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# Buyers, Suppliers, and R&D Spillovers *

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## Abstract

The role of buyers and suppliers has received little attention in the literature on research and development (R&D) spillovers and productivity, which has focused primarily on the moderating roles of technological and geographic proximity. In this study, we examine R&D spillovers that result from buyer and supplier relationships at the transaction level, utilizing a unique dataset identifying individual buyers and suppliers of Japanese manufacturing firms, matched with data from R&D surveys and the Census of Manufactures. In an analysis of more than 20,000 Japanese manufacturing plants, we find that R&D stocks of buyers and suppliers provide a substantial productivity performance premium over and above the effect of technologically and geographically proximate R&D stocks. These effects are magnified if the supplier and buyer have business group ties based on capital ownership relationships. While the effects of technologically proximate R&D decay with distance, this is not the case for spillovers from buyers and suppliers. Our results identify transaction-based spillovers as a key influence on productivity and social returns to R&D.

*Keywords*: Productivity, Location, R&D, Spillovers
*JEL codes*: D24, O32.



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## 1. INTRODUCTION

The extant literature on R&D spillovers and social returns to R&D has largely focused on the attenuating roles of geographic and technological distance between firms (Jaffe et al., 1993; Adams and Jaffe, 1996; Aldieri and Cincera, 2009; Lychagin et al., 2010; Bloom et al., 2013; Orlando, 2004; Griffith et al., 2009; Mairesse and Mulkay, 2008). These studies examine the productivity effects of 'pure' knowledge spillovers due to the partial public good nature of knowledge, independent of any transactions between firms. Much less attention has been given in this literature to 'transaction based' R&D spillovers that result from buyer and supplier relationships and how they influence productivity growth. A separate stream of literature on the role of spillovers in the context of foreign direct investments has, however, suggested that 'vertical' spillovers through buyer-supplier relationships is often a key channel through which spillovers due to multinational firms' investments in local firms occur (e.g. Haskel et al., 2007; Görg and Strobl, 2001; Javorcik, 2004; Kugler, 2006). Similarly, research based on community innovation surveys regarding the sources of knowledge for the effective innovation of firms has demonstrated the relative frequency and importance of knowledge originating from buyers and suppliers as opposed to firms in the same industry (e.g. Belderbos, Carree, and Lokshin, 2004; Belderbos, Gilsing, and Lokshin, 2012; Crespi et al., 2008).

In this study, we examine the relative importance of R&D spillovers from buyers and suppliers as compared with R&D spillovers from geographically and technologically proximate firms. In contrast to prior work that has made use of input-output tables to establish indicators of 'relational proximity' (e.g. Goto and Suzuki, 1989) we identify the presence of actual transaction relationships between pairs of firms by utilizing a unique dataset identifying the major individual buyers and suppliers of Japanese manufacturing firms in 2006 as well as capital ties between the firms. We match this data with plant-level micro data drawn from the census of manufacturers and Japan's comprehensive R&D survey to analyse plant-level total factor productivity in relationship with firms' own R&D stock, geographically and technologically distributed R&D stocks of the population of other firms in Japan, and the R&D stocks of the firms suppliers and buyers. The R&D survey data in combination with the census data allows us to construct relevant R&D stocks weighted by technological proximity between industries (e.g. Bloom et al., 2013), while the information on plant locations allows us to explore the role of geographic distance between firms. We utilize data on bilateral buyer-supplier linkages in the database compiled by Tokyo Shoko Research (TSR, 2006) and can examine the relationship with productivity for more than 20,000 manufacturing plants. We adopt the standard knowledge stock augmented production function framework (e.g. Hall et al., 2012). We identify distance effects by estimating exponential decay parameters for plant-level R&D stocks (e.g. Lychagin et al., 2010; Duranton and Overman, 2005). Our key research objectives are to 1) establish the role of R&D spillovers through buyer and supplier linkages – with and without capital relationships with the focal firm – in comparison with the influence of general spillovers due to geographic and technological proximity, and 2) to assess the (reduced) effect of geographic distance on the magnitude of spillovers in cases in which there is an established buyer-supplier relationship.

We note that knowledge spillovers in buyer-supplier relationships will have purposeful and pecuniary elements. First, since knowledge usually has important tacit and non-codified elements and is costly to transfer (e.g. Teece, 1977; Feldman and Lichtenberg, 1998), buyer or supplier interactions between firms are likely to aid information flows and may assist in effective knowledge spillovers or purposeful knowledge transfers. Second, to the extent that knowledge due to suppliers is embedded in intermediate inputs, its value tends not to be fully reflected in the price of such intermediates, leading to 'pecuniary' or rent spillovers due to transactions with suppliers (Hall et al., 2012; Crespi et al., 2008).[1] In this case, productivity increases on the part of the clients do not necessarily represent technological advances or externalities. Belderbos and Mohnen (2013) argue that productivity-enhancing effects of pecuniary spillovers are hard to dissociate from spillover effects. Tacit knowledge flows may occur in addition to the rent generating effects of the input supplied. Firms utilizing the higher quality, technology-embodied inputs will often have to adapt technologies and processes to optimize the use of these inputs, creating productivity benefits, and potentially providing technological opportunities for further productivity improvement. Hence, pecuniary spillovers will often incorporate or be correlated

[1] We note that rent spillovers are unlikely to be a feature of customer-originating spillovers. The role of pecuniary spillovers due to mispricing are less likely to play a role or to play a different role: quality improvements may be less reflected in the price of the intermediate inputs, as sophisticated, demanding users providing guidance on specifications and standards are probably able to negotiate input prices downwards. Any productivity improvement due to customer interaction is therefore most likely to reflect improved quality of products and processes.

with elements of 'pure' knowledge spillovers and technological advances in the downstream industry. Compared with 'horizontal' spillovers within narrowly defined industries among firms in technological proximity of one another, the absence of market rivalry provides greater incentives for productivity and growth enhancing knowledge exchange and spillovers through supplier-buyer relationships (e.g. Bloom et al., 2013). Studies demonstrating a positive relationship between knowledge originating with suppliers and firm innovation performance attest to this (e.g. Belderbos, Carree, and Lokshin, 2004; Belderbos and Grimpe, 2012). In the current study, we are unable to disentangle rent spillover from knowledge spillover effects in buyer-supplier relationships. We do disentangle technological proximity and 'relational' proximity effects by identifying (plants of) individual buyers and suppliers, their industries, and their geographic proximity to the focal firm's plants.

Our study relates to a limited set of papers examining productivity effects of supplier and buyer relationships. Crespi et al. use direct measures of knowledge flows as they are revealed in U.K. innovation surveys to establish a relationship with Total Factor Productivity (TFP). They find that knowledge spillovers from competitors and suppliers contribute to TFP growth and complement intra-firm technology transfers. Belderbos and Grimpe (2012), using German innovation survey data, find positive productivity effects of knowledge flows from domestic customers and competitors. These studies did not identify specific buyers or suppliers and the R&D conducted or not. A recent exception is the study by Isaksson, Simeth, and Seifert (2014), which examines the relationship between firms' patent productivity and the patent productivity of major buyers for 192 supplying firms in the U.S. They find positive buyer effects in particular if the buyer relationship is long lasting. Another exception is Todo et al. (2015), who examine the effects of buyer-supplier networks on firms' productivity and innovative capability (measured by the number of patent applications), focusing on the role of geographic proximity. They find positive effects of the number of distant suppliers and neighbouring clients on productivity and positive effects of the number of distant suppliers and clients on innovative capability. However, Todo et al. (2015) do not examine the effects of spillovers from external knowledge sources captured by R&D investment or patent stock outside the firm. Earlier work on R&D and productivity in business groups also identified individual firms, but has been limited to identified, publicly listed firms with business group ties. Suzuki (1993) and Branstetter (2000) find positive effects on productivity growth of R&D stocks when there are related firms in the Japanese business group, and they attribute this to intra-group knowledge sharing and stable supply relationships (Belderbos, Wakasugi, and Zou, 2012).

Our study is the first to provide direct evidence on the relationship between productivity and R&D investments of both individual buyers and suppliers. We find that R&D stocks of buyers and suppliers provide a substantial productivity performance premium over and above the effect of technologically and geographically proximate R&D stocks. These effects are magnified if the supplier and buyer have capital ties. While the effects of technologically proximate R&D decay with distance, this is not the case for spillovers from buyer and supplier plants. While distance is likely to affect the likelihood that transaction relationships occur, as exemplified by geographically concentrated buyer and supplier plants, given that transactions take place, distance no longer attenuates knowledge spillovers. Our results identify transaction-based spillovers as key influences on productivity and social returns to R&D.

