received on the firm's patents filed (and eventually granted), scaled by the number of the patents filed (and eventually granted) in year t+1. Other variable definitions are in Appendix A. In parentheses are p-values based on standard errors adjusted for heteroskedasticity (White, 1980) and firm clustering (Petersen, 2009). ***, **, and * stand for statistical significance based on two-sided tests at the 1%, 5%, and 10% level, respectively. We control for year and industry fixed effects in columns (1) and (3) and year and supplier-customer pair fixed effects in columns (2) and (4).

Panel A: Log(1+patents)

	(1)	(2)	(3)	(4)
Dependent variable	Log(patents)	Log(patents)	Log(patents)	Log(patents)
Connected	0.063**	0.065**		
	(0.013)	(0.040)		
Log(connections)			0.135***	0.060**
			(0.000)	(0.010)
Supplier size	0.307***	0.135***	0.277***	0.133***
	(0.000)	(0.000)	(0.000)	(0.000)
Supplier leverage	-0.426***	-0.133**	-0.425***	-0.134**
	(0.000)	(0.038)	(0.000)	(0.038)
Supplier MB ratio	0.071***	0.016*	0.069***	0.016*
	(0.000)	(0.058)	(0.000)	(0.053)
Supplier tangibility	-0.289***	-0.290	-0.289*	-0.301*
	(0.001)	(0.102)	(0.052)	(0.090)
Supplier ROA	-0.127**	-0.023	-0.107*	-0.022
	(0.043)	(0.182)	(0.067)	(0.201)
Supplier Capex	0.728***	0.197	0.768***	0.206
	(0.000)	(0.310)	(0.001)	(0.290)
HIndex	1.265*	1.508	1.152	1.557
	(0.071)	(0.132)	(0.260)	(0.120)
HIndex squared	-2.194***	-2.555***	-2.054**	-2.569***
	(0.001)	(0.000)	(0.019)	(0.000)
Customer R&D	1.504***	0.491	1.127***	0.485
	(0.000)	(0.202)	(0.001)	(0.206)
Customer leverage	-0.191***	-0.098	-0.209*	-0.093
	(0.004)	(0.514)	(0.058)	(0.535)
Sales to customer	-0.081	0.248***	-0.099	0.245***
	(0.114)	(0.001)	(0.226)	(0.001)
Log(distance)	0.001	0.047	0.013	0.039
	(0.844)	(0.510)	(0.271)	(0.597)
Year FE	X	X	X	X
Industry FE	X		X	
Pair FE		X		X
Observations	9,566	9,566	9,566	9,566
Adjusted R-squared	0.381	0.781	0.388	0.782

Panel B: Log(1+citations)

	(1)	(2)	(3)	(4)
Dependent variable	Log(citations)	Log(citations)	Log(citations)	Log(citations)
Connected	0.029**	0.028**		
	(0.018)	(0.049)		
Log(connections)			0.050***	0.047***
			(0.000)	(0.000)
Supplier size	0.040***	0.059***	0.030***	0.056***
	(0.000)	(0.000)	(0.000)	(0.000)
Supplier leverage	-0.090***	-0.022	-0.091***	-0.025
	(0.001)	(0.625)	(0.000)	(0.576)
Supplier MB ratio	0.021***	0.017**	0.020***	0.018**
	(0.000)	(0.021)	(0.000)	(0.016)
Supplier tangibility	-0.004	0.033	-0.005	0.027
	(0.926)	(0.709)	(0.911)	(0.766)
Supplier ROA	-0.017	-0.003	-0.009	-0.002
	(0.277)	(0.810)	(0.494)	(0.863)
Supplier Capex	0.198**	0.092	0.216**	0.102
	(0.027)	(0.449)	(0.017)	(0.405)
HIndex	0.998***	1.510***	0.961***	1.508***
	(0.002)	(0.000)	(0.002)	(0.000)
HIndex squared	-0.801***	-1.121***	-0.752**	-1.093***
	(0.009)	(0.000)	(0.012)	(0.000)
Customer R&D	1.695***	0.929***	1.494***	0.879***
	(0.000)	(0.000)	(0.000)	(0.001)
Customer leverage	0.059	0.095**	0.047	0.093**
	(0.195)	(0.042)	(0.292)	(0.044)
Sales to customer	-0.011	0.049	-0.019	0.041
	(0.691)	(0.173)	(0.499)	(0.260)
Log(distance)	-0.007	-0.002	-0.003	0.002
	(0.112)	(0.710)	(0.488)	(0.722)
Year FE	X	X	X	X
Industry FE	X		X	
Pair FE		X		X
Observations	9,566	9,566	9,566	9,566
Adjusted R-squared	0.138	0.382	0.146	0.385

