Sources of Private and Public R&D Spillovers: Technological, Geographic and Relational Proximity

Kenta Ikeuchi (NISTEP)
Kyoji Fukao (Hitotsubashi University, NISTEP and RIETI)

Joint research with:

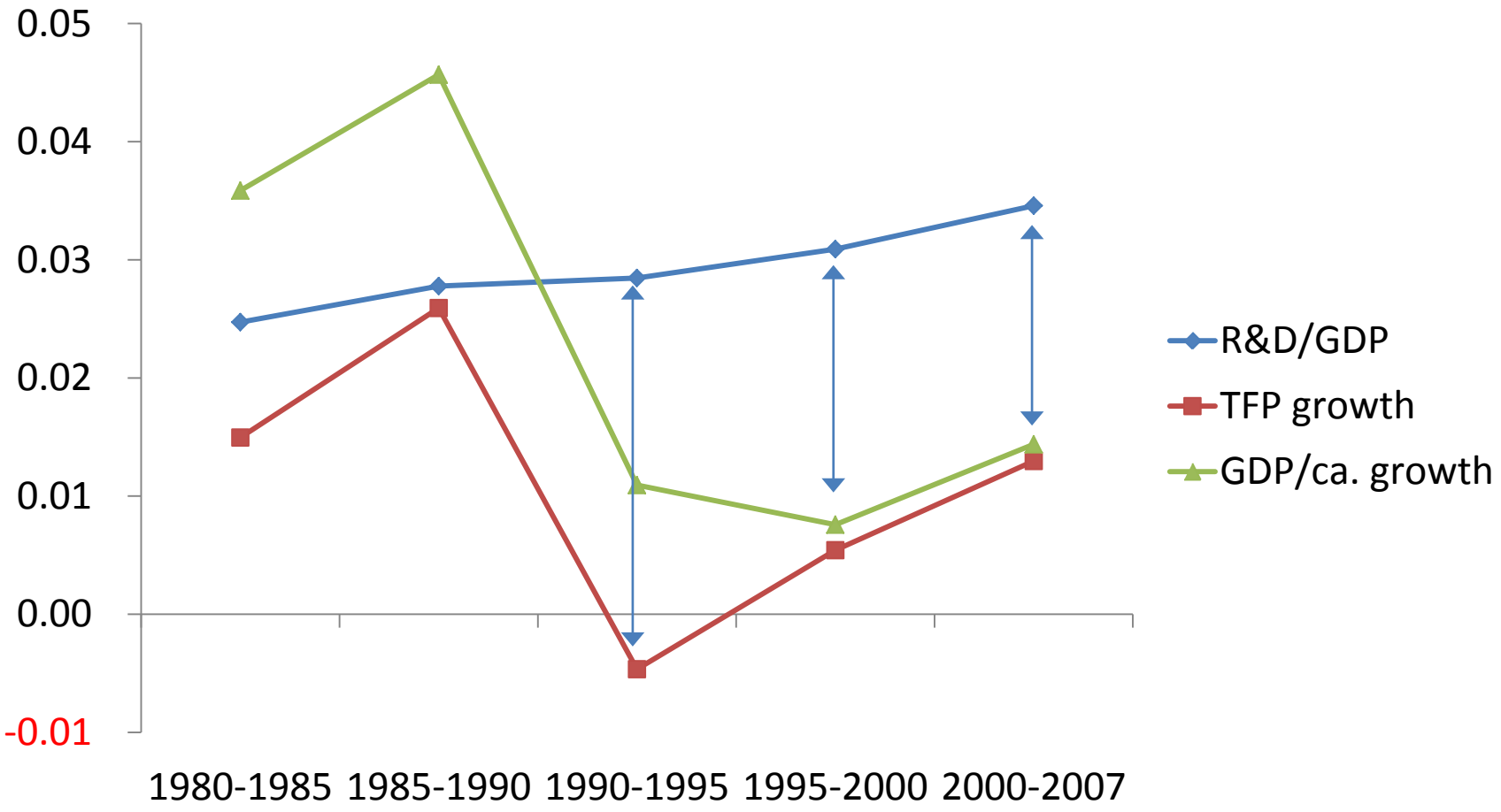
- Rene Belderbos (University of Leuven, Maastricht University, UNU-MERIT and NISTEP)
- Young Gak Kim (Senshu University and NISTEP)
- Hyeog Ug Kwon (Nihon University, NISTEP and RIETI)

Prepared for HIT-TDB-RIETI International Workshop on the Economics of Inter-firm Networks, November 29-30, RIETI.