## 2. MODEL AND FRAMEWORK

We conduct a plant-level panel analysis of total factor productivity, in which we relate plant-level TFP to R&D spillover pools, and in particular R&D stocks of the individual suppliers and buyers of the firm that operates the plant. The models include firms' own R&D stock and a set of plant-, firm-, and industry-level controls. We assume that firm-level R&D stocks are available to all the firms' plants and that R&D spillovers occur between plants due to the R&D stock to which the plants have access. This allows us to investigate the geographic dimension of R&D spillovers in detail, taking into account the population of R&D-conducting firms in Japan, the plants of individual suppliers and customers, and the spatial configuration of these plants.

We adopt the standard knowledge stock augmented production function framework (e.g. Hall et al., 2012). We define the production function of plant *i* operated by firm *j* as:

$$Q_i = f(L_i, K_i, M_i)g\left(R_{f_i}, S_i, \mathrm{X}_i\right)U_i \quad (1)$$

where:

$Q_i$: Gross output of plant $i$

$L_i, K_i, M_i$: Inputs of plant $i$ in year $t$

$R_{f_i}$: Firm-level R&D stock available to plant $i$ ($f_i$ denotes the firm plant $i$ belongs to)

$S_i$: R&D spillover pool due to all other plants in Japan

$\mathrm{X}_i$: a vector of observable firm and plant-level variables affecting plant productivity

$U_i$: plant-year specific unobserved efficiency influences

Total factor productivity (TFP) is defined as:

$$TFP_i \equiv \frac{Q_i}{f(L_i, K_i, M_i)} = g\left(R_{f_i}, S_i, \mathbf{X}_i\right) U_i \tag{2}$$

R&D stocks are assumed to influence production with a two-year lag to reflect that the application of new knowledge and insights due to R&D takes time.[2] If we adopt a log-linear specification for $g\left(R_{f_i}, S_i\right)$ and model $U_{it} = e^{\mu_{s_i} + \varepsilon_i}$, we obtain:

$$\ln TFP_i = \alpha_R \ln R_{f_i} + \alpha_S \ln S_i + \alpha_X \mathrm{X}_i + \mu_{s_i} + \varepsilon_i \tag{3}$$

where $\mu_{s_i}$ represents industry effects (with $s_i$ denoting the industry of plant $i$) and $\varepsilon_i$ represents measurement error.

R&D spillovers $S_i$ may stem from R&D conducted at technologically proximate plants and from R&D conducted by individual suppliers and customers. Each plant with access to parent firm R&D is a potential source of spillovers due to these exponents of technological or supplier-buyer relatedness. To avoid double counting of R&D stocks in cases in which firms operate multiple plants, we allocate firms' R&D stocks to their plants based on the output share of the plant in the firm's total production in Japan. The total spillover pool available to plant *i* of firm *f* is defined as the weighted sum of other all other firms' R&D stocks in Japan:

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[2] The lag between firms' own R&D investment and productivity is taken to be one year. Results are robust to the specific lag chosen.

$$S_i = \sum_{f' \neq f_i} \sum_{i' \in P_{f'}} w_{ii'} \frac{O_{i'}}{O_{f'}} R_{f'} \quad (4)$$

where $P_{f'}$ denotes the set of plants owned by firm $f'$, $w_{ii'}$ is the spillover weight of plant $i'$ to plant $i$, $O_{i'}$ is the output of plant $i'$, $O_{f'}$ is the total output of firm $f'$, and $R_{f'}$ is the R&D stock of firm $f'$. The spillover weight depends on technological relatedness between the industries of the plants $i'$ and $i$, $T(s_i, s_{i'})$, the geographic distance between the plants, $d_{ii'}$, and the presence of and type of buyer-supplier relationships between firms operating these plants, $I_k(f_i, f_{i'})$. We distinguish two types of capital relationships, as there may be asymmetry depending on which party is the controlling firm: suppliers or customers that are shareholders of the focal firm, and suppliers or customers in which the focal firm holds equity. We model this as follows:

$$w_{ii'} = \left(1 - \sum_k I_k(f_i, f_{i'})\right) T(s_i, s_{i'}) e^{\tau_o d_{ii'}} + \sum_k I_k(f_i, f_{i'}) \left[T(s_i, s_{i'}) + \delta_k\right] e^{\tau_k d_{ii'}} \quad (5)$$

where $I_k(f_i, f_{i'})$ is an indicator function taking the value one in case of the following specific inter-firm relationships:

- $I_{bo}(f_i, f_{i'}) = 1$ if the firm of plant $i'$ buys from and is not a shareholder of the firm of plant $i$
- $I_{so}(f_i, f_{i'}) = 1$ if the firm of plant $i'$ supplies and is not a shareholder of the firm of plant $i$
- $I_{bh}(f_i, f_{i'}) = 1$ if the firm of plant $i'$ buys from and is a shareholder of the firm of plant $i$
- $I_{sh}(f_i, f_{i'}) = 1$ if the firm of plant $i'$ supplies and is a shareholder of the firm of plant $i$.

$\delta_k$ is a parameter to be estimated reflecting the differential importance of specific plants belonging to parent firms with a specific buyer-supplier relationship type $k$. $d_{ii'}$ is the geographic distance between plant $i$ and plant $i'$. $\tau_k$ is a decay parameter to be estimated (with $\tau_k < 0$).

Hence, in the absence of supplier or customer relationships ($I_k(f_i, f_{i'}) = 0$ for all $k$), the spillover weight is just a function of technological proximity and distance (with distance decay parameter $\tau_o$); the estimated elasticity of productivity with respect to the R&D spillover pool is $\alpha_S$ in equation (3). In the presence of supplier or customer relationships, the model allows for an additional spillover effect $\delta_k$ (a spillover 'mark-up') on top of the 'base' effect of technological proximity, while simultaneously allowing differential geographic decay functions $\tau_k$. We expect the strongest spillovers from the 'major' firms in vertical chains: the suppliers or customers that are shareholders (e.g. Branstetter, 2000). We model an exponential decay function on the effectiveness of spillovers with parameter $\tau$ to be estimated, in line with recent studies (e.g. Lychagin et al. 2010). Distance *d* is the distance between a pair of locations and is measured as the geo-distance between the centre of cities, wards, towns, and villages. In order to correct for differences in the geographic areas covered by the regions, distance is the radius of the region if plants are located in the same region.

## 3. DATA SOURCES AND SAMPLE

We match plant-level data from the Japanese *Census of Manufacturers* with information on R&D expenditures from the yearly (comprehensive) *Survey of R&D Activities* in Japan, and information on buyer-supplier linkages in the database compiled by Tokyo Shoko Research (TSR, 2006)[3]. The manufacturing census comprehensively covers manufacturing plants with more than four employees. The Survey of R&D Activities in Japan is a comprehensive and mandatory survey of R&D-performing firms in Japan with a response rate of approximately 90 per cent. Large firms (with more than 1 billion Yen in capital) are always included in the survey; smaller firms are included in the survey more frequently if they are identified as R&D-conducting firms in the previous survey. In our analysis, we only include plants of firms responding to the R&D surveys, as we require valid information on firms' own R&D expenditures or on the absence thereof. In terms of R&D spillover pools, we sought comprehensiveness by using the weights provided in the R&D survey to correct for non-response and to arrive at an estimate of total

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3 This study utilizes data licensed from TSR to Research Institute of Economy, Trade and Industry (RIETI) in 2006.

R&D expenditures in Japan and their distribution over locations. The TSR data was collected for the purpose of credit rating services. It identifies the most important buyers and suppliers of Japanese firms, with a maximum of 24. The 2006 version of the data represents the actual buyers and suppliers in 2005. By combining buyers and suppliers mentioned in the survey from both sides (buyers reporting suppliers and suppliers reporting buyers), the number of identified buyers and suppliers is further increased. We can match close to 12,000 firms in the TSR data to the R&D surveys. These firms operated more than 20,000 manufacturing plants in Japan in 2005. For about 40 per cent of the plant observations, plants are owned by parent firms for which we could confirm the absence of formal R&D.