Table 6. Social connections with customers and supplier innovation: robustness checks

The table presents the robustness check results from regressions of supplier's innovation outcomes on the social connections between the supplier and customer. Panel A examines innovation outcomes in T+2 and T+3. Panel B reports the results on subsamples where firm-years with zero patents or citations are excluded. Panel C reports the results from negative binomial regressions where the dependent variable is the number of patents or the number of citations per patent. We control for the same set of variables as those used in Table 5. The coefficients of these control variables are suppressed for brevity.

Panel A: Innovation measures in T+2 and T+3

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dependent variable	$Log(patents)_{t+2}$	$Log(patents)_{t+2}$	$Log(patents)_{t+2}$	$Log(patents)_{t+2}$	$Log(patents)_{t+3}$	$Log(patents)_{t+3}$	$Log(patents)_{t+3}$	$Log(patents)_{t+3}$
Connected	0.059**	0.086**			0.050*	0.093**		
	(0.025)	(0.014)			(0.077)	(0.023)		
Log(connections)			0.125***	0.057**			0.114***	0.019
			(0.000)	(0.032)			(0.000)	(0.251)
Control variables	X	X	X	X	X	X	X	X
Year FE	X	X	X	X	X	X	X	X
Industry FE	X		X		X		X	
Pair FE		X		X		X		X
Observations	8,315	8,315	8,315	8,315	7,183	7,183	7,183	7,183
Adjusted R-squared	0.372	0.772	0.378	0.772	0.331	0.750	0.353	0.765

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dependent variable	$Log(citations)_{t+2}$	$Log(citations)_{t+2}$	$Log(citations)_{t+2}$	$Log(citations)_{t+2}$	$Log(citations)_{t+3}$	$Log(citations)_{t+3}$	$Log(citations)_{t+3}$	$Log(citations)_{t+3}$
Connected	0.032***	0.028**			0.024**	0.022*		
	(0.004)	(0.045)			(0.020)	(0.075)		
Log(connections)			0.043***	0.040***			0.033***	0.026***
			(0.000)	(0.000)			(0.000)	(0.001)
Control variables	X	X	X	X	X	X	X	X
Year FE	X	X	X	X	X	X	X	X
Industry FE	X		X		X		X	
Pair FE		X		X		X		X
Observations	8,315	8,315	8,315	8,315	7,183	7,183	7,183	7,183
Adjusted R-squared	0.120	0.367	0.127	0.371	0.107	0.356	0.112	0.358

Panel B: Exclude firm-years with zero patents or citations

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dependent variable	Log(patents)	Log(patents)	Log(patents)	Log(patents)	Log(citations)	Log(citations)	Log(citations)	Log(citations)
Connected	0.146***	0.119*			0.141**	0.109*		
	(0.005)	(0.052)			(0.012)	(0.073)		
Log(connections)			0.156***	0.094**			0.160***	0.172***
			(0.000)	(0.028)			(0.000)	(0.000)
Control variables	X	X	X	X	X	X	X	X
Year FE	X	X	X	X	X	X	X	X
Industry FE	X		X		X		X	
Pair FE		X		X		X		X
Observations	3,063	3,063	3,063	3,063	2,483	2,483	2,483	2,483
Adjusted R-squared	0.436	0.857	0.444	0.858	0.167	0.395	0.193	0.410

Panel C: Negative binomial regressions

	(1)	(2)	(3)	(4)
Dependent variable	# of patents	# of patents	# of citations per patent	# of citations per patent
Connected	0.329**		0.163*	
	(0.014)		(0.084)	
Log(connections)		0.227***		0.092**
		(0.000)		(0.047)
Control variables	X	X	X	X
Year FE	X	X	X	X
Industry FE	X	X	X	X
Observations	9,566	9,566	9,566	9,566

Table 7. Social connections with customers and supplier RSI: Director or senior manager departures

The table presents the results from event studies that examine the impact of the severing of supplier's social connections with the customer on its relationship-specific investments (RSI). Events are the retirements or deaths of directors or senior managers at the customer where the retirees or deceased members have both socially connected and unconnected suppliers. The event window contains 5 years centered on the retirement or death year ([-2, 2]). *After* is a dummy variable which equals to 1 for fiscal years after the retirement or death and 0 otherwise. *Connected departure* is a dummy variable which equals to 1 if at least one education connection or prior employment connection exists between the retiree or deceased member at the customer and the directors or senior managers at the supplier and 0 otherwise. Other variable definitions are in Appendix A. In parentheses are p-values based on standard errors adjusted for heteroskedasticity (White, 1980) and firm clustering (Petersen, 2009). ***, **, and * stand for statistical significance based on two-sided tests at the 1%, 5%, and 10% level, respectively.

