RIETI Discussion Paper Series 25-E-127

R&D Spillovers through Buyer-supplier Networks

BAJGAR, Matěj
CERGE-EI / Charles University

ITO, Keiko
Chiba University

TIMMIS, Jonathan
World Bank

RIETI
Research Institute of Economy, Trade & Industry, IAA

The Research Institute of Economy, Trade and Industry
https://www.rieti.go.jp/en/

RIETI Discussion Paper Series 25-E-127
December 2025

R&D Spillovers through Buyer-Supplier Networks[1]

Matěj BAJGAR
CERGE-EI
Institute of Economic Studies, Charles University
Keiko ITO
Chiba University
Jonathan TIMMIS
World Bank

Abstract

We study how R&D spillovers propagate through buyer–supplier networks. The R&D tax credit for large firms in Japan—originally based on incremental increases in R&D expenditures—was revised in 2003 to cover total R&D expenditures. This reduced the cost of marginal R&D outlays for large firms below the ceiling on R&D expenditure, but not for large firms above the ceiling or for SMEs. In a difference-in-differences setting, we find that the reform increased R&D expenditure, innovative output and sales of the treated firms. We further present evidence of positive forward spillovers to downstream firms: the reform led to productivity increases among firms that had a greater share of suppliers treated by the reform. Conversely, we do not find any evidence of backward spillovers to upstream firms. We also do not find any robust effects of the reform on the R&D expenditure and economic performance of Japanese firms' overseas affiliates.

Keywords: Research & Development (R&D), spillovers, tax incentives, buyer or supplier network, TFP
JEL classification: O33, O38, D22, D24, L14, H25, F23

[1] This study is conducted as a part of the Project "East Asian Industrial Productivity" undertaken at the Research Institute of Economy, Trade and Industry (RIETI). The authors would like to thank Kyoji Fukao, Eiichi Tomiura, Kenta Ikeuchi, and the participants at the RIETI DP Seminar for their helpful comments and suggestions. This study utilizes the micro data of the questionnaire information based on "the Basic Survey of Japanese Business Structure and Activities" and "the Basic Survey on Overseas Business Activities," which are conducted by the Ministry of Economy, Trade and Industry (METI), and the Kikatsu-Kaiji and Kikatsu-Oyako converters, which are provided by RIETI. Matěj Bajgar acknowledges financial support from the Czech Science Foundation (project 24-11566S). Keiko Ito gratefully acknowledges financial support from the JSPS KAKENHI (Grant Nos. 23K01396 and 23K25514) and the Japan Center for Economic Research. The opinions expressed and arguments employed herein are solely those of the authors and do not necessarily reflect the official views of the World Bank or its member countries.

1 Introduction

Spillover effects from firms' investments in research and experimental development (R&D) play a central role in modern theories of economic growth (Romer, 1990; Aghion and Howitt, 1992) and are viewed as the leading justification for public support to private innovation. However, existing micro-econometric evidence of R&D spillovers comes from studies that analyse spillovers among large, publicly traded, patenting companies in the United States and identify externalities primarily through technological or geographic proximity between firms.[1] Much less is known about whether and how benefits of other firms' R&D extend to smaller firms, to firms that do not invest in R&D themselves, and to firms that are not necessarily technologically close to the innovating firms.

In particular, the existing evidence largely overlooks that firms receive positive externalities through the exchange of intermediate inputs. Studies have documented that firms increase their productivity or improve their products thanks to contact with buyers and suppliers that are foreign-owned (Javorcik, 2004; Bajgar and Javorcik, 2020; Alfaro-Ureña et al., 2022), located abroad (Lileeva and Trefler, 2010; Amiti and Konings, 2007; Bas and Strauss-Kahn, 2015) or 'superstars' more generally (Amiti et al., 2024), but there is little rigorous evidence on external benefits from buyers' and suppliers' R&D activity.[2]

This paper examines how R&D spillovers propagate through buyer–supplier networks by exploiting a major reform of Japan's R&D tax credit system in 2003 as a natural experiment. The reform, which converted an incremental R&D tax credit into a volume-based scheme, sharply reduced the marginal cost of R&D for large firms below the tax credit ceiling but left small firms, and large firms above the ceiling, unaffected. We trace how these shocks affected not only the treated firms themselves but also their customers, suppliers, investee firms and overseas affiliates. Combining firm-level data on R&D activity and performance of Japanese firms from the *Basic Survey of Japanese Business Structure and Activities* with information on Japanese firms' overseas affiliates from the *Basic Survey on Overseas Business Activities* and, crucially, with firm-to-firm input-output and ownership link data from the Tokyo Shoko Research, we estimate difference-in-differences models with rich sets of fixed effects to isolate the effects of exogenous R&D increases due to the reform from endogenous drivers of firms' R&D investments. We quantify both the direct effects of the reform on treated firms' R&D, innovation, size and productivity and the indirect effects transmitted to connected firms through production and ownership networks.

We find that the reform led to a substantial increase in R&D spending among the firms directly affected by the change in tax incentives. Treated firms increased their R&D

[1]See Griliches (1981), Jaffe (1986), Lychagin et al. (2016), König et al. (2019), Zacchia (2020), Arqué-Castells and Spulber (2022).

[2]Existing papers observe input-output links only at the industry level and lack an explicit identification strategy (e.g. Los and Verspagen, 2000; Medda and Piga, 2014; Goya et al., 2016).

expenditure by roughly 14% relative to comparable control firms and exhibited higher innovative output, particularly in the number of utility patents filed. These firms also expanded in scale, with post-reform increases in sales, value added, assets, and employment of about 2–3 percent. We detect little short-run improvement in productivity measures, suggesting that the policy primarily stimulated the level of innovative and production activity rather than immediate efficiency gains. Consistent with this interpretation, we find no significant effects on the R&D or performance of treated firms' overseas affiliates, indicating that the reform's impact was concentrated within Japan.

Beyond these direct effects, we document evidence of R&D spillovers transmitted through buyer–supplier linkages. Firms whose suppliers benefited from the reform experienced higher sales, value added, and productivity growth, indicating positive forward spillovers from suppliers' R&D to downstream firms. The estimated productivity gains amount to around 1–3 percent, depending on the measure used. In contrast, we find no evidence of backward spillovers from customers' R&D or of performance effects stemming from shareholders' R&D. Taken together, the results highlight that R&D spillovers operate primarily along supply chains, benefiting downstream firms rather than upstream firms or firms connected through ownership ties.