We utilize plant-level TFP data from the Japan Industrial Productivity Database (JIP) 2010 (Fukao et al., 2008). TFP is measured using the index number method (see Belderbos et al., 2013). One of the main advantages of the index number method is that it allows for heterogeneity in the production technology of individual firms, while other methods controlling for the endogeneity of inputs (e.g. Olley and Pakes, 1996; Levinsohn and Petrin, 2003) assume an identical production technology among firms within an industry (Van Biesebroeck, 2007; Aw et al., 2001). TFP data are calculated for 58 manufacturing industries (see Table 1). TFP data are currently available up to the year 2007. R&D stocks are calculated via the perpetual inventory method. We use industry-specific depreciation rates to reflect differences in the speed of obsolescence and technology life cycles. Industry-specific depreciation rates are based on Japanese official surveys of the 'life-span' of technology conducted in 1986 and 2009 among R&D conducting firms[4] and vary between 8 (food industry) and 25 per cent (precision instruments). To calculate initial R&D stocks (Hall and Oriani, 2006), we similarly use industry-specific growth rates, which we calculate from the R&D survey as average R&D growth rates per field in the 1980s**.** R&D investments are deflated using a deflator for private R&D from the JIP database, calculated from the price indices of the input factors for R&D expenditures for each industry. We calculate focal plant-level R&D stocks as the R&D stock of the parent, assuming that all parent firm R&D provides relevant productivity-improving inputs to

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[4] See "White Paper on Science and Technology" (1986, Science and Technology Agency) and "Survey on Research Activities of Private Corporations" (2009, National Institute of Science and Technology Policy).

the plants.[5] Zero R&D cases are not compatible with the specification in natural logarithms in (3) but provide important variation in the sample. We deal with this by including for R&D engagement and by adding the value one to the R&D stock before taking the logarithm (e.g. Klette, 1996). When calculating R&D stocks by location and industry, we avoid double counting by allocating parent firms' R&D stocks to their plants based on the output share of the plant in the total output of all the firm's plants. We map R&D stocks across industries and space by using the information on the location of the plant, where we distinguish more than 1,800 cities, wards, towns, and villages, and the bilateral distances between these. Distance is measured as the geo-distance between the centre of cities, wards, towns, and villages. In order to correct for differences in the geographic areas covered by the regions, distance is the radius of the region if plants are located in the same region. The technological relatedness measure is derived from patent data and based on Leten et al. (2007). The relatedness between technologies will be reflected in the intensity with which technologies in a field build on prior art in a different field. Patent citation data are available at the four-digit International Patent Classification (IPC) level. The IPC codes can subsequently be mapped onto industries using the industry-technology concordance table developed by Johnson (2002) in which each technology field is linked to corresponding Japan Standard Industry Classification (SIC) codes.

The vector of plant- and firm-specific characteristics $\mathbf{X}_i$ in equation (3) includes, in addition to parent R&D stock (in logs) and the dummy for positive R&D stock, plant size (number of employees), a dummy variable indicating whether the plant is active in multiple industries (at the four-digit level), a dummy taking the value one if the plant is exiting in the subsequent year, a dummy taking the value one if the plant was established the previous year, plant age, firm age, the number of firm employees, and the number of plants operated by the firm. The entry and exit dummies are included to control for unobserved plant heterogeneity (Adams and Jaffe, 1996). The models also include a set of industry dummies.

**Specification**

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[5] Given that R&D at the firm level is often organized to benefit from scope economies (e.g. Henderson and Cockburn, 1996; Argyres and Silverman, 2004) and involves active knowledge transfer to business units and plants, this may be a suitable assumption.

The empirical models relate TFP of the plants in 2007 to parent firm R&D in 2006 and R&D spillover stocks in 2005, with buyer-supplier relationships measured in 2005. Given that we only have one year in which we can measure buyer and supplier relationships, the analysis has to be limited to a cross section. Hence, equation (3) is estimated as a nonlinear regression model (due to the specification of the spillover pool exponential form of the distance effects and the differencing effects of the types of buyer-relationships[6]). We assume that the buyer and supplier relationships are relatively stable – which is not a demanding assumption for the two-year period we consider and given the relatively stable buyer supplier relationships in Japan.

The cross-section specification and the inability to control for all unobserved heterogeneity make it difficult to interpret the estimates as causal relationships. In future work, we aim to identify the effects of supplier and buyer R&D spillovers through changes in R&D stocks by estimating a differenced equation. Identification will require sufficient change in these stocks or in the plants of buyers and suppliers embedding these R&D stocks (through entry and exits), or it will require potential changes due to plant entry and exits. Another and more onerous caveat is potential endogeneity through reverse causality. It is conceivable that the most productive buyers are attracted to suppliers with the highest R&D stocks and vice versa. In a supplementary analysis, however, we show that this is not the case in practice. Rather, existing productivity is negatively related to relationships with buyers and suppliers with both positive R&D stocks and the highest R&D stocks.

**Descriptive Statistics**

Table 1 shows the distribution of plants over industries. The largest numbers of plants are active in miscellaneous foods, fabricated metals, special machinery, and motor vehicle parts. Supplier R&D stocks are highest in semiconductors, motor vehicles, and communication equipment. Customer parent stocks are generally higher and most prominent in electronics parts, semiconductors, miscellaneous machinery, communication equipment, electronic measurement equipment, and computers. The smallest customer and supplier R&D stocks are generally found

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[6] The distance decay parameters, $\tau_k$, and the parameter reflecting the relative importance of each type of the buyer-supplier relationships, $\delta_k$, are estimated using a Taylor approximation. See Belderbos et al. (2013) for details.

in food industries, textiles, and cement. R&D stocks of capital ownership-related suppliers and buyers are most prominent in electronics equipment, semiconductors, other transportation, chemical fibres, and organic chemicals, electronics and semiconductors, communication equipment, electrical machinery, and motor vehicles (customers).

Table 2 provides a set of descriptive statistics for the sample and variables. In addition to the variable descriptives for the focal plant and firms (the top panel), a comparison is made between two groups: 1) total numbers of suppliers in the TSR data and those suppliers and customers that are in manufacturing industries and can be linked to the census and 2) suppliers and customers with positive R&D stock providing R&D spillovers. The bottom panel describes the actual suppliers and customer R&D stock variables. Table 3 shows correlations between the variables. High correlations are generally only observed for variables that are not simultaneously included in the models (e.g. supplier R&D stock and affiliated supplier R&D stock). An exception is the correlation coefficient of 69 per cent between affiliated suppliers' and customers' R&D stocks. This correlation is due to the presence of vertically integrated core manufacturing firms controlling firms at both the supply and demand sides. In practice, this makes it difficult to identify the effects of all four capital stock-related buyers and suppliers. We will report results in the current paper with 1) suppliers (buyers) that are major shareholders of the focal firm (where we expect most directional knowledge flows) and 2) a broader definition of capital ties with R&D stocks of suppliers (buyers) that are either affiliated firms controlled by the focal firm or major shareholders of the focal firm.

Figure 1 shows the distance between the focal plants and R&D conducting plants providing potential R&D spillovers. The median distance from supplier and buyer plants is about 170 kilometres, half the distance from other manufacturing plants. For those plants operated by R&D investing firms, the median distance is smaller, at 115 kilometres. Roughly half of these plants are located within a 100-kilometre radius.

## 4. EMPIRICAL RESULTS

Table 4 shows the results of the models distinguishing generic spillovers, spillovers from suppliers and buyers, and spillovers from buyers and suppliers that are a major shareholder of the focal firm. Model 1 only contains general R&D spillovers and Models 2-5 add specific spillovers. In Model 1, the coefficient for parent R&D suggests an elasticity of TFP with respect to R&D of 0.021 per cent, which is at the lower end of the plant-level elasticities estimated in earlier work (Adams and Jaffe, 1996; Belderbos et al. 2013). The elasticity of the private R&D stock is lower at 0.007 per cent, while spillover effects decay with distance, as the significant distance parameter suggests. The coefficient for the private R&D stock increases to 0.015 when the models contain more detail regarding the source of spillovers and include a separate distance coefficient for buyers and suppliers. Model 3 shows that there is a spillover premium if R&D stocks belong to buyers or suppliers and that the effects of these spillovers do not decay with distance. Model 4 suggests that supplier spillovers have the highest premium; Model 5 indicates that spillovers of supplying firms that are shareholders of the focal firm result in by far the highest productivity effects. The control variable indicates a positive relationship between productivity and recent entry and a negative association with multi-plant firms, the number of other plants of the firm, subsequent exit, and plant age (in its squared form). Firm age has an inverted-u shaped relationship with productivity.