Panel A: supplier R&D

	(1)	(2)	(3)	(4)
Dependent variable	Supplier R&D	Supplier R&D	Supplier R&D	Supplier R&D
After	0.005***	-0.000	-0.002	-0.002
	(0.006)	(0.840)	(0.496)	(0.139)
After*Connected departure	-0.009**	-0.005**	0.004	0.004
	(0.044)	(0.048)	(0.399)	(0.168)
After*Connected departure*Customer R&D			-0.506***	-0.415***
			(0.001)	(0.002)
Connected departure*Customer R&D			0.882***	0.367***
			(0.000)	(0.007)
After*Customer R&D			0.262***	0.119***
			(0.000)	(0.001)
Connected departure	0.012**	0.002	-0.008	-0.005*
	(0.025)	(0.262)	(0.162)	(0.080)
Supplier size	-0.002	-0.016***	-0.001	-0.015***
	(0.102)	(0.000)	(0.455)	(0.000)
Supplier leverage	-0.040***	-0.031**	-0.051***	-0.031***
	(0.000)	(0.010)	(0.000)	(0.008)
Supplier MB ratio	0.019***	0.003	0.021***	0.003
	(0.000)	(0.234)	(0.000)	(0.162)
Supplier tangibility	-0.073***	0.061**	-0.042**	0.059*
	(0.000)	(0.044)	(0.025)	(0.054)
Supplier ROA	-0.216***	-0.107***	-0.234***	-0.108***
	(0.000)	(0.000)	(0.000)	(0.000)
Supplier Capex	0.062	0.109***	0.077	0.111***
	(0.282)	(0.005)	(0.210)	(0.004)
HIndex	-0.161***	-0.026	0.010	-0.032
	(0.001)	(0.428)	(0.917)	(0.336)
HIndex squared	0.193***	-0.003	0.050	0.006
	(0.000)	(0.921)	(0.474)	(0.809)
Customer R&D	0.470*	0.301*	0.028	0.092
	(0.067)	(0.066)	(0.751)	(0.243)
Customer leverage	0.006	0.001	-0.003	0.000
	(0.827)	(0.889)	(0.855)	(0.988)
Sales to customer	-0.009	0.011	-0.005	0.011
	(0.522)	(0.273)	(0.797)	(0.251)
Log(distance)	-0.000	0.001	0.001	0.001
	(0.758)	(0.516)	(0.370)	(0.651)
Year FE	X	X	X	X
Industry FE	X		X	
Firm FE		X		X
Observations	3,461	3,461	3,461	3,461
Adjusted R-squared	0.570	0.884	0.532	0.886

Panel B: supplier innovation

	(1)	(2)	(3)	(4)
Dependent variable	Log(patents)	Log(patents)	Log(citations)	Log(citations)
After	0.016	0.020	0.003	0.003
	(0.647)	(0.441)	(0.799)	(0.733)
After*Connected departure	-0.199**	-0.119*	-0.067**	-0.070**
	(0.049)	(0.080)	(0.046)	(0.024)
Connected departure	0.186	0.170***	0.065**	0.053*
	(0.167)	(0.006)	(0.014)	(0.061)
Supplier size	0.331***	0.074	0.038***	0.038**
	(0.000)	(0.126)	(0.000)	(0.024)
Supplier leverage	-0.538***	-0.149	-0.045	0.006
	(0.006)	(0.211)	(0.124)	(0.896)
Supplier MB ratio	0.101***	0.008	0.013***	-0.000
	(0.000)	(0.564)	(0.002)	(0.957)
Supplier tangibility	-0.928**	-0.544*	0.059	0.244**
	(0.013)	(0.063)	(0.409)	(0.021)
Supplier ROA	-0.330*	0.010	-0.058**	0.037
	(0.058)	(0.891)	(0.024)	(0.265)
Supplier Capex	3.040**	1.121*	0.395*	0.106
	(0.016)	(0.062)	(0.099)	(0.659)
HIndex	-2.785*	1.360	0.602	1.058***
	(0.061)	(0.331)	(0.380)	(0.000)
HIndex squared	2.817*	-2.364	-0.519	-0.953***
	(0.061)	(0.105)	(0.481)	(0.000)
Customer R&D	-2.581	-0.887	1.245***	0.687
	(0.185)	(0.260)	(0.000)	(0.262)
Customer leverage	-0.375	0.506**	0.212***	0.246***
	(0.346)	(0.011)	(0.000)	(0.008)
Sales to customer	-0.027	0.182	0.032	0.103**
	(0.901)	(0.127)	(0.370)	(0.011)
Log(distance)	-0.028	-0.047**	-0.007	0.022
	(0.350)	(0.039)	(0.108)	(0.108)
Year FE	X	X	X	X
Industry FE	X		X	
Firm FE		X		X
Observations	2,574	2,574	2,574	2,574
Adjusted R-squared	0.363	0.844	0.356	0.662