Related Literature. Our paper builds on the long-standing empirical literature on R&D spillovers. Following the seminal contributions of Griliches (1981) and Jaffe (1986), a growing number of studies have estimated how one firm's R&D affects the productivity and market value of other firms, with a focus on publicly traded firms in the United States (e.g. Bloom et al., 2013; Lychagin et al., 2016; Lucking et al., 2019; Arqué-Castells and Spulber, 2022). More recent work begins to open the black box of mechanisms: Zacchia (2020) studies knowledge diffusion through networks of collaborating scientists, and König et al. (2019) develop and estimate a model of spillovers through R&D alliance networks. This literature has established that social returns to R&D exceed private returns, but almost all existing evidence identifies spillovers through technological relatedness, co-location, or research collaborations, and focuses on large R&D performers. We contribute by shifting attention to spillovers operating along buyer–supplier and ownership links, allowing us to study how R&D shocks at treated firms affect a much broader set of connected firms, including those that do not conduct R&D themselves.

Second, we contribute to the literature on knowledge spillovers transmitted through production and ownership linkages. A large body of work documents vertical spillovers from foreign direct investment (FDI), whereby domestic firms benefit from selling to or buying from multinationals (e.g. Javorcik, 2004; Blalock and Gertler, 2008; Bajgar and Javorcik, 2020; Alfaro-Ureña et al., 2022). Related studies show that better access to imported intermediate inputs and relationships with highly productive or "superstar" buyers can raise firm productivity and induce quality upgrading (e.g. Amiti and Konings, 2007; Goldberg et al., 2010; Bas and Strauss-Kahn, 2015; Amiti et al., 2024). These papers demonstrate that firm-to-firm relationships are important conduits for technology and know-how, but they typically focus on foreign ownership, trade liberalisation, or buyer size, and do not isolate spillovers arising specifically from R&D investments. Our contribution is to show that analogous vertical transmission operates for innovation: we identify how an exogenous increase in suppliers' R&D, induced by a domestic tax-credit reform, affects downstream firms' performance, while finding little evidence of spillovers through customers or shareholders.

Finally, our work is connected to a rapidly expanding literature that uses firm-to-firm transaction data to study the propagation of shocks through production networks. Recent papers exploit buyer–supplier data from Belgium, Costa Rica, Turkey, and other countries to show how idiosyncratic demand, supply, credit, or FDI shocks are transmitted across firms (e.g. Carvalho, 2014; Barrot and Sauvagnat, 2016; Bernard et al., 2022; Alfaro-Ureña et al., 2022; Amiti et al., 2024). Several studies use the same Japanese buyer–supplier network data as our paper to analyse the propagation of natural disasters, credit shocks, and firm bankruptcies (e.g. Bernard et al., 2019; Inoue and Todo, 2019; Carvalho et al., 2020). This literature establishes that production networks amplify and reshape the impact of firm-level shocks, but has so far largely focused on changes in demand conditions, trade costs, or foreign entry. We add to this evidence by studying a specific, policy-induced innovation shock: a large-scale R&D tax-credit reform. By combining rich Japanese firm-level data with detailed buyer–supplier and ownership links, we provide, to our knowledge, the first causal evidence on how R&D policy shocks translate into vertical R&D spillovers at the firm-to-firm level.

2 R&D Tax Credits in Japan

In Japan, the R&D tax credit system was substantially revised in 2003. The scheme, which had previously allowed tax credits only for incremental increases in R&D expenditures compared with a base year, was changed to a volume-based system that allowed firms to claim tax credits for a fixed percentage of their total R&D spending.

Under the incremental (increase-based) system, from fiscal years 1999 to 2002, firms could claim a credit of up to 15% of the eligible excess R&D expenditures, with the total credit amount capped at 12% of the corporate tax liability.[3] Since fiscal year 2003, the R&D tax credit has been calculated as a fixed percentage of a firm's total R&D

[3] The benchmark R&D expenditure for fiscal years 1999 to 2002 was defined as the average of a firm's three highest annual R&D expenditures over the previous five years. In addition, to qualify for the tax credit, the firm's current-year R&D spending had to exceed its highest R&D expenditure in the preceding two years. On the other hand, from fiscal years 1976 to 1998, firms could claim a credit of up to 20% of the eligible excess R&D expenditures, with the total credit amount capped at 10% of the corporate tax liability.

expenditures in the current year. The credit rate is determined based on the R&D intensity, defined as the ratio of current R&D spending to the average sales over the previous three years, and the maximum allowable credit is capped at 20% of the corporate tax liability.[4] In addition, in FY2008, a major reform introduced a "high-level" R&D tax credit scheme to provide preferential treatment for R&D-intensive firms with an R&D intensity exceeding 10%.

The 2003 reform from an incremental to a volume-based scheme likely encouraged a larger number of firms to take advantage of the preferential tax treatment. Under the previous incremental system, even firms conducting R&D in a given year were not eligible for the credit unless their R&D expenditures exceeded the benchmark level. In contrast, under the volume-based system, any firm with positive taxable income could benefit from the credit as long as it incurred R&D expenses. Indeed, following the 2003 reform, Koga (2019) documented a sharp increase in the number of firms claiming the tax credit, and Kasahara et al. (2014) also found that the aggregate R&D expenditures rose significantly.

The Japanese government has frequently introduced minor revisions to the R&D tax credit system, such as optional schemes that allow additional credit rates. However, according to Koga (2019) and others, the 2003 reform—from an incremental system to a volume-based system—brought about the most significant change in the tax credit. Therefore, this study uses the 2003 reform as an exogenous shock that altered firms' R&D expenditures.

As noted above, in fiscal year 2008, a "high-level" R&D tax credit was newly introduced, followed by further changes such as adjustments to the credit ceiling and a modification of the incremental scheme into the "enhanced volume-based" scheme. To abstract from these later institutional changes, our analysis focuses on the period up to fiscal year 2007. We estimate how the 2003 reform affected firms' own R&D spending and performance, and further examine how these effects propagated through buyer–supplier relationships to influence the performance of their suppliers and customers.

In addition to the general scheme, mostly targetting large firms, Japan also operated a separate R&D tax credit scheme for small and medium-sized enterprises (SMEs). Firms eligible for the SME scheme were corporations with capital of 100 million yen or less that were not majority-owned (50% or more) by large enterprises.[5] The SME scheme provided more favourable conditions than the general system. Volume-based R&D tax credits were available to SMEs already before 2003, when they became also available to large firms. Moreover, the R&D tax credit rate for SMEs was set at a higher level, and

[4] As a temporary measure, the ceiling was raised to 30% in FY2009, and since FY2015, it has been set at 25% of the corporate tax liability. Moreover, from FY2017 onward, the credit rate has been adjusted based on the extent to which a firm's current R&D spending exceeds a benchmark level.