Table 5 focuses on the role of spillovers from affiliated firms rather than shareholding firms. As discussed above, since relationships with affiliated firms occur often simultaneously with suppliers and with buyers (a feature of larger firms controlling the vertical chain), we aggregate supplier and buyer spillovers in this case. The results indicate that while spillovers from shareholders are about twice as large, spillovers from affiliated firms also play an important role and feature a significant and large premium.

The decay function for spillovers from plants that are not buyers or suppliers, based on the results in Table 4, Model 5, is depicted in Figure 2. Spillover effects decline and become negligible at about 300 kilometres. This pattern suggests somewhat stronger decay effects compared to the estimates reported in Belderbos et al. (2013) for Japanese plants and in Lychagin et al. (2010) for U.S.-listed manufacturing firms based on inventor locations. One explanation for the stronger estimated decay effects is that the separate estimation of distance effects due to buyer and supplier spillovers, brings the remaining R&D spillover variable closer to a 'pure' spillover measure unaffected by transactional transfers. Pure spillovers tend to occur in closer vicinity.

**Supplementary analysis**

We modelled the spillovers from buyers and suppliers as additive to the effect of technological proximity. An alternative specification is to model these as multiplicative. The choice between the two is not trivial: in the latter case, the assumption is that the effect of buyers and suppliers spillovers is strongly reduced if the buyer and supplier industries share no specific technologies. In general, we found much weaker effects in this specification, indicating that productivity gains can occur in the absence of technological proximity, as long as there is relational proximity.

We also addressed the issue of endogenous 'matching' of suppliers and buyers. In an auxiliary regression, buyer and supplier R&D stocks were regressed on the focal firm's past TFP and two sets of industry dummies - for the focal plant and for the industry of the buyer (supplier). Empirical results reported in Table 6 strongly suggest that there is negative, rather than a positive, effect of prior TFP on the likelihood that the firm's buyer or supplier invests in R&D, and on the level of the R&D stock of buyers and suppliers. Although this is a surprising pattern that invites further investigation in future work, it does suggest that the estimated R&D spillover effects of buyers and suppliers are not likely to be biased by reverse causality.

## 5. CONCLUSIONS

The role of buyers and suppliers has received little attention in the literature on R&D spillovers and productivity, which has focused primarily on the moderating roles of technological and geographic proximity. In this paper, we have examined R&D spillovers due to buyer and supplier relationships at the transaction level, utilizing a unique dataset identifying individual buyers and suppliers of Japanese manufacturing firms, matched with data from the census of manufacturers and R&D surveys. In an analysis of more than 20,000 Japanese manufacturing plants, we find that R&D stocks of buyers and suppliers provide a substantial productivity performance premium over and above the effect of technologically and geographically proximate R&D stocks. These effects are magnified if the supplier and buyer have business group ties based on capital ownership relationships. The strongest such effects are observed for spillovers from buyers of suppliers that are the ‘core’ firms in the vertical chain and are shareholders of the focal firm. The latter finding is consistent with prior findings for the automobile and electronics industries in Japan (e.g. Branstetter, 2000; Suzuki, 1993). While distance is likely to affect the likelihood that transaction relationships occur, as exemplified by geographically concentrated buyer and supplier plants, given that transactions take place, distance no longer attenuates knowledge spillovers. We confirmed that the associations we find are not driven by a matching process in which the more productive firms tie up with R&D intensive suppliers and customers. Our results identify transaction-based spillovers as key influences on productivity and social returns to R&D.

We envisage addressing a number of specification issues and undertaking supplementary analyses in future work, of which we mention three. First, we aim to assess the magnitude of buyer and supplier spillovers compared to R&D spillovers from other plants by performing a decomposition analysis. While the effects of (capital-related) buyer and supplier spillovers are large, such relationships are also relatively rare compared with the spillovers from the population of (technologically proximate) plants. It is then of interest to gain insight into the overall contribution of supplier- and buyer-related spillovers to productivity. Second, it may be of interest to investigate potential spillovers from capital relationships in the absence of supplier or buyer ties. Third, we aim to perform a sensitivity analysis related to the likely imperfect coverage of buyer and supplier relationships in the TSR data, e.g. by limiting the analysis to firms with a minimum number of suppliers and buyers or by including indicators regarding the presence of limited information in the TSR data.

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## Table 1. Sample characteristics