Motivation

- Discrepancy between the trends in R&D expenditures and TFP growth in Japan
  - Japan's total factor productivity growth has been declining since the mid 1980s (e.g. Fukao and Kwon, 2011)
  - R&D expenditure to GDP ratio has been steadily increasing to reach 3.8% in 2008.
- ➢ Decline in aggregate returns to R&D
- One possible explanation: a decline in R&D spillovers
  - Loosening of traditional stable supplier-buyer relationships
  - Firms increasingly shield off their technologies: focus on intellectual property rights protection and appropriation
  - Relocation of increasingly sophisticated manufacturing plants abroad. Changing patterns of R&D agglomeration and R&D specialization
- ➢ Examine (changing) patterns of R&D spillovers in Japanese manufacturing industries, and possible moderators

R&D and TFP Growth in Japan



Sources: Japanese Science and Technology Indicators 2012, JIP database 2011, National Accounts for 2008.

Literature on Spillovers and Productivity at the Firm Level

Two moderators have received most attention:

- Geographic proximity attenuates the effectiveness of R&D spillovers (Jaffe et al, 2003; Keller, 2002)
  - E.g. Adams and Jaffe, 1996; Aldieri and Cincera, 2009; Orlando, 2004
- Spillovers more likely for related technologies: technological proximity matters
  - E.g. Orlando, 2004; Aldieri and Cincera, 2009; Bloom et al 2010; Jaffe, 1988

Literature on Buyer-Supplier Linkages and Spillovers

Spillovers may also occur through buyer-supplier linkages: '*relational proximity*'

- Goto and Suzuki (1989): R&D weighted with input-output tables (industry level analysis). Crespi et al, 2007: knowledge flows from suppliers increase productivity (UK)
- Buyer-supplier relationships have been found to be a key channel of spillovers from foreign direct investments to local firms.
  - e.g. Haskel et al, 2007; Görg and Strobl, 2001; Javorcik, 2004; Kugler, 2006
  - Knowledge from suppliers and clients
  - Purposeful knowledge exchange to facilitate transactions
  - Quality demands & specifications of buyers
  - 'Pecuniary spillovers' (Hall et al, 2010) from suppliers: prices of intermediates do not reflect full value of embedded technology
- In the context of Japanese firms:
  - Stable supplier relationships (for instance those within vertical business groups) have been associated with knowledge sharing and technology spillovers (Suzuki, 1993; Branstetter, 2000)

Limitations of Previous Studies

1. Abstracted from the role of public research
   - Different research stream focusing on the role of knowledge spillovers from (proximate) public research (e.g. Jaffe, 1989; Adams, 1990; Anselin et al, 1997; Furman et al, 2006; Shankerman and Belenzon, 2010)
2. Limited attention to relational proximities
   - Except for industry level analyses of Terleckyj (1974) and Goto and Suzuki (1989), and firm level analyses of Suzuki (1993) and Branstetter (2000)
3. Typically relied on:
   - Single industry empirical settings (Adams and Jaffe, 1996)
   - Smaller samples of publicly listed firms, using consolidated firm data (Orlando, 2004; Aldieri and Cincera, 2009)
     - No plant level data with detail on location/geography

Our Research Ambition

Simultaneous consideration of all potential spillovers

- Private R&D spillovers moderated by:
  - Geographic proximity
  - Technological proximity
  - Relational proximity:
    - Buyer-supplier and capital relationship
- Public R&D spillovers moderated by:
  - Geographic and technological proximity

Based on long panel of manufacturing plants census matched with:

- Comprehensive survey data on R&D expenditure of firms and public institutions
- Buyer-supplier linkage data identifying the major customers and suppliers of the firm (but only for cross section)

Data Sources

- Census of Manufacturers
  - > 240,000 plants yearly
  - After 2000, only plants > 30 employees with yearly capital stock data (> 40,000 plants)
  - TFP of manufacturing plants available (JIP project)
- Survey of R&D
  - Mandatory yearly survey, ca. 9000 responding firms, response rate > 90%.
  - R&D by industry/field
- Inter-firm linkage database of Tokyo Shoko Research (TSR)
  - Buyer-supplier and capital relationship at the firm-level
  - Detailed information on customers, suppliers and shareholders of the firms makes it possible to easily match their R&D data
  - Cross section data for 2006 are only available