[5] These firms are those classified as "small and medium-sized enterprises" under the Act on the Promotion of Core Business Activities of Small and Medium-Sized Enterprises. In general, these are Industry-specific thresholds also apply to firms in wholesale, retail, and service sectors.

the eligibility requirements were simplified. The tax credits for SMEs also underwent changes in 2003, as SMEs became eligible for higher credit rates—typically up to 12% of total R&D spending—with the total credit capped at 20% of corporate tax liability. However, the increase in the effective subsidy rates was much less pronounced than for large firms. Subsequent revisions introduced temporary enhancements to further promote R&D among innovative SMEs.

SMEs can choose between the R&D tax credit system for SMEs and that for all firms. In this study, our baseline sample comprises all manufacturing firms covered by the firm-level survey conducted by the Japanese government (see Section 3.1 for details), and we restrict our sample to large firms for robustness checks. We mainly focus on the scheme for large firms as it saw a much more drastic change in 2003 and, according to the *Survey of Research and Development* for 2003 conducted by the Statistics Bureau, the share of total business enterprise R&D expenditure accounted for by SMEs was small—less than 4%.

3 Data and Measurement

3.1 The METI Data

Our main data source is the Basic Survey of Japanese Business Structure and Activities (BSJBSA), conducted annually by the Ministry of Economy, Trade and Industry (METI), Japan. The survey contains detailed firm-level information such as their 3-digit industry, the number of employees, sales, purchases, exports, and imports. The BSJBSA also contains information on firm financials including costs, profits, investment, debt, assets, R&D expenditures, and patents. The survey is compulsory, covering all firms with at least 50 employees and 30 million yen of paid-in capital in the manufacturing, mining, wholesale and retail and other services sectors. We mainly use the firm-level panel data for the period from 1995 to 2007, covering approximately 23,000 firms annually, 10,000 of which are in the manufacturing sector.

We also utilize the Basic Survey on Overseas Business Activities (BSOBA), conducted annually by METI. The BSOBA covers foreign affiliates of Japanese firms based on the following criteria: (a) foreign affiliates in which a Japanese corporation holds at least 10% of the capital; (b) foreign affiliates in which a subsidiary, defined as a firm more than 50% owned by a Japanese corporation, holds more than 50% of the capital; and (c) foreign affiliates in which a Japanese corporation and a subsidiary that is more than 50% owned by a Japanese corporation collectively hold more than 50% of the capital. The BSOBA covers all sectors except for finance, insurance, and real estate. The BSOBA contains information on the location (country) and the 3-digit industry of foreign affiliates, and affiliate-level financial data such as sales, costs, employment, and R&D expenditures.

The BSOBA covers over 2,000 (in 1995) - 3,000 (in 2007) Japanese MNEs at the headquarter level. Nearly 70% of them fall into the manufacturing sector. The BSOBA covers over 10,000 (in 1995) - 16,000 (in 2007) foreign affiliates of Japanese MNEs, and half of them fall into the manufacturing sector. In 1995, the average number of foreign affiliates for each MNE is 4.4 while the corresponding figure for 2007 is 5.0 affiliates per MNE. Out of the 2,000 - 3,000 Japanese MNEs covered by the BSOBA, approximately 1,000 (in 1995) - 2,800 (in 2007) firms are also covered by the BSJBSA.

3.2 The Tokyo Shoko Research Data

To capture firm-level transaction relationships, we use data on buyer-supplier relationships and shareholders complied by the Tokyo Shoko Research Ltd. (TSR), a private credit rating agency in Japan. Firms provide information to TSR to obtain credit scores for loans. Covering almost all firms with over 4 employees in Japan, the TSR data contains annual information on roughly 1 million firms, including employment, sales, location, its founding year, number of establishments and their main (4-digit) industry (up to 3).[6]

In this paper, we use both the TSR Company Information Database and the TSR Company Linkage Database where the latter provides information on firm-to-firm relationships. Each firm surveyed by the TSR is asked to report the names of its top 24 suppliers, top 24 customers, and 3 main shareholders. To avoid the "top 24" cutoff from limiting the sample coverage of the production network, we use a two-way matching method to maximize the number of links, using information reported by a customer about its suppliers and vice versa. Since a relationship with a customer or supplier can be reported by either end of a relationship, the number of customers (suppliers) of a supplier (customer) can be much greater than 24. In fact, the top supplier (customer) in our constructed network data in Japan has 7,139 customers (7,475 suppliers) in 2006. The average numbers of customers and suppliers are 5.6 and 4.9 firms, respectively in 2006. The distribution of the customer-supplier links is very skewed, with most of the firms having substantially fewer customers and suppliers.[7]

Although the TSR Company Linkage Database covers many small firms, there is no information on the value of transaction for each customer-supplier link unfortunately. While the 2006 TSR Company Linkage Database provides the ranking of customers or suppliers for each firm in order of transaction value, the Data since 2007 does not include information on rank order of transaction value. Therefore, by using the ranking information as of 2006 and assuming that the ranking did not change over time, we identify

[6] According to Kodama and Li (2018), the 2014 TSR data covers 66% of firms and 70% of employment, compared to the 2014 Economic Census for Business Frame.

[7] However, as noted later again, suppliers and customers used for our analysis are limited to those included in the BSJBSA.

major suppliers/customers for each firm.

3.3 The BSJBSA-TSR-BSOBA Matched Data

We match the METI's BSJBSA data with the firm-to-firm relationships from the TSR data, mainly using Corporate Numbers designated by the Japanese National Tax Agency which is a unique identifier to each firm. Since 2018, government statistical surveys have included Corporate Numbers in their survey records, thereby enabling the linkage of government statistics with firm-level datasets provided and sold by private-sector data vendors. For firms where the Corporate Number was not available, we match the BSJBSA and the TSR using firm names, telephone numbers, and mailing addresses. This dataset allows us to estimate a relationship between a firm's performance on the one hand and, on the other hand, R&D investments by a given firm but also R&D investments of its suppliers and buyers.