| Industry (JIP industry classification) | Number of unique plants | Number of unique firms | Total R&D stock (billion yen) | Avg. # of major business partners with R&D stock | | | | | | Total R&D stock of major business partners (billion yen) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Buyer -shareholder | Buyer - affiliated | Buyer - no capital ties | Supplier -shareholder | Supplier - affiliated | Supplier - no capital ties | Buyer -shareholder | Buyer - affiliated | Buyer - no capital ties | Supplier -shareholder | Supplier - affiliated | Supplier - no capital ties |
| 8 Livestock products | 517 | 365 | 353 | 0.2 | 0.0 | 1.1 | 0.2 | 0.0 | 3.5 | 5 | 0 | 21 | 5 | 0 | 77 |
| 9 Seafood products | 363 | 310 | 51 | 0.1 | 0.0 | 0.9 | 0.1 | 0.0 | 1.2 | 0 | 0 | 13 | 1 | 0 | 33 |
| 10 Flour and grain mill products | 55 | 48 | 28 | 0.1 | 0.0 | 1.5 | 0.1 | 0.0 | 1.7 | 1 | 0 | 5 | 0 | 0 | 8 |
| 11 Miscellaneous foods and related products | 1,886 | 1,446 | 1,552 | 0.1 | 0.0 | 1.0 | 0.1 | 0.1 | 2.0 | 18 | 0 | 158 | 15 | 1 | 282 |
| 12 Prepared animal foods and organic fertilizers | 52 | 38 | 47 | 0.1 | 0.1 | 1.4 | 0.1 | 0.1 | 2.1 | 0 | 0 | 3 | 0 | 0 | 11 |
| 13 Beverages | 320 | 241 | 815 | 0.1 | 0.1 | 1.3 | 0.0 | 0.2 | 4.7 | 5 | 0 | 53 | 3 | 1 | 124 |
| 14 Tobacco | 16 | 1 | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 15 Textile products | 616 | 526 | 367 | 0.1 | 0.1 | 1.7 | 0.1 | 0.1 | 1.3 | 18 | 0 | 301 | 13 | 0 | 91 |
| 18 Pulp, paper, and coated and glazed paper | 192 | 141 | 414 | 0.2 | 0.3 | 3.8 | 0.2 | 0.4 | 3.0 | 2 | 1 | 143 | 4 | 1 | 25 |
| 19 Paper products | 708 | 550 | 490 | 0.1 | 0.0 | 4.8 | 0.1 | 0.0 | 1.7 | 6 | 0 | 1,051 | 6 | 0 | 164 |
| 20 Printing, plate making for printing and bookbinding | 1,123 | 977 | 638 | 0.1 | 0.1 | 3.9 | 0.1 | 0.1 | 2.4 | 39 | 0 | 1,530 | 23 | 3 | 508 |
| 22 Rubber products | 341 | 259 | 1,138 | 0.2 | 0.1 | 4.6 | 0.2 | 0.2 | 2.8 | 66 | 0 | 1,354 | 15 | 1 | 66 |
| 23 Chemical fertilizers | 28 | 20 | 23 | 0.3 | 0.1 | 1.4 | 0.6 | 0.1 | 1.4 | 2 | 0 | 9 | 3 | 0 | 4 |
| 24 Basic inorganic chemicals | 164 | 136 | 958 | 0.3 | 0.3 | 4.4 | 0.3 | 0.3 | 2.3 | 24 | 0 | 277 | 22 | 0 | 45 |
| 25 Basic organic chemicals | 6 | 6 | 646 | 0.3 | 5.5 | 24.0 | 0.3 | 3.3 | 16.2 | 0 | 1 | 11 | 0 | 0 | 3 |
| 26 Organic chemicals | 303 | 231 | 4,686 | 0.4 | 1.3 | 8.1 | 0.4 | 0.8 | 5.7 | 54 | 9 | 336 | 47 | 2 | 142 |
| 27 Chemical fibers | 22 | 20 | 998 | 0.3 | 2.8 | 8.4 | 0.3 | 2.1 | 8.6 | 2 | 1 | 15 | 3 | 0 | 7 |
| 28 Miscellaneous chemical products | 553 | 437 | 4,200 | 0.2 | 0.4 | 5.0 | 0.2 | 0.3 | 4.4 | 49 | 4 | 808 | 43 | 2 | 213 |
| 29 Pharmaceutical products | 313 | 254 | 5,513 | 0.2 | 0.3 | 3.6 | 0.2 | 0.4 | 5.0 | 31 | 3 | 214 | 19 | 4 | 124 |
| 30 Petroleum products | 44 | 33 | 325 | 0.2 | 0.1 | 6.4 | 0.1 | 0.1 | 4.3 | 2 | 0 | 120 | 0 | 0 | 10 |
| 31 Coal products | 15 | 14 | 347 | 0.2 | 1.1 | 7.4 | 0.3 | 0.7 | 4.0 | 2 | 1 | 15 | 2 | 0 | 3 |
| 32 Glass and its products | 218 | 161 | 704 | 0.4 | 0.5 | 5.2 | 0.3 | 0.4 | 2.8 | 47 | 1 | 529 | 13 | 1 | 66 |
| 33 Cement and its products | 296 | 202 | 547 | 0.1 | 0.5 | 2.6 | 0.2 | 0.4 | 2.4 | 2 | 1 | 74 | 11 | 1 | 36 |
| 34 Pottery | 91 | 73 | 690 | 0.1 | 0.3 | 3.6 | 0.1 | 0.4 | 3.9 | 1 | 0 | 192 | 1 | 0 | 46 |
| 35 Miscellaneous ceramic, stone, and clay products | 282 | 231 | 849 | 0.3 | 0.2 | 3.9 | 0.2 | 0.2 | 1.7 | 20 | 0 | 553 | 10 | 0 | 48 |
| 36 Pig iron and crude steel | 60 | 45 | 1,255 | 0.4 | 3.0 | 7.1 | 0.2 | 3.7 | 13.8 | 31 | 2 | 187 | 9 | 2 | 18 |
| 37 Miscellaneous iron and steel | 682 | 580 | 1,582 | 0.2 | 0.3 | 4.0 | 0.1 | 0.3 | 2.2 | 98 | 2 | 1,404 | 58 | 2 | 158 |
| 38 Smelting and refining of non-ferrous metals | 85 | 70 | 459 | 0.4 | 0.9 | 6.3 | 0.3 | 0.6 | 2.8 | 6 | 0 | 400 | 4 | 0 | 83 |
| 39 Non-ferrous metal products | 421 | 350 | 1,474 | 0.3 | 0.5 | 4.7 | 0.3 | 0.4 | 2.3 | 92 | 2 | 1,131 | 33 | 1 | 141 |
| 40 Fabricated constructional and architectural metal products | 754 | 668 | 496 | 0.1 | 0.0 | 2.5 | 0.1 | 0.0 | 1.8 | 15 | 0 | 743 | 16 | 0 | 138 |
| 41 Miscellaneous fabricated metal products | 1,551 | 1,329 | 878 | 0.1 | 0.1 | 4.3 | 0.1 | 0.1 | 1.1 | 119 | 3 | 4,040 | 28 | 1 | 389 |
| 42 General industry machinery | 843 | 776 | 9,110 | 0.1 | 0.2 | 4.6 | 0.1 | 0.3 | 4.1 | 157 | 22 | 2,483 | 57 | 7 | 376 |
| 43 Special industry machinery | 1,501 | 1,388 | 8,585 | 0.1 | 0.1 | 3.6 | 0.1 | 0.1 | 2.3 | 185 | 8 | 3,952 | 85 | 3 | 484 |
| 44 Miscellaneous machinery | 802 | 728 | 3,404 | 0.2 | 0.0 | 4.1 | 0.1 | 0.1 | 1.4 | 92 | 1 | 2,620 | 30 | 1 | 182 |
| 45 Office and service industry machines | 328 | 301 | 8,461 | 0.2 | 0.3 | 4.1 | 0.1 | 0.3 | 5.0 | 56 | 16 | 825 | 61 | 8 | 212 |
| 46 Electrical generating, transmission, distribution and industrial apparatus | 913 | 784 | 6,237 | 0.2 | 0.2 | 3.7 | 0.2 | 0.3 | 3.8 | 284 | 4 | 3,071 | 213 | 6 | 696 |
| 47 Household electric appliances | 181 | 166 | 4,392 | 0.1 | 0.8 | 6.3 | 0.1 | 0.8 | 10.6 | 25 | 27 | 699 | 29 | 15 | 236 |
| 48 Electronic data processing machines, digital and analog computer equipment and accessories | 168 | 161 | 4,788 | 0.3 | 0.2 | 3.8 | 0.2 | 0.3 | 3.9 | 124 | 6 | 599 | 90 | 3 | 201 |
| 49 Communication equipment | 264 | 235 | 12,928 | 0.3 | 0.6 | 4.9 | 0.2 | 0.7 | 10.3 | 104 | 23 | 947 | 78 | 13 | 436 |
| 50 Electronic equipment and electric measuring instruments | 285 | 272 | 4,288 | 0.2 | 0.3 | 5.4 | 0.1 | 0.3 | 5.1 | 95 | 16 | 1,500 | 70 | 9 | 239 |
| 51 Semiconductor devices and integrated circuits | 183 | 144 | 7,815 | 0.3 | 0.9 | 4.6 | 0.3 | 1.1 | 13.3 | 107 | 9 | 666 | 85 | 7 | 307 |
| 52 Electronic parts | 934 | 797 | 10,700 | 0.2 | 0.1 | 4.3 | 0.2 | 0.2 | 3.3 | 208 | 9 | 3,912 | 148 | 6 | 723 |
| 53 Miscellaneous electrical machinery equipment | 266 | 219 | 6,684 | 0.3 | 0.3 | 4.9 | 0.2 | 0.4 | 6.8 | 129 | 7 | 901 | 46 | 5 | 222 |
| 54 Motor vehicles | 119 | 94 | 11,707 | 0.4 | 1.4 | 3.4 | 0.3 | 3.3 | 24.6 | 153 | 13 | 232 | 102 | 35 | 249 |
| 55 Motor vehicle parts and accessories | 1,561 | 1,175 | 15,036 | 0.4 | 0.2 | 4.0 | 0.3 | 0.5 | 4.3 | 1,245 | 27 | 5,145 | 564 | 54 | 1,188 |
| 56 Other transportation equipment | 321 | 284 | 2,597 | 0.2 | 0.4 | 3.2 | 0.2 | 0.6 | 8.8 | 55 | 14 | 668 | 92 | 4 | 373 |
| 57 Precision machinery & equipment | 460 | 403 | 2,916 | 0.2 | 0.1 | 3.1 | 0.1 | 0.1 | 2.3 | 86 | 1 | 1,390 | 21 | 0 | 193 |