Database Matching and Sample

- >90% of total R&D expenditures by manufacturing firms linked to census plants:
  - Allocated to R&D fields and locations
- Non-matched firms' R&D
  - Allocated to R&D fields and firms' HQ locations at the city-level

➢ Sample in the panel data:

>160,000 plants operated by >140,000 firms, 1987-2007

- Buyer-supplier and capital ties information in 2006 matched at the firm level with productivity data in 2007 :
  - >70% of manufacturing firms with relational data successfully matched with census plants

➢ Sample size of the 2007 cross section data: >20,000 plants

Empirical Model

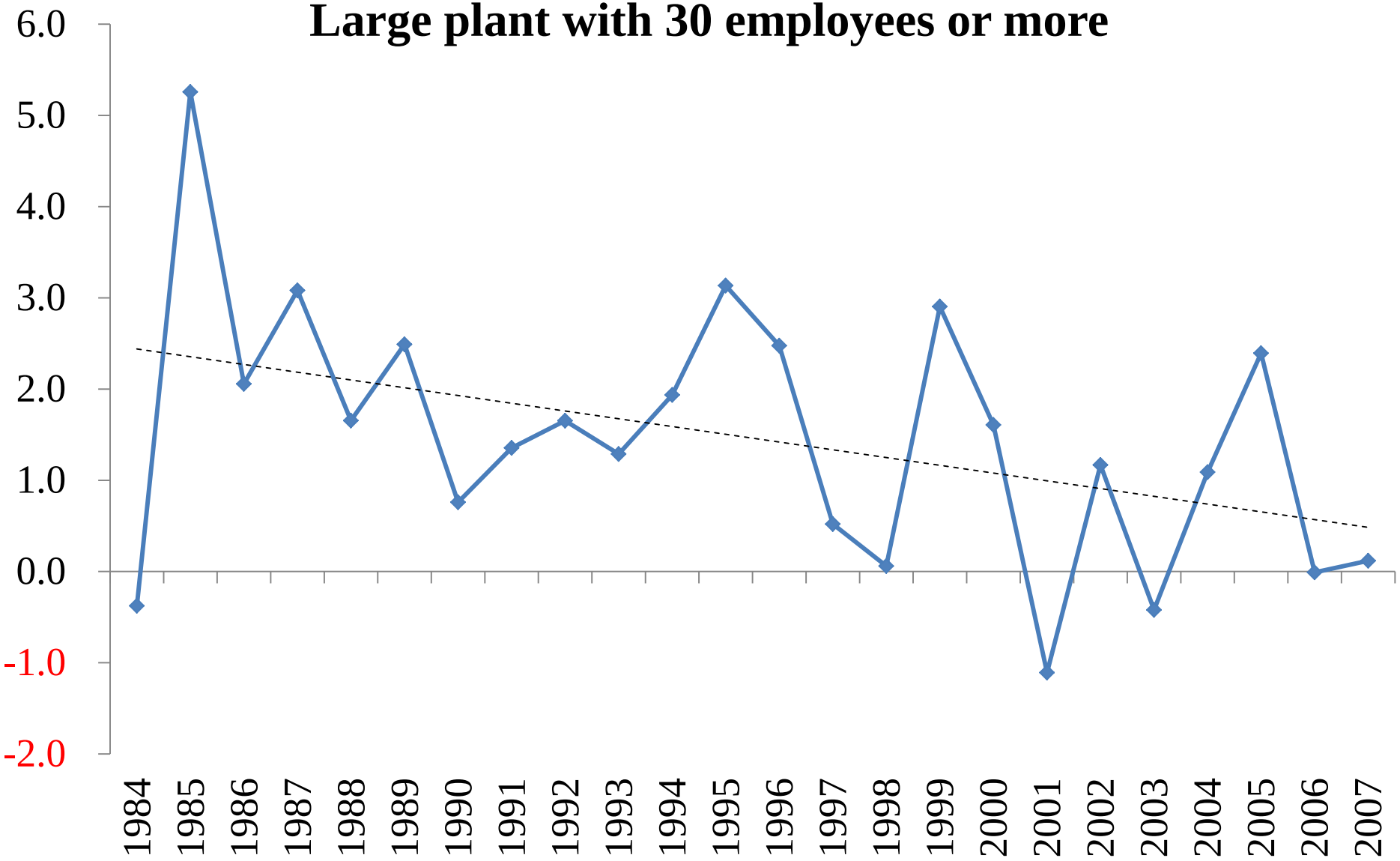
- Dependent variable: 100 * ln (plant-level TFP index)
- Main independent variables: lagged R&D stocks
  - Parent R&D stock
    - Tech-relatedness weighted total of the parent firm's R&D stocks by field
  - Private R&D stocks of the other firms:
    - In industries technologically related to the industry of focal plant
    - With plants located closed to focal plant
    - In supplier and customer industries of the industry of focal plant
    - Suppliers and customers of the parent firm of focal plant
  - Public R&D stocks
    - In science fields technologically related to the industry of focal plant
    - In locations closed to focal plant
- Control variables
  - Firm size, plant size, age of plant, number of sister plants of the same parent firm, multi-product plant dummy
  - Industry and year dummies