Although the TSR data do not cover buyer-supplier relationships across borders and we cannot analyze cross-border inter-firm R&D spillovers using this dataset, we take global ownership networks of Japanese multinational enterprises (MNEs) into account. We further match the METI's BSJBSA data with the BSOBA data at the parent level in order to capture R&D and other performance measures of overseas affiliates of Japanese firms.

Since many firms that engage in R&D on a continuous basis and provide reliable information on their R&D expenditures are manufacturing firms, Our baseline specification focuses on the manufacturing sector.

4 Empirical Strategy

4.1 Identification and Definition of the Treatment and Control Firms

We exploit the 2003 reform of Japan's R&D tax credit system as a natural experiment that changed the marginal incentives to invest in R&D for a subset of firms. Before the reform, large firms in Japan could claim a tax credit only for incremental increases in R&D expenditure relative to a baseline level. This incremental scheme offered relatively weak incentives for investing in R&D, because higher R&D spending in one year meant a higher baseline—and thus lower R&D tax credit—in subsequent years. The 2003 reform introduced a volume-based credit that allowed large firms to deduct a fixed percentage of total R&D expenditures, thereby substantially lowering the marginal cost of R&D for firms whose below the credit ceiling. This policy change provides exogenous variation in the after-tax cost of R&D, which we use to identify the causal effects of R&D incentives on firms' own R&D activity and on spillovers to connected firms.

Importantly, while the reform officially took effect in 2003, it influenced firms' R&D behaviour already in 2002, when the policy change was announced. Under the incremental tax credit system in place before 2003, firms faced a dynamic disincentive: increasing R&D expenditure in a given year raised the baseline for future years, thereby reducing the incremental tax credit they could claim subsequently. However, once firms learned that the system would shift to a volume-based scheme in 2003, this disincentive was eliminated for 2002. Firms could increase their R&D spending in 2002 without worrying about raising future baselines, since the baseline concept would no longer apply under the new system. This is why we define the post-treatment period as starting already in 2002.

In our analysis, the treatment group consists of large firms (firms not classified as SMEs for tax purposes)[8] for which the 2003 reform reduced the marginal cost of R&D. More concretely, we mark firms as treated if their estimated tax credit—calculated based on their R&D spending prior to the tax reform—is below the credit limit. The tax credit rate is computed as 10% plus 0.2 times the firm's R&D intensity, and the implied credit amount is obtained by multiplying this rate by the firm's past R&D expenditures.[9] If this estimated credit amount is smaller than 20% of the corporate tax liability—the ceiling valid from 2003 onwards—the firm is classified as treated. This means that, other things equal, more profitable, and less R&D intensive, firms are more likely to be treated. The control group consists of large firms above the ceiling, and firms defined as SMEs for tax purposes.

In order to identify the treatment group firms, we compute R&D expenditure for tax purposes as the sum of own and outsourced nominal R&D expenditures. Using the same R&D expenditure measure, the R&D intensity for the credit rate calculation is computed as the ratio of R&D expenditures to the average sales over the previous three years. We also need information on the corporate tax liabilities for each firm to calculate the credit limit. As the BSJBSA data do not contain this information, we follow Kasahara et al. (2014) and proxy corporate tax liabilities by multiplying the corporate tax rate by each firm's taxable income, calculated as ordinary profit net of accumulated tax losses carried forward under the loss carry-over provision.[10]

[8]Following the Act on the Promotion of Core Business Activities of Small and Medium-Sized Enterprises, SMEs are defined as corporations with capital below 100 million yen that are not majority-owned by publicly listed firms. As mentioned in Section 2, the volume-based R&D tax credit had been already available to SMEs before the 2003 tax reform. Therefore, we exclude SMEs from the treatment group and include them in the control group.

[9]Under the 2003 reform, the credit rate for the volume-based scheme was set at 8% + 0.2 × R&D intensity. However, a temporary 2-percentage-point increase was allowed in fiscal year 2003, so we use 10% + 0.2 × R&D intensity in our calculation. Although the maximum credit rate for large firms was formally capped at 10% (12% for SMEs), we apply the temporary 2-percentage-point increase to both groups and therefore use 12% as the upper limit in this study.

[10]In practice, taxable income is calculated by including extraordinary gains and losses and other

In all calculations determining firm treatment status, we use the averages of R&D expenditures, sales, and taxable income over the 1995–1997 period. We rely on data from this earlier period to avoid potential bias arising from short-term fluctuations or regression to the mean. By using R&D expenditure levels observed several years before the 2003 tax reform, we capture firms' underlying or structural R&D intensity rather than temporary variations immediately prior to the reform.

4.2 Construction of Spillover Exposure Measures

To estimate knowledge spillover effects transmitted through firm-to-firm transactions, it is common to examine the relationship between a firm's performance and the technological knowledge stock of its customers or suppliers. In this study, we instead take a reduced form approach and construct variables that measure the extent to which a firm's suppliers, customers and shareholders have been exposed to the R&D tax credit reform. Therefore, our spillover variables take larger values when a firm's major suppliers or customers—those with large R&D stocks and higher ranks in transaction size—belong to the treatment group. Although our main focus is on spillovers from a firm's suppliers and customers, we also construct a spillover variable for its shareholders in the same manner

In the 2006 TSR data, we observe each firm's top 24 suppliers, top 24 customers, and up to three shareholders. This allows us to compute time-invariant exposure measures that combine information on (i) whether each connected firm is classified as treated, (ii) the strength of the link, and (iii) the connected firm's R&D stock prior to the reform. The treatment indicators are defined as above. The strength of the links is measured by the inverse rank of each supplier, customer or shareholder based on transaction value. While the TSR data do not report actual transaction amounts, the 2006 TSR data provide rankings of suppliers and customers according to their transaction size as described in Section 3.2. We utilize these rankings by assigning greater weights to higher-ranked suppliers, customers and sharehodlers in the calculation of weighted averages.[11] The R&D stock is measured in 2001 and computed using the perpetual-inventory method with a 15% depreciation rate following Bloom et al. (2013), using deflators from the OECD MultiProd project.

For each firm i, the spillover exposure from suppliers, customers, or shareholders is defined as the weighted average of the treatment indicators of the connected firms, where the weight assigned to partner k is proportional to the product of two components: the inverse of the reported transaction rank ($1/\text{rank}_{ik}$) and the partner's R&D stock in 2001.[12]

deductions. However, since such information is not available, we compute accumulated tax losses using data on ordinary profit. For more details, see footnote 9 in Kasahara et al. (2014).