**Table 2. Descriptive statistics**

| Variables | Mean | S.D. | Median | Min. | 25% | 75% | Max. |
|---|---|---|---|---|---|---|---|
| TFP (ln.) | 0.157 | 0.466 | 0.046 | -3.126 | -0.102 | 0.266 | 3.269 |
| Parent R&D stock (ln.) | 0.973 | 2.024 | 0.000 | -3.653 | 0.000 | 0.000 | 10.751 |
| Parent R&D > 0 (dummy) | 0.247 | 0.431 | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 |
| Unmatched buyers and suppliers | 0.507 | 0.212 | 0.500 | 0.000 | 0.357 | 0.670 | 0.962 |
| Number of other plants (ln.) | 0.565 | 0.718 | 0.000 | 0.000 | 0.000 | 1.099 | 3.555 |
| Number of firm employees (ln.) | 4.955 | 1.195 | 4.682 | 3.401 | 4.043 | 5.557 | 11.133 |
| Number of plant employees (ln.) | 4.530 | 0.858 | 4.344 | 3.401 | 3.871 | 4.984 | 9.298 |
| Multi-products plants (4 digit, dummy) | 0.543 | 0.498 | 1.000 | 0.000 | 0.000 | 1.000 | 1.000 |
| Plant age | 21.126 | 7.383 | 26.000 | 2.000 | 17.000 | 26.000 | 26.000 |
| Firm age | 23.212 | 5.940 | 26.000 | 2.000 | 25.000 | 26.000 | 26.000 |
| Entry plant (dummy) | 0.010 | 0.100 | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 |
| Closing plant (dummy) | 0.000 | 0.007 | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 |
| *Number of major business partners (all)* | | | | | | | |
| Buyer | 62.3 | 279.3 | 11.0 | 0.0 | 6.0 | 23.0 | 4647.0 |
| Supplier | 79.8 | 432.3 | 12.0 | 0.0 | 6.0 | 25.0 | 7488.0 |
| Buyer - no capital ties | 59.2 | 268.3 | 11.0 | 0.0 | 5.0 | 21.0 | 4587.0 |
| Supplier - no capital ties | 77.0 | 422.2 | 11.0 | 0.0 | 6.0 | 24.0 | 7459.0 |
| Buyer or supplier - shareholder | 0.6 | 1.1 | 0.0 | 0.0 | 0.0 | 1.0 | 12.0 |
| Buyer or supplier - affiliated | 5.2 | 26.0 | 0.0 | 0.0 | 0.0 | 1.0 | 398.0 |
| Buyer - shareholder | 0.3 | 0.6 | 0.0 | 0.0 | 0.0 | 1.0 | 8.0 |
| Buyer - affiliated | 2.8 | 15.2 | 0.0 | 0.0 | 0.0 | 1.0 | 293.0 |
| Supplier - shareholder | 0.3 | 0.6 | 0.0 | 0.0 | 0.0 | 0.0 | 9.0 |
| Supplier - affiliated | 2.4 | 11.6 | 0.0 | 0.0 | 0.0 | 1.0 | 176.0 |
| Both buyer and supplier (two-way) | 7.0 | 33.6 | 1.0 | 0.0 | 0.0 | 3.0 | 562.0 |
| Buyer or supplier with two-way capital ties | 0.0 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 | 7.0 |
| Not buyer or supplier - shareholder | 0.9 | 2.0 | 0.0 | 0.0 | 0.0 | 1.0 | 13.0 |
| Not buyer or supplier - affiliated | 2.0 | 10.8 | 0.0 | 0.0 | 0.0 | 0.0 | 271.0 |
| *Number of major business partners in the Census for Manufacturers* | | | | | | | |
| Buyer | 16.2 | 58.2 | 6.0 | 0.0 | 2.0 | 11.0 | 1347.0 |
| Supplier | 29.0 | 134.3 | 5.0 | 0.0 | 3.0 | 12.0 | 2423.0 |
| Buyer - no capital ties | 15.1 | 55.8 | 5.0 | 0.0 | 2.0 | 10.0 | 1313.0 |
| Supplier - no capital ties | 27.8 | 131.1 | 5.0 | 0.0 | 2.0 | 11.0 | 2392.0 |
| Buyer or supplier - shareholder | 0.4 | 0.9 | 0.0 | 0.0 | 0.0 | 0.0 | 10.0 |
| Buyer or supplier - affiliated | 1.9 | 7.7 | 0.0 | 0.0 | 0.0 | 0.0 | 109.0 |
| Buyer - shareholder | 0.2 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 5.0 |
| Buyer - affiliated | 0.9 | 3.7 | 0.0 | 0.0 | 0.0 | 0.0 | 85.0 |
| Supplier - shareholder | 0.2 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 5.0 |
| Supplier - affiliated | 1.0 | 4.2 | 0.0 | 0.0 | 0.0 | 0.0 | 74.0 |
| Not buyer or supplier - shareholder | 0.1 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 7.0 |
| Not buyer or supplier - affiliated | 0.5 | 3.1 | 0.0 | 0.0 | 0.0 | 0.0 | 116.0 |

**Table 2 (continued)**

| Variables | Mean | S.D. | Median | Min. | 25% | 75% | Max. |
|---|---|---|---|---|---|---|---|
| *Number of major business partners with positive R&D stock* | | | | | | | |
| Buyer | 4.0 | 7.6 | 2.0 | 0.0 | 1.0 | 5.0 | 125.0 |
| Supplier | 3.7 | 14.9 | 1.0 | 0.0 | 0.0 | 3.0 | 214.0 |
| Buyer - no capital ties | 3.6 | 6.8 | 2.0 | 0.0 | 1.0 | 5.0 | 123.0 |
| Supplier - no capital ties | 3.3 | 13.5 | 1.0 | 0.0 | 0.0 | 2.0 | 199.0 |
| Buyer or supplier - shareholder | 0.3 | 0.8 | 0.0 | 0.0 | 0.0 | 0.0 | 10.0 |
| Buyer or supplier - affiliated | 0.5 | 3.1 | 0.0 | 0.0 | 0.0 | 0.0 | 73.0 |
| Buyer - shareholder | 0.2 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 5.0 |
| Buyer - affiliated | 0.2 | 1.4 | 0.0 | 0.0 | 0.0 | 0.0 | 19.0 |
| Supplier - shareholder | 0.2 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 5.0 |
| Supplier - affiliated | 0.3 | 1.8 | 0.0 | 0.0 | 0.0 | 0.0 | 57.0 |
| Not buyer or supplier - shareholder | 0.1 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 | 5.0 |
| Not buyer or supplier - affiliated | 0.2 | 1.1 | 0.0 | 0.0 | 0.0 | 0.0 | 29.0 |
| *Plants having a major business partner with positive R&D stock* | | | | | | | |
| Buyer | 0.854 | 0.353 | 1.000 | 0.000 | 1.000 | 1.000 | 1.000 |
| Supplier | 0.704 | 0.457 | 1.000 | 0.000 | 0.000 | 1.000 | 1.000 |
| Buyer - no capital ties | 0.783 | 0.412 | 1.000 | 0.000 | 1.000 | 1.000 | 1.000 |
| Supplier - no capital ties | 0.646 | 0.478 | 1.000 | 0.000 | 0.000 | 1.000 | 1.000 |
| Buyer or supplier - shareholder | 0.207 | 0.405 | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 |
| Buyer or supplier - affiliated | 0.073 | 0.261 | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 |
| Buyer - shareholder | 0.175 | 0.380 | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 |
| Buyer - affiliated | 0.057 | 0.233 | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 |
| Supplier - shareholder | 0.139 | 0.346 | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 |
| Supplier - affiliated | 0.063 | 0.244 | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 |
| Not buyer or supplier - shareholder | 0.072 | 0.258 | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 |
| Not buyer or supplier - affiliated | 0.059 | 0.236 | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 |
| *Total R&D stock of the major business partner (1 billion yen)* | | | | | | | |
| Buyer | 2.329 | 4.577 | 0.272 | 0.000 | 0.012 | 2.420 | 40.965 |
| Supplier | 0.555 | 1.595 | 0.029 | 0.000 | 0.000 | 0.345 | 31.825 |
| Buyer - no capital ties | 2.136 | 4.360 | 0.194 | 0.000 | 0.002 | 2.047 | 38.403 |
| Supplier - no capital ties | 0.443 | 1.368 | 0.012 | 0.000 | 0.000 | 0.264 | 31.825 |
| Buyer or supplier - shareholder | 0.285 | 1.565 | 0.000 | 0.000 | 0.000 | 0.000 | 22.281 |
| Buyer or supplier - affiliated | 0.021 | 0.318 | 0.000 | 0.000 | 0.000 | 0.000 | 9.202 |
| Buyer - shareholder | 0.182 | 1.043 | 0.000 | 0.000 | 0.000 | 0.000 | 11.105 |
| Buyer - affiliated | 0.011 | 0.178 | 0.000 | 0.000 | 0.000 | 0.000 | 5.327 |
| Supplier - shareholder | 0.103 | 0.703 | 0.000 | 0.000 | 0.000 | 0.000 | 11.943 |
| Supplier - affiliated | 0.009 | 0.168 | 0.000 | 0.000 | 0.000 | 0.000 | 6.902 |
| Not buyer or supplier - shareholder | 0.053 | 0.527 | 0.000 | 0.000 | 0.000 | 0.000 | 14.777 |
| Not buyer or supplier - affiliated | 0.005 | 0.059 | 0.000 | 0.000 | 0.000 | 0.000 | 1.705 |