Plant TFP

- Calculated as an index of the TFP level of a hypothetical representative plant in 58 manufacturing industries
  - Non-parametric factor share method (Good et al, 1997)
  - Deflators and capital cost are taken from JIP project

➢ Declining trend in TFP of sample plants

Avg. TFP growth rate in the sample (%)
Large plant with 30 employees or more



Note: Weighted average by gross-output.

Parent R&D Stock

- R&D stock at the *firm-field* level
  - Firm R&D distinguished by 30 fields: mapped into 25 (2-digit) industries
  - Stocks calculated with perpetual inventory method, using 15% depreciation rate and industry deflators
- *Technological relatedness index* based on patent citation data
  - Citations between different 4-digit IPC classes relative to within-class citations (e.g. Leten et al, 2007) : relatedness between technologies
  - IPC/technology classes mapped into industries using concordance table (Schmoch et al. 2003): relatedness between the 25 industries
- ➢ R&D stock at the *plant* level
  - Sum of the technological relatedness weighted parent firm R&D in all fields

Technological Relatedness Index (Propensity of Patent Citation) between Industries

	Citing industries																				
Cited industries	[04]	[05]	[06]	[07]	[08]	[09]	[10]	[11]	[12]	[13]	[14]	[15]	[16]	[17]	[18]	[19]	[20]	[21]	[22]	[23]	[24]
[04] Food products	1.000	.007	.022	.000	.009	.026	.031	.004	.000	.003	.001	.001	.001	.010	.022	.000	.000	.000	.000	.003	.011
[05] Textile mill products	.003	1.000	.073	.011	.020	.002	.032	.004	.008	.064	.006	.009	.009	.012	.015	.003	.001	.003	.004	.009	.019
[06] Pulp and paper products	.006	.045	1.000	.042	.008	.001	.012	.002	.001	.026	.002	.003	.012	.008	.003	.001	.003	.001	.001	.004	.009
[07] Printing	.000	.024	.126	1.000	.015	.001	.035	.001	.001	.021	.013	.030	.015	.007	.004	.001	.008	.001	.001	.007	.007
[08] Chemical fertilizers and industrial chemicals	.125	.631	.415	.270	1.000	.147	.488	.763	.400	.439	.248	.392	.066	.114	.091	.080	.024	.028	.032	.070	.180
[09] Drugs and medicine	.359	.065	.049	.021	.147	1.000	.128	.031	.002	.015	.011	.020	.006	.019	.012	.003	.003	.001	.002	.129	.007
[10] Miscellaneous chemicals	.041	.104	.089	.095	.050	.013	1.000	.143	.006	.047	.028	.042	.016	.018	.022	.004	.005	.008	.012	.011	.024
[11] Petroleum and coal products	.001	.001	.002	.000	.012	.000	.020	1.000	.000	.001	.004	.004	.004	.005	.001	.003	.001	.002	.003	.003	.001
[12] Rubber products	.000	.002	.000	.000	.004	.000	.000	.000	1.000	.001	.007	.010	.000	.001	.000	.000	.000	.003	.000	.001	.008
[13] Ceramic, stone and clay products	.004	.172	.100	.028	.039	.002	.038	.008	.008	1.000	.120	.187	.104	.040	.039	.019	.008	.017	.031	.019	.106
[14] Iron and steel	.001	.007	.003	.008	.007	.000	.008	.006	.014	.030	1.000	1.000	.025	.019	.014	.013	.003	.004	.006	.003	.007
[15] Non-ferrous metals and products	.001	.006	.003	.011	.007	.000	.007	.005	.011	.027	.580	.978	.024	.013	.010	.015	.003	.004	.005	.003	.006
[16] Fabricated metal products	.001	.023	.043	.020	.005	.000	.010	.014	.004	.073	.069	.108	1.000	.033	.039	.026	.005	.029	.064	.009	.042
[17] General-purpose machinery	.094	.243	.301	.085	.070	.010	.093	.209	.030	.225	.410	.486	.259	1.000	.188	.084	.027	.183	.260	.078	.184
[18] Household appliances	.021	.026	.009	.003	.005	.001	.010	.003	.001	.020	.030	.034	.027	.018	1.000	.022	.005	.012	.008	.007	.034
[19] Electrical machinery	.001	.013	.008	.003	.010	.000	.006	.036	.005	.022	.059	.111	.050	.020	.057	1.000	.026	.046	.043	.030	.023
[20] Info.&com. electronics	.003	.033	.190	.181	.032	.005	.057	.074	.028	.108	.152	.233	.082	.059	.121	.244	1.000	.055	.041	.151	.076
[21] Motor vehicles, parts and accessories	.002	.019	.004	.002	.006	.000	.014	.030	.064	.032	.036	.052	.081	.078	.056	.082	.010	1.000	.197	.030	.048
[22] Other transportation equipment	.000	.005	.001	.000	.001	.000	.003	.004	.002	.008	.008	.009	.025	.014	.004	.009	.001	.022	1.000	.003	.009
[23] Precision instruments and machinery	.026	.148	.123	.087	.041	.076	.055	.130	.050	.112	.065	.097	.070	.082	.079	.127	.068	.076	.060	1.000	.117
[24] Miscellaneous manufacturing	.026	.114	.083	.017	.027	.001	.036	.014	.116	.197	.048	.075	.102	.058	.106	.031	.009	.041	.064	.035	1.000