[11]The TSR transaction relationship data are available only from 2006 onward, with the rankings available only for year 2006. We assume that the buyer-supplier network did not change much over time and the transaction relationships observed in 2006 apply in all sample years.

[12]It should be noted that suppliers and customers are limited to firms included in the BSJBSA, since

The weights are normalised to sum to one within each firm–link type. Since the partner R&D stocks are measured in 2001, prior to the treatment, and the network structure is fixed in 2006, the exposure variables are predetermined and time-invariant, mitigating concerns about simultaneity.

4.3 Estimating Equations

4.3.1 Estimating the effects of being directly treated by the reform

To estimate the effects of firms being themselves directly treated by the reform, we compare the evolution of outcomes for treated and control firms before and after the reform:

$$y_{it} = \beta \left(Treat_i \times Post_t \right) + \psi_i + \delta_{jt} + \gamma_{st} + \eta_{at} + \varepsilon_{it}, \tag{1}$$

where y_{ijt} is the logarithm of the outcome variable for firm i in industry j and year t; $Treat_{ij}$ is an indicator for treated firms; $Post_t$ equals one during the post-treatment period (2002-2007);[13] the terms ψ_i, δ_{jt}, γ_{st}, and η_{at} denote firm fixed effects, industry-year fixed effects, size quintile-year fixed effects, and age quintile–year fixed effects, respectively. Standard errors are clustered at the firm level.

As outcome variables, we analyse R&D expenditure; innovation outputs in the form of patents, utility models[14] and designs; firm size measured in terms of sales, value added, total assets and number of employees; and productivity measured using labor productivity and three different measures of total factor productivity (TFP).[15]

We also examine the impact of the reform on overseas affiliates of treated firms. For the outcome variables of overseas affiliates, we include R&D expenditure, sales, purchases, and employment. While affiliate-level financial information is available in the BSOBA, the affiliate identification number is not permanent, making it difficult to construct consistent affiliate-level panel data. Therefore, here, when a firm has multiple overseas affiliates, we use the financial data aggregated at the firm-group level, summing across all its foreign affiliates.[16] All outcome variables are expressed in logarithmic form.[17]

R&D expenditure information is available only for the BSJBSA firms.

[13] See subsection 4.1 for a discussion of why year 2002 is considered treated.

[14] In Japan, *utility model* rights are granted for small-scale technical inventions concerning the shape or structure of products, whereas *design rights* cover the external appearance and aesthetic features of industrial goods.

[15] The firm-level TFP is calculated by estimating the production function for each 2-digit industry using the MultiProd Version 2.1.1.1 Stata routines developed by the OECD MultiProd team.

[16] In future work, we may extend the analysis by distinguishing between countries or regions of overseas affiliates.

[17] Since R&D expenditures and innovation outputs contain many zero observations, we add a constant K to each observation. Chen and Roth (2023) show that estimation results with this widely-used transformation are not scale-invariant, as the transformation affects the relative weight of the extensive and intensive margins in the regressions. We take one of the approaches suggested by Chen and Roth (2023) to tackle this issue, which is to establish an explicit trade-off between the extensive and intensive margin. Specifically, we set K equal to the 10th percentile value among the strictly positive observations

To examine dynamic treatment effects and test for pre-trends, we also estimate the corresponding event-study specification:

$$y_{it} = \sum_{\substack{p=1999 \\ p\neq 2001}}^{2007} \beta_p(Treat_i \times Y_t^p) + \psi_i + \delta_{jt} + \gamma_{st} + \eta_{at} + \varepsilon_{it}, \tag{2}$$

where Y_t^p is a full set of year dummies and 2001 serves as the omitted base year. The coefficients β_t trace the evolution of outcomes for treated firms relative to controls over time, conditional on the same fixed effects as in Equation (1).

Our estimation sample for the analysis of the effects of own direct treatment represents a balanced panel of consistent R&D performers, including manufacturing firms that report positive R&D expenditures in each year between 1999 and 2007. As a result, our baseline estimation sample includes 2,432 manufacturing firms per year. The descriptive statistics of the outcome variables for our baseline sample are shown in Appendix Table A1.

4.3.2 Estimating the effects of the reform on firms connected to treated firms

Next, we estimate whether the effects of the reform propagated to firms connected to treated firms through supply-chain or ownership links:

$$\begin{aligned} y_{it} = {} & \beta_s \left(Treat\_Supplier_i \times Post_t\right) + \beta_c \left(Treat\_Customer_i \times Post_t\right) \\ & + \beta_h \left(Treat\_Shareholder_i \times Post_t\right) + \psi_i + \delta_{jt} + \gamma_{st} + \eta_{at} + \varepsilon_{it}. \end{aligned} \tag{3}$$

Here, $Treat\_Supplier_{ij}$, $Treat\_Customer_{ij}$, and $Treat\_Shareholder_{ij}$ represent the continuous exposure measures described above, capturing the share of treated suppliers, customers, and shareholders (weighted by connection strength and pre-reform R&D stock). The sample includes all manufacturing firms with at least one observed supplier or customer link between 1999 and 2007. This specification allows us to quantify the extent of R&D spillovers transmitted through buyer–supplier and ownership networks.

5 Results

5.1 Effects of Own Treatment

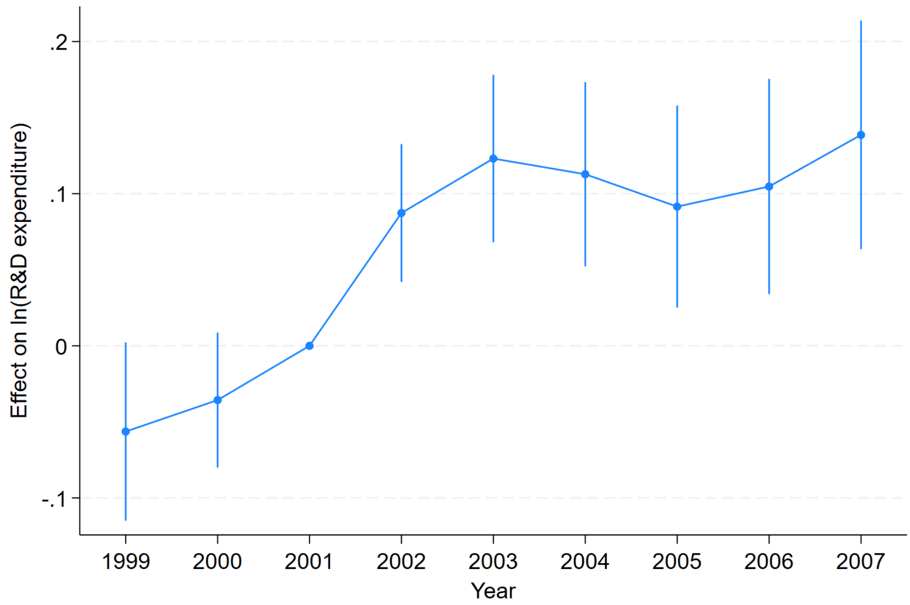
Figure 1 provides a visual summary of the dynamics of R&D expenditure around the 2003 tax-credit reform.[18] The figure plots coefficients from an event-study specification in

of the respective variable before taking logs. This implies that a change from zero to a strictly positive value on the 10^{th} percentile is equivalent to an intensive-margin change that doubles the variable.