Table 8. Director or senior manager departures: robustness checks

The table presents the robustness check results from event studies that examine the impact of the severing of supplier's social connections with the customer on its relationship-specific investments (RSI). Panel A reports the results on a subsample where the business relationship continues to exist for at least 3 years after the event. Panel B reports the results on a subsample of productive relationships where the supplier has produced at least one patent citing the customer's patents within 3 years prior to the event. Panel C reports the results on a subsample where the departure is due to director or senior manager deaths. We control for the same set of variables as those used in Table 7. The coefficients of these control variables are suppressed for brevity.

Panel A: Lasting relationships

	(1)	(2)	(3)	(4)
Dependent variable	Supplier R&D	Supplier R&D	Supplier R&D	Supplier R&D
After	-0.004	0.001	-0.010***	-0.001
	(0.220)	(0.691)	(0.008)	(0.553)
After*Connected departure	-0.010*	-0.007**	0.005	0.003
	(0.054)	(0.046)	(0.568)	(0.444)
After*Connected departure*Customer R&D			-0.511**	-0.413***
			(0.033)	(0.009)
Connected departure*Customer R&D			1.102***	0.420**
			(0.000)	(0.011)
After*Customer R&D			0.371***	0.125**
			(0.001)	(0.024)
Connected departure	0.022**	0.003	-0.008	-0.007
	(0.018)	(0.449)	(0.288)	(0.116)
Control variables	X	X	X	X
Year FE	X	X	X	X
Industry FE	X		X	
Firm FE		X		X
Observations	2,106	2,106	2,106	2,106
Adjusted R-squared	0.578	0.901	0.525	0.903

	(1)	(2)	(3)	(4)
Dependent variable	Log(patents)	Log(patents)	Log(citations)	Log(citations)
After	-0.006	0.037	0.001	-0.006
	(0.888)	(0.241)	(0.944)	(0.579)
After*Connected departure	-0.257**	-0.159*	-0.068*	-0.067**
	(0.021)	(0.083)	(0.094)	(0.027)
Connected departure	0.381**	0.279***	0.062	0.039
	(0.025)	(0.005)	(0.128)	(0.263)
Control variables	X	X	X	X
Year FE	X	X	X	X
Industry FE	X		X	
Firm FE		X		X
Observations	1,879	1,879	1,879	1,879
Adjusted R-squared	0.451	0.845	0.422	0.699

Panel B: Productive relationships

	(1)	(2)	(3)	(4)
Dependent variable	Supplier R&D	Supplier R&D	Supplier R&D	Supplier R&D
After	0.013**	0.008*	0.001	0.007
	(0.039)	(0.058)	(0.840)	(0.134)
After*Connected departure	-0.026***	-0.013**	0.003	-0.009
	(0.006)	(0.038)	(0.777)	(0.195)
After*Connected departure*Customer R&D			-0.390**	-0.008
			(0.041)	(0.942)
Connected departure*Customer R&D			0.359*	-0.151
			(0.071)	(0.183)
After*Customer R&D			0.334***	0.197*
			(0.000)	(0.062)
Connected departure	0.032***	0.007	-0.002	0.012**
	(0.001)	(0.156)	(0.867)	(0.028)
Control variables	X	X	X	X
Year FE	X	X	X	X
Industry FE	X		X	
Firm FE		X		X
Observations	414	414	414	414
Adjusted R-squared	0.604	0.920	0.576	0.917