Source: Patent data used in Leten et. al (2007)

Descriptions of R&D Stock by Industry

Industry of plants/R&D fields	# of unique plants with non-zero R&D stock	Parent firm R&D stock (avg.; 1 billion yen)			
		All fields	Same field	Other fields	Other fields (weighted)
[18] Home electronics	168	249.3	90.4	158.9	2.3
[20] Info.&com. electronics	1,274	163.6	104.2	59.4	5.3
[21] Motor vehicles, parts and accessories	910	139.8	107.5	32.3	1.2
[19] Electrical machinery	928	85.6	17.5	68.1	2.8
[22] Other transportation equipment	160	84.0	18.3	65.8	1.1
[17] General-purpose machinery	1,743	52.1	17.3	34.8	3.6
[14] Iron and steel	384	39.0	14.0	25.0	1.1
[09] Drugs and medicine	455	37.9	32.3	5.6	0.8
[12] Rubber products	241	35.9	32.9	3.0	0.0
[08] Chemical fertilizers and industrial chemicals	657	31.5	13.7	17.8	2.9
[15] Non-ferrous metals and products	340	27.5	6.5	21.0	1.4
[23] Precision instruments and machinery	386	27.2	9.2	18.0	1.4
[10] Miscellaneous chemicals	719	25.7	14.0	11.7	0.4
[07] Printing	122	24.7	8.7	15.9	0.2
[05] Textile mill products	315	20.2	4.9	15.3	0.4
[11] Petroleum and coal products	93	15.3	5.6	9.7	0.2
[13] Ceramic, stone and clay products	638	14.7	4.2	10.5	0.6
[16] Fabricated metal products	971	14.4	2.5	11.9	0.4
[04] Food products	1,443	14.4	5.0	9.3	0.2
[06] Pulp and paper products	343	8.8	5.3	3.5	0.1
Total	12,290	1,111.6	514.0	597.6	26.5

Private R&D Spillovers: Technological and Geographic Proximity

Technological proximity

- Other firms' R&D weighted by technological relatedness:

➢ 'Relevant' private R&D stock

Geographic proximity

- Assume that results of firms' R&D are diffused to each plant: locus of spillovers is at the plant level
- Geographic distance is distance between cities in which plants are located
  - Multiple plants of the same firm: distance to nearest plant to get the R&D spillovers
  - Within city distance: approximated depending on city radius

➢ Examine effects of the total relevant private R&D stock and additional effects of geographic concentration