[18] To mitigate the influence of outliers, we exclude observations in the top 1% of the distribution of each outcome variable when estimating the regressions. As a robustness check, we also exclude the top

which firm-level R&D spending is regressed on year dummies interacted with an indicator for treated firms, controlling for firm fixed effects, industry-year fixed effects, size-year fixed effects and age-year fixed effects. Note that the reform affected R&D expenditure already in 2002, as the switch to a volume-based tax credit in 2003 increased the value of the incremental tax credit in 2002 (see subsection 4.1). The pre-reform coefficients are close to zero and statistically insignificant, indicating no differential trends between treated and control firms prior to the policy change. In 2002, the coefficients rise sharply and remain positive in subsequent years, suggesting a sustained increase in R&D spending among firms eligible for the more generous credit.

Figure 1: **The R&D Tax Credit Reform and Firms' R&D Expenditure**



Notes: The figure plots the event study coefficients obtained by estimating Equation 2, together with their 95% confidence intervals. The coefficients represent the log changes in R&D expenditure of treated firms relative to control firms. The baseline year is 2001.

Table 1 reports the difference-in-differences estimates of the effects of the 2003 tax-credit reform on firms' R&D activity, innovation outcomes, size, and productivity.[19] Panel A shows that treated firms increased their R&D expenditure by about 14 percent relative to control firms, a highly significant response consistent with the sharp post-reform increase observed in Figure 1. The number of utility patents also sharply increased among treated firm by about 9%. The coefficients for patents and designs are positive but smaller

5% of each variable's distribution, and the results are highly similar.

[19]As mentioned in Section 4.1, firms classified as SMEs for tax purposes are included in the control group in our baseline estimations. Although it is reasonable to include them in the control group, given that they were already subject to the volume-based tax incentive scheme prior to the 2003 tax reform, we also re-estimated the models after excluding SMEs from the sample. The resulting estimates are highly consistent with the baseline findings, indicating that our conclusions are not driven by the inclusion of SMEs.

and not statistically significant.

Panel B indicates that treated firms subsequently expanded in scale: sales, value added, assets, and employment all rose by roughly 2–3 percent after the reform. Finally, Panel C shows small and statistically insignificant effects on productivity measures, implying that the reform primarily stimulated the level of innovative and production activity rather than immediate efficiency gains. As suggested by the estimation results in Panels A and B, the treated firms increased their R&D expenditures, employment, and capital inputs following the tax reform. However, because these are increases in production inputs, even if sales or value added rise, they may not immediately translate into substantial gains in productivity. Taken together, these results confirm that the reform successfully increased private R&D investment and innovation while having more limited short-run effects on productivity.

Table 1: **Effects of Own Treatment**

	(1)	(2)	(3)	(4)
Panel A. Effects on R&D and innovation				
	R&D exp.	Patents	Utility pat.	Designs
Treated × Post	0.140***	0.012	0.086**	0.025
	(0.026)	(0.034)	(0.035)	(0.028)
N	20,970	20,691	20,529	20,709
Panel B. Effects on firm size				
	Sales	Value added	Assets	Employment
Treated × Post	0.027**	0.028**	0.024**	0.020**
	(0.011)	(0.014)	(0.010)	(0.009)
N	20,979	20,939	20,988	20,997
Panel C. Effects on productivity				
	LP	TFP (Solow)	TFP (Wool.)	TFP (ACF)
Treated × Post	0.008	0.001	0.002	–0.001
	(0.011)	(0.004)	(0.011)	(0.003)
N	20,963	20,881	20,799	20,804

Notes: *** 1%, ** 5%, * 10%. For each outcome, the table reports the effect of the 2003 R&D tax credit reform obtained by estimating Equation 1. All outcomes enter the regressions as logs. All regressions control for firm fixed effects, industry-year fixed effects, size-year fixed effects and age-year fixed effects. Robust standard errors clustered at the firm level are reported in parentheses.

Table 2 assesses whether the reform affected the overseas operations of treated Japanese firms. Rather than looking at domestic outcomes, it investigates the aggregate performance of each Japanese parent's foreign affiliates. Across outcomes, we find no statistically significant effects on affiliates' R&D expenditure, sales, purchases or employment. These results suggest that the reform's primary impact was on domestic activity, with no detectable short-run reallocation to, or contraction/expansion within, foreign affiliates.

Table 2: **Effects of Own Treatment on Overseas Affiliates**

	(1)	(2)	(3)	(4)
	R&D exp.	Sales	Purchases	Employment
Treated × Post	-0.053	0.011	-0.065	0.055
	(0.132)	(0.066)	(0.070)	(0.068)
N	4,621	4,570	4,377	4,583

Notes: *** 1%, ** 5%, * 10%. For each outcome, the table reports the effect of the 2003 R&D tax credit reform obtained by estimating Equation 1. All outcomes represent the combined figures across all overseas affiliates of a given Japanese company and enter the regressions as logs. All regressions control for firm fixed effects, industry-year fixed effects, size-year fixed effects and age-year fixed effects. Robust standard errors clustered at the firm level are reported in parentheses.

5.2 Effects of Supplier, Buyer and Shareholder Treatment

Table 3 investigates whether the effects of the 2003 reform propagated to firms connected to treated firms through supply-chain or ownership links. The results reveal clear heterogeneity across types of connections.

Panel A shows no significant effects of suppliers, customers or shareholders being treated by the reform on the R&D spending or innovative output of the connected firms, indicating that the reform did not directly stimulate R&D activity beyond the treated firms themselves.