## Table 3. Correlations

| Variables | [1] | [2] | [3] | [4] | [5] | [6] | [7] | [8] | [9] | [10] | [11] | [12] | [13] | [14] | [15] | [16] | [17] | [18] | [19] | [20] | [21] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| [1] TFP (ln.) | 1.000 | | | | | | | | | | | | | | | | | | | | |
| [2] Parent R&D stock (ln. of 100 million yen) | 0.152 | 1.000 | | | | | | | | | | | | | | | | | | | |
| [3] Parent R&D > 0 (dummy) | 0.114 | 0.839 | 1.000 | | | | | | | | | | | | | | | | | | |
| [4] Number of other plants (ln. of +1) | 0.049 | 0.580 | 0.458 | 1.000 | | | | | | | | | | | | | | | | | |
| [5] Number of firm employees (ln.) | 0.149 | 0.683 | 0.542 | 0.704 | 1.000 | | | | | | | | | | | | | | | | |
| [6] Number of plant employees (ln.) | 0.176 | 0.535 | 0.426 | 0.312 | 0.795 | 1.000 | | | | | | | | | | | | | | | |
| [7] Multi-products plants (4 digit, dummy) | -0.032 | 0.093 | 0.087 | 0.001 | 0.066 | 0.130 | 1.000 | | | | | | | | | | | | | | |
| [8] Entry plant (dummy) | -0.002 | -0.014 | -0.016 | 0.003 | 0.012 | 0.006 | -0.018 | 1.000 | | | | | | | | | | | | | |
| [9] Plant age | -0.029 | 0.049 | 0.054 | -0.038 | -0.040 | 0.022 | 0.094 | -0.261 | 1.000 | | | | | | | | | | | | |
| [10] Firm age | -0.014 | 0.158 | 0.163 | 0.242 | 0.150 | 0.059 | 0.044 | -0.194 | 0.710 | 1.000 | | | | | | | | | | | |
| [11] Closing plant (dummy) | -0.002 | -0.003 | -0.004 | -0.005 | 0.005 | 0.011 | 0.006 | -0.001 | -0.009 | -0.014 | 1.000 | | | | | | | | | | |
| [12] R&D stock of suppliers | 0.157 | 0.325 | 0.201 | 0.217 | 0.328 | 0.311 | 0.052 | 0.000 | -0.005 | 0.044 | 0.000 | 1.000 | | | | | | | | | |
| [13] R&D stock of customers | 0.127 | 0.223 | 0.193 | 0.187 | 0.234 | 0.207 | 0.006 | -0.003 | 0.016 | 0.068 | -0.003 | 0.214 | 1.000 | | | | | | | | |
| [14] R&D stock of suppliers without capital ties | 0.138 | 0.266 | 0.153 | 0.191 | 0.256 | 0.236 | 0.043 | -0.001 | 0.009 | 0.048 | 0.000 | 0.892 | 0.165 | 1.000 | | | | | | | |
| [15] R&D stock of customers without capital ties | 0.116 | 0.166 | 0.152 | 0.157 | 0.174 | 0.146 | -0.004 | -0.002 | 0.019 | 0.063 | -0.003 | 0.143 | 0.973 | 0.154 | 1.000 | | | | | | |
| [16] R&D stock of suppliers or customers - shareholders | 0.078 | 0.236 | 0.190 | 0.125 | 0.270 | 0.275 | 0.040 | -0.002 | -0.023 | 0.022 | -0.001 | 0.411 | 0.266 | 0.045 | 0.056 | 1.000 | | | | | |
| [17] R&D stock of suppliers or customers - affiliated | 0.060 | 0.265 | 0.113 | 0.200 | 0.228 | 0.184 | 0.035 | 0.004 | 0.016 | 0.029 | 0.000 | 0.305 | 0.118 | 0.225 | 0.076 | 0.051 | 1.000 | | | | |
| [18] R&D stock of suppliers - shareholders | 0.079 | 0.167 | 0.136 | 0.083 | 0.201 | 0.209 | 0.028 | 0.001 | -0.033 | 0.001 | -0.001 | 0.468 | 0.148 | 0.031 | 0.014 | 0.843 | 0.043 | 1.000 | | | |
| [19] R&D stock of suppliers - affiliated | 0.046 | 0.234 | 0.098 | 0.166 | 0.211 | 0.172 | 0.031 | 0.004 | 0.014 | 0.024 | 0.000 | 0.297 | 0.083 | 0.205 | 0.049 | 0.050 | 0.914 | 0.043 | 1.000 | | |
| [20] R&D stock of customers - shareholders | 0.064 | 0.241 | 0.194 | 0.131 | 0.269 | 0.272 | 0.041 | -0.005 | -0.013 | 0.032 | -0.001 | 0.301 | 0.300 | 0.046 | 0.075 | 0.932 | 0.047 | 0.591 | 0.046 | 1.000 | |
| [21] R&D stock of customers - affiliated | 0.063 | 0.253 | 0.109 | 0.200 | 0.209 | 0.165 | 0.033 | 0.003 | 0.015 | 0.028 | 0.000 | 0.265 | 0.133 | 0.209 | 0.090 | 0.044 | 0.924 | 0.037 | 0.690 | 0.041 | 1.000 |

**Table 4. TFP and buyer-supplier R&D spillovers: unrelated buyers/suppliers vs. shareholders**

| | [1] | [2] | [3] | [4] | [5] |
|---|---|---|---|---|---|
| *τ (distance parameter)* | | | | | |
| all other firms | -0.013<br>[0.00769]* | -0.003<br>[0.00189]* | | | |
| all firms - no supplier/customer relation | | | -0.011<br>[0.00506]** | -0.011<br>[0.00503]** | -0.011<br>[0.00473]** |
| all suppliers and customers | | | 0.000<br>[0.00093] | 0.000<br>[0.00092] | 0.000<br>[0.00085] |
| *δ (spillover 'markup')* | | | | | |
| all suppliers and customers | | 305.028<br>[0.00000]*** | 1.798<br>[0.00054]*** | | |
| all suppliers | | | | 4.180<br>[0.00053]*** | |
| all customers | | | | 1.637<br>[0.00130]*** | |
| suppliers - shareholders | | | | | 46.548<br>[0.00003]*** |
| suppliers - affiliated or no capital ties | | | | | 2.865<br>[0.00096]*** |
| customers - shareholders | | | | | 2.528<br>[0.00007]*** |
| customers - affiliated or no capital ties | | | | | 1.869<br>[0.00094]*** |
| *R&D stock elasticity:* | | | | | |
| Parent R&D stock | 0.021<br>[0.00230]*** | 0.020<br>[0.00230]*** | 0.020<br>[0.00231]*** | 0.020<br>[0.00231]*** | 0.020<br>[0.00231]*** |
| R&D spillover stock | 0.007<br>[0.00203]*** | 0.007<br>[0.00116]*** | 0.014<br>[0.00267]*** | 0.015<br>[0.00273]*** | 0.015<br>[0.00263]*** |
| *Other parameters:* | | | | | |
| Parent R&D stock > 0 (dummy) | 0.000<br>[0.00815] | 0.000<br>[0.00813] | -0.001<br>[0.00814] | -0.001<br>[0.00814] | -0.002<br>[0.00815] |
| Number of other plants | -0.008<br>[0.00481]* | -0.010<br>[0.00482]** | -0.010<br>[0.00482]** | -0.010<br>[0.00482]** | -0.009<br>[0.00481]** |
| Multi-products (4-digit) plant (dummy) | -0.021<br>[0.00357]*** | -0.021<br>[0.00357]*** | -0.021<br>[0.00357]*** | -0.021<br>[0.00357]*** | -0.021<br>[0.00357]*** |
| Number of plant employees | -0.001<br>[0.00495] | -0.002<br>[0.00495] | -0.002<br>[0.00495] | -0.002<br>[0.00495] | -0.002<br>[0.00496] |
| Entry plant (dummy) | 0.050<br>[0.02536]* | 0.048<br>[0.02540]* | 0.048<br>[0.02539]* | 0.048<br>[0.02539]* | 0.050<br>[0.02538]** |
| Plant age | 0.171<br>[0.03894]*** | 0.164<br>[0.03896]*** | 0.165<br>[0.03893]*** | 0.166<br>[0.03892]*** | 0.170<br>[0.03891]*** |
| Plant age squared | -0.032<br>[0.00803]*** | -0.031<br>[0.00803]*** | -0.031<br>[0.00802]*** | -0.031<br>[0.00802]*** | -0.032<br>[0.00802]*** |
| Firm age | -0.170<br>[0.04371]*** | -0.162<br>[0.04380]*** | -0.162<br>[0.04378]*** | -0.162<br>[0.04378]*** | -0.165<br>[0.04374]*** |
| Firm age squared | 0.032<br>[0.00906]*** | 0.030<br>[0.00908]*** | 0.030<br>[0.00908]*** | 0.030<br>[0.00907]*** | 0.031<br>[0.00907]*** |
| Closing plant (dummy) | -0.023<br>[0.00881]*** | -0.030<br>[0.00898]*** | -0.030<br>[0.00885]*** | -0.032<br>[0.00890]*** | -0.030<br>[0.00877]*** |
| Constant | 0.039<br>[0.05901] | 0.022<br>[0.04976] | -0.096<br>[0.06987] | -0.104<br>[0.07087] | -0.113<br>[0.06910] |
| Industry dummies (JIP industry level) | Yes | Yes | Yes | Yes | Yes |
| # observations | 21206 | 21206 | 21206 | 21206 | 21206 |
| R-squared | 0.7052 | 0.7055 | 0.7057 | 0.7058 | 0.7059 |
| F statistic | 50569.65*** | 50643.49*** | 50699.30*** | 50705.69*** | 50739.70*** |
| Relative F statistic | | [1]<br>22.48*** | [2]<br>17.15*** | [3]<br>2.58 | [4]<br>5.71*** |