	(1)	(2)	(3)	(4)
Dependent variable	Log(patents)	Log(patents)	Log(citations)	Log(citations)
After	-0.115	0.047	0.087	0.016
	(0.321)	(0.612)	(0.364)	(0.836)
After*Connected departure	-0.410**	-0.279*	-0.283*	-0.172
	(0.032)	(0.058)	(0.074)	(0.226)
Connected departure	0.334**	0.219*	0.221	0.180
	(0.050)	(0.071)	(0.131)	(0.203)
Control variables	X	X	X	X
Year FE	X	X	X	X
Industry FE	X		X	
Firm FE		X		X
Observations	404	404	404	404
Adjusted R-squared	0.758	0.895	0.424	0.623

Panel C: Departures due to deaths

	(1)	(2)	(3)	(4)
Dependent variable	Supplier R&D	Supplier R&D	Supplier R&D	Supplier R&D
After	0.001	0.002	-0.007	0.002
	(0.854)	(0.742)	(0.343)	(0.758)
After*Connected death	-0.018*	-0.015**	-0.007	-0.012
	(0.094)	(0.037)	(0.517)	(0.138)
After*Connected death*Customer R&D			-1.291**	-0.199
			(0.043)	(0.646)
Connected death*Customer R&D			2.086**	0.189
			(0.027)	(0.802)
After*Customer R&D			1.157**	0.023
			(0.043)	(0.924)
Connected death	0.052***	0.019*	0.015	0.015
	(0.000)	(0.085)	(0.486)	(0.361)
Control variables	X	X	X	X
Year FE	X	X	X	X
Industry FE	X		X	
Firm FE		X		X
Observations	269	269	269	269
Adjusted R-squared	0.814	0.948	0.844	0.947

	(1)	(2)	(3)	(4)
Dependent variable	Log(patents)	Log(patents)	Log(citations)	Log(citations)
After	0.076	0.055	0.057	0.058
	(0.210)	(0.542)	(0.302)	(0.391)
After*Connected death	-0.238**	-0.260*	-0.151*	-0.175**
	(0.034)	(0.072)	(0.050)	(0.018)
Connected death	0.292**	0.167	0.136*	0.119
	(0.041)	(0.124)	(0.086)	(0.205)
Control variables	X	X	X	X
Year FE	X	X	X	X
Industry FE	X		X	
Firm FE		X		X
Observations	242	242	242	242
Adjusted R-squared	0.401	0.662	0.320	0.638

Appendix A. Variable definitions

Variable	Definitions
Dependent variables	
Supplier R&D	Supplier's R&D expenses (XRD) over book value of total assets (AT).
Alliance	Dummy variable: 1 if the supplier has established a strategic alliance with the customer and 0 otherwise.
Cross citation	Dummy variable: 1 if the supplier has produced any patent that cites the customer's patent in year t+1 and 0 otherwise.
Log(cross citations)	Natural logarithm of one plus the total number of citations made by supplier's patents filed (and eventually granted) in year t+1 toward customer's patents.
Log(patents)	Natural logarithm of one plus a firm's total number of patents filed (and eventually granted) in year t+1.
Log(citations)	Natural logarithm of one plus a firm's total number of non-self-citations received on the firm's patents filed (and eventually granted), scaled by the number of the patents filed (and eventually granted) in year t+1.
Social connections	
Connected	Dummy variable: 1 if at least one education connection or prior employment connection exists between the supplier and customer and 0 otherwise.
Log(connections)	Natural logarithm of one plus the supplier's total number of education and prior employment connections with the customer.
Supplier characteristics	
Supplier size	Natural logarithm of the supplier's book value of total assets (AT).
Supplier leverage	Supplier's book value of debts (DLTT + DLC) over market value of total assets (AT - CEQ + CSHO × PRCC).
Supplier MB ratio	Supplier's market value of total assets (AT - CEQ + CSHO × PRCC) over book value of total assets (AT).
Supplier tangibility	Supplier's net PPE (property, plant and equipment) (PPENT) over book value of total assets (AT).
Supplier ROA	Supplier's income before extraordinary items (IB) over book value of total assets (AT).
Supplier Capex	Supplier's capital expenditures (CAPX) over book value of total assets (AT).
HIndex	The sum of squared market shares in sales (SALE) of the supplier's industry. Industry is defined using two-digit SIC code.
Customer characteristics	
Customer R&D	Customer's R&D expenses (XRD) over book value of total assets (AT).
Customer leverage	Customer's book value of debts (DLTT + DLC) over market value of total assets (AT - CEQ + CSHO × PRCC).
Sales to customer	Supplier's sales to the customer (SALECS) firm scaled by supplier's book value of total assets (AT).
Distance	The geographical distance (in miles) between the headquarters of the supplier and its customer.