Panel B shows some evidence that suppliers being treated by the reform was associated with greater sales and value added of the downstream firms, indicating that firms benefited from increased R&D among their suppliers. On the contrary, customers' treatment by the reform was associated with smaller sales and value added of upstream firms, which is consistent with the customers being able to replace some input purchases with in-house production as a result of their increased R&D. We do not find any effects of shareholders' treatment on the size of the affiliated firms.

Panel C examines productivity outcomes. The coefficients indicate that suppliers being treated was associated with statistically significant improvements in both the labour productivity and the total factor productivity of downstream firms by about 1–3%. This represents evidence of positive productivity spillovers from supplier R&D to downstream firms. In contrast, we do not find any evidence of similar spillovers stemming from customers' or shareholders' R&D.

Table 3: **Effects of Supplier, Buyer and Shareholder Treatment**

	(1)	(2)	(3)	(4)
Panel A. Effects on R&D and innovation				
	R&D exp.	Patents	Utility pat.	Designs
Treatment (suppliers) × Post	-0.007	-0.035	-0.024	-0.035
	(0.046)	(0.035)	(0.033)	(0.024)
Treatment (customers) × Post	-0.020	-0.005	0.018	-0.024
	(0.044)	(0.037)	(0.035)	(0.027)
Treatment (shareholders) × Post	-0.019	0.039	0.047	0.052*
	(0.048)	(0.038)	(0.034)	(0.027)
N	29,361	29,348	29,369	29,463
Panel B. Effects on firm size				
	Sales	Value added	Assets	Employment
Treatment (suppliers) × Post	0.026*	0.028*	0.007	0.008
	(0.015)	(0.016)	(0.014)	(0.011)
Treatment (customers) × Post	-0.033**	-0.031*	-0.024	-0.016
	(0.016)	(0.017)	(0.016)	(0.012)
Treatment (shareholders) × Post	0.001	-0.006	0.011	0.008
	(0.016)	(0.017)	(0.015)	(0.012)
N	29,310	29,042	29,325	29,396
Panel C. Effects on productivity				
	LP	TFP (Solow)	TFP (Wool.)	TFP (ACF)
Treatment (suppliers) × Post	0.025**	0.012**	0.027**	0.010**
	(0.012)	(0.005)	(0.013)	(0.004)
Treatment (customers) × Post	-0.012	-0.002	-0.021	-0.004
	(0.014)	(0.005)	(0.014)	(0.004)
Treatment (shareholders) × Post	-0.012	-0.005	-0.005	-0.006
	(0.013)	(0.005)	(0.013)	(0.004)
N	29,084	28,730	28,668	28,648

Notes: *** 1%, ** 5%, * 10%. For each outcome, the table reports the effect of the 2003 R&D tax credit reform obtained by estimating Equation 3. All outcomes enter the regressions as logs. All regressions control for firm fixed effects, industry-year fixed effects, size-year fixed effects and age-year fixed effects. Robust standard errors clustered at the firm level are reported in parentheses.

6 Concluding Remarks

This paper has examined how R&D spillovers propagate through buyer–supplier and ownership networks by exploiting a major reform of Japan's R&D tax credit system in 2003 as a natural experiment. The reform reduced the marginal cost of R&D for large firms below the tax-credit ceiling and led to a substantial increase in their R&D investment and innovative activity, and treated firms experienced a faster growth as a result. We find little evidence of immediate productivity gains, suggesting that the primary effect of the policy was to stimulate innovation effort and firm growth rather than efficiency improvements.

We then explored how these shocks to firms' R&D behaviour transmitted to other parts of the economy. The results reveal significant forward spillovers: firms with a larger share of suppliers affected by the reform experienced higher sales, value added, and productivity growth. By contrast, we find no evidence of backward spillovers to suppliers, nor of performance effects through ownership links, indicating that R&D spillovers in production networks flow predominantly downstream. These findings are consistent with technological knowledge being embodied in improved intermediate inputs and production know-how that diffuse from innovating suppliers to their customers. However, Ikeuchi et al. (2015) report evidence suggesting that R&D spillovers are larger from buyers and suppliers with equity ties than from those without such ties. We will explore the interaction between trading relationships and equity relationships when further developing the results presented here.

Our results contribute to a growing body of evidence that R&D policies can generate social returns beyond the firms that claim the tax credits. At the same time, they suggest that the diffusion of innovation is highly asymmetric within production networks, with benefits concentrated among downstream partners. Understanding the mechanisms behind such directed spillovers—such as learning-by-using, input upgrading, or relational knowledge transfer—remains an important avenue for future research. From a policy perspective, the findings imply that the full impact of R&D support depends not only on the responsiveness of treated firms but also on the structure of the networks through which innovation spreads.

References

Aghion, Philippe and Peter Howitt, "A Model of Growth Through Creative Destruction," *Econometrica*, March 1992, *60* (2), 323.

Alfaro-Ureña, Alonso, Isabela Manelici, and Jose P Vasquez, "The Effects of Joining Multinational Supply Chains: New Evidence from Firm-to-Firm Linkages," *The Quarterly Journal of Economics*, 01 2022, *137* (3), 1495–1552.

Amiti, Mary and Jozef Konings, "Trade Liberalization, Intermediate Inputs, and Productivity: Evidence from Indonesia," *American Economic Review*, December 2007, *97* (5), 1611–1638.

_ , **Cédric Duprez, Jozef Konings, and John Van Reenen**, "FDI and Superstar Spillovers: Evidence from Firm-to-Firm Transactions," *Journal of International Economics*, 2024, *152*, 103972.

Arqué-Castells, Pere and Daniel F. Spulber, "Measuring the Private and Social Returns to R&D: Unintended Spillovers versus Technology Markets," *Journal of Political Economy*, 2022, *130* (7), 1860–1918.

Bajgar, Matej and Beata Javorcik, "Climbing the Rungs of the Quality Ladder: FDI and Domestic Exporters in Romania," *The Economic Journal*, 01 2020, *130* (628), 937–955.

Barrot, Jean-Noël and Julien Sauvagnat, "Input Specificity and the Propagation of Idiosyncratic Shocks in Production Networks *," *The Quarterly Journal of Economics*, 05 2016, *131* (3), 1543–1592.

Bas, Maria and Vanessa Strauss-Kahn, "Input-Trade Liberalization, Export Prices and Quality Upgrading," *Journal of International Economics*, March 2015, *95* (2), 250–262.

Bernard, Andrew B., Andreas Moxnes, and Yukiko U. Saito, "Production Networks, Geography, and Firm Performance," *Journal of Political Economy*, 2019, *127* (2), 639–688.