***p<0.01, ** p <0.05, * p <0.10. Robust standard errors are reported in brackets.

**Table 5. TFP and buyer-supplier R&D spillovers:**
**buyers and suppliers as shareholders vs. affiliated buyers and suppliers**

| | |
|---|---|
| *τ (distance parameter)* | |
| all firms - no supplier/customer relation | -0.014 |
| | [0.00636]** |
| all suppliers and customers | 0.000 |
| | [0.00095] |
| *δ (spillover 'markup')* | |
| suppliers - no capital ties | 3.639 |
| | [0.00066]*** |
| customers - no capital ties | 2.401 |
| | [0.00064]*** |
| suppliers or customers - shareholders | 24.549 |
| | [0.00005]*** |
| suppliers or customers - affiliated | 12.200 |
| | [0.00001]*** |
| Parent R&D stock | 0.021 |
| | [0.00231]*** |
| R&D spillover stock | 0.013 |
| | [0.00229]*** |
| *Other parameters:* | |
| Parent R&D stock > 0 (dummy) | -0.006 |
| | [0.00818] |
| Number of other plants | -0.012 |
| | [0.00477]** |
| Multi-products (4digit) plant (dummy) | -0.021 |
| | [0.00357]*** |
| Number of plant employees | -0.004 |
| | [0.00488] |
| Entry plant (dummy) | 0.050 |
| | [0.02535]** |
| Plant age | 0.171 |
| | [0.03891]*** |
| Plant age squared | -0.032 |
| | [0.00801]*** |
| Firm age | -0.168 |
| | [0.04368]*** |
| Firm age squared | 0.032 |
| | [0.00905]*** |
| Closing plant (dummy) | -0.028 |
| | [0.00871]*** |
| Constant | -0.070 |
| | [0.06365] |
| Industry dummies (JIP industry level) | Yes |
| # observations | 21206 |
| R-squared | 0.7059 |
| F statistic | 50727.48*** |

***p<0.01, ** p <0.05, * p <0.10. Robust standard errors are reported in brackets.

**Table 6. Reverse causality: do high productivity firms self select R&D intensive buyers and suppliers?**

| | Dependent variables | | | |
|---|---|---|---|---|
| Independent variables | ln (supplier R&D) | I(supplier R&D > 0) | ln (customer R&D) | I(customer R&D > 0) |
| ln (plant TFP) | -0,1516 | -0,0258 | -0,3020 | -0,0618 |
| | [0.00521]*** | [0.0015]*** | [0.0120]*** | [0.0025]*** |
| Plant industry dummies | Yes | Yes | Yes | Yes |
| Partners' industry dummies | Yes | Yes | Yes | Yes |
| R squared | 0,103 | 0,097 | 0,221 | 0,184 |
| N | 552.593 | 552.593 | 323.828 | 323.828 |

***p<0.01. Standard errors are in brackets.

**Figure 1. Buyer/supplier relationships and distance between plants (cumulative percentage of total number of plants)**

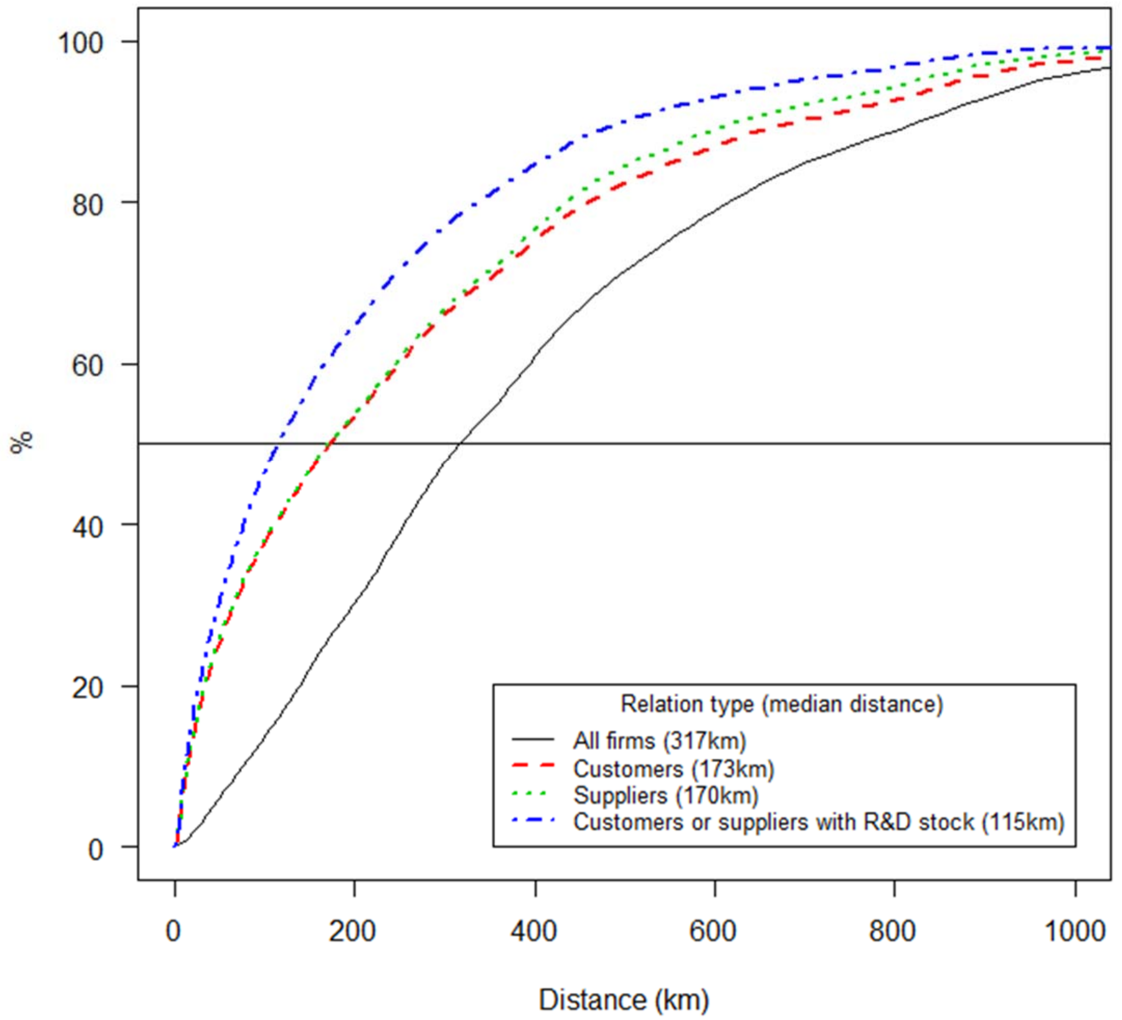

**Figure 2. Decay in R&D spillovers (vertical axis) as a function of geographic distance (horizontal axis)**