_ , **Emmanuel Dhyne, Glenn Magerman, Kalina Manova, and Andreas Moxnes**, "The Origins of Firm Heterogeneity: A Production Network Approach," *Journal of Political Economy*, 2022, *130* (7), 1765–1804.

Blalock, Garrick and Paul J. Gertler, "Welfare Gains from Foreign Direct Investment through Technology Transfer to Local Suppliers," *Journal of International Economics*, March 2008, *74* (2), 402–421.

Bloom, Nicholas, Mark Schankerman, and John Van Reenen, "Identifying Technology Spillovers and Product Market Rivalry," *Econometrica*, July 2013, *81* (4), 1347–1393.

Carvalho, Vasco M., "From Micro to Macro via Production Networks," *Journal of Economic Perspectives*, November 2014, *28* (4), 23–48.

Carvalho, Vasco M, Makoto Nirei, Yukiko U Saito, and Alireza Tahbaz-Salehi, "Supply Chain Disruptions: Evidence from the Great East Japan Earthquake*," *The Quarterly Journal of Economics*, 12 2020, *136* (2), 1255–1321.

Chen, Jiafeng and Jonathan Roth, "Logs with Zeros? Some Problems and Solutions*," *The Quarterly Journal of Economics*, 12 2023, *139* (2), 891–936.

Goldberg, Pinelopi Koujianou, Amit Kumar Khandelwal, Nina Pavcnik, and Petia Topalova, "Imported Intermediate Inputs and Domestic Product Growth: Evidence from India*," *The Quarterly Journal of Economics*, 11 2010, *125* (4), 1727–1767.

Goya, Esther, Esther Vayá, and Jordi Suriñach, "Innovation Spillovers and Firm Performance: Micro Evidence from Spain (2004–2009)," *Journal of Productivity Analysis*, 2016, *45* (1), 1–22.

Griliches, Zvi, "Market Value, R&D, and Patents," *Economics Letters*, 1981, *7* (2), 183–187.

Ikeuchi, Kenta, René Belderbos, Kyoji Fukao, Young Gak Kim, and Hyeog Ug Kwon, "Buyers, Suppliers, and R&D Spillovers," Discussion papers 15-E-047, Research Institute of Economy, Trade and Industry (RIETI) April 2015.

Inoue, Hiroyasu and Yasuyuki Todo, "Firm-level propagation of shocks through supply-chain networks," *Nature Sustainability*, 2019, *2* (9), 841–847.

Jaffe, Adam B., "Technological Opportunity and Spillovers of R&D: Evidence from Firms' Patents, Profits, and Market Value," *The American Economic Review*, 1986, *76* (5), 984–1001.

Javorcik, Beata S., "Does Foreign Direct Investment Increase the Productivity of Domestic Firms? In Search of Spillovers Through Backward Linkages," *American Economic Review*, June 2004, *94* (3), 605–627.

Kasahara, Hiroyuki, Katsumi Shimotsu, and Michio Suzuki, "Does an R&D Tax Credit Affect R&D Expenditure? The Japanese R&D Tax Credit Reform in 2003," *Journal of the Japanese and International Economies*, March 2014, *31*, 72–97.

Kodama, Naomi and Huiyu Li, "Manager Characteristics and Firm Performance," Discussion papers 18-E-060, Research Institute of Economy, Trade and Industry (RIETI) September 2018.

Koga, Tadahisa, "Taxation for Large Firms' R&D in Japan: 1990-2017," *Economic Review (Kansai University)*, 2019, *69* (2-3), 115–164. (*in Japanese*).

König, Michael D., Xiaodong Liu, and Yves Zenou, "R&D Networks: Theory, Empirics, and Policy Implications," *The Review of Economics and Statistics*, 07 2019, *101* (3), 476–491.

Lileeva, Alla and Daniel Trefler, "Improved Access to Foreign Markets Raises Plant-level Productivity…For Some Plants," *The Quarterly Journal of Economics*, August 2010, *125* (3), 1051–1099.

Los, Bart and Bart Verspagen, "R&D Spillovers and Productivity: Evidence from U.S. Manufacturing Microdata," *Empirical Economics*, 2000, *25* (1), 127–148.

Lucking, Brian, Nicholas Bloom, and John Van Reenen, "Have R&D Spillovers Declined in the 21st Century?," *Fiscal Studies*, 2019, *40* (4), 561–590.

Lychagin, Oleg, Joris Pinkse, Margaret E. Slade, and John Van Reenen, "Spillovers in Space: Does Geography Matter?," *The Journal of Industrial Economics*, 2016, *64* (2), 295–335.

Medda, Giuseppe and Claudio A. Piga, "Technological Spillovers and Productivity in Italian Manufacturing Firms," *Journal of Productivity Analysis*, June 2014, *41*, 419–434.

Romer, Paul M., "Endogenous Technological Change," *Journal of Political Economy*, October 1990, *98* (5), S71–S102.

Zacchia, Paolo, "Spillovers Through Networks of Scientists," *The Review of Economic Studies*, 2020, *87* (3), 1195–1225.

Appendix

A Appendix Table A1. Descriptive Statistics

	obs.	mean	p50	sd	min	max
R&D expenditure	21888	5.12	4.88	2.07	1.60	13.60
Number of patents owned	21888	2.39	2.08	2.25	0.00	10.93
Number of utility model rights owned	21888	1.14	0.00	1.56	0.00	9.19
Number of design rights owned	21888	1.14	0.00	1.75	0.00	10.76
Sales	21888	9.34	9.11	1.54	5.39	16.30
Value added	21804	7.94	7.73	1.44	2.19	14.68
Total assets	21888	9.36	9.11	1.57	5.49	16.18
Employment	21888	5.84	5.63	1.19	3.91	11.30
Labor productivity	21804	2.10	2.10	0.53	-2.88	5.45
TFP (Solow)	21737	2.60	2.62	0.51	0.46	5.32
TFP (Wooldridge)	21700	9.40	9.10	1.74	4.48	16.09
TFP (ACF)	21732	3.18	3.04	0.82	1.43	6.05
Affiliates' R&D expenditure	4824	1.99	0.69	2.25	0.69	11.15
Affiliates' sales	4666	9.02	8.85	2.34	0.69	17.30
Affiliates' purchases	4500	8.54	8.37	2.41	0.00	17.22
Affiliates' employment	4715	6.06	6.16	2.12	0.00	11.72