Private R&D Spillovers: Relational Proximity – Industry-level

- Input-output table based weights
  - Supplier industry R&D
    - Sum of the R&D in other industries weighted by input share from the industry in total input of the focal industry AND output share to the focal industry in total output of the industry
  - Customer industry R&D
    - Sum of the R&D in other industries weighted by output share to the industry in total output of the focal industry AND input share from the focal industry in total input of the industry

Input Share of Customer Industries

Supplier industry	Customer industry [04]	[05]	[06]	[07]	[08]	[09]	[10]	[11]	[12]	[13]	[14]	[15]	[16]	[17]	[18]	[19]	[20]	[21]	[22]	[23]	[24]
[04] Food products	.198	.005	.005	.006	.004	.020	.009	.001	.002	.004	.001	.001	.004	.003	.002	.003	.004	.001	.002	.003	.006
[05] Textile mill products	.004	.390	.011	.003	.001	.005	.002	.001	.038	.008	.001	.003	.004	.003	.007	.006	.006	.003	.005	.005	.011
[06] Pulp and paper products	.027	.013	.430	.244	.007	.055	.053	.001	.014	.032	.001	.005	.008	.006	.017	.019	.015	.004	.003	.017	.020
[07] Printing	.012	.014	.016	.188	.002	.011	.018	.000	.003	.005	.001	.002	.008	.007	.018	.005	.009	.002	.006	.007	.006
[08] Chemical fertilizers and industrial chemicals	.010	.048	.030	.003	.478	.121	.278	.006	.315	.029	.006	.016	.004	.002	.014	.011	.010	.003	.004	.008	.134
[09] Drugs and medicine	.001	.000	.000	.000	.000	.084	.002	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
[10] Miscellaneous chemicals	.003	.011	.018	.057	.009	.021	.110	.005	.012	.012	.002	.003	.015	.009	.005	.007	.007	.010	.019	.005	.023
[11] Petroleum and coal products	.007	.009	.021	.007	.117	.005	.007	.075	.011	.039	.039	.009	.010	.005	.003	.004	.003	.002	.005	.005	.008
[12] Rubber products	.000	.004	.001	.002	.001	.003	.001	.000	.074	.003	.002	.000	.004	.020	.009	.010	.006	.024	.019	.009	.005
[13] Ceramic, stone and clay products	.009	.001	.002	.000	.004	.021	.008	.001	.002	.163	.010	.006	.007	.008	.004	.013	.019	.008	.008	.028	.010
[14] Iron and steel	.000	.000	.000	.000	.000	.000	.000	.000	.005	.019	.635	.002	.333	.125	.032	.060	.005	.038	.113	.017	.012
[15] Non-ferrous metals and products	.002	.000	.000	.004	.005	.002	.007	.000	.002	.007	.010	.376	.096	.031	.033	.107	.026	.021	.022	.035	.012
[16] Fabricated metal products	.032	.003	.002	.001	.006	.021	.024	.004	.039	.017	.001	.003	.116	.060	.038	.039	.018	.011	.040	.022	.021
[17] General-purpose machinery	.000	.000	.000	.000	.000	.002	.001	.000	.000	.005	.001	.001	.004	.316	.032	.025	.006	.014	.050	.020	.006
[18] Household appliances	.000	.000	.000	.001	.000	.001	.000	.000	.000	.000	.000	.000	.001	.000	.145	.000	.001	.007	.004	.000	.000
[19] Electrical machinery	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.002	.038	.050	.245	.051	.046	.032	.025	.001
[20] Info.&com. electronics	.000	.000	.000	.002	.000	.002	.001	.000	.000	.000	.000	.001	.006	.030	.159	.046	.382	.005	.011	.071	.007
[21] Motor vehicles, parts and accessories	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.598	.041	.000	.000
[22] Other transportation equipment	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.270	.000	.000
[23] Precision instruments and machinery	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.007	.003	.002	.000	.001	.002	.175	.000
[24] Miscellaneous manufacturing	.026	.034	.070	.084	.006	.062	.045	.002	.059	.024	.002	.023	.013	.020	.070	.051	.041	.030	.027	.070	.259

Source: JIP database 2010

Output Share of Supplier Industries

Customer industry \ Supplier industry	[04]	[05]	[06]	[07]	[08]	[09]	[10]	[11]	[12]	[13]	[14]	[15]	[16]	[17]	[18]	[19]	[20]	[21]	[22]	[23]	[24]
[04] Food products	.113	.006	.068	.038	.018	.002	.009	.011	.002	.023	.000	.005	.050	.000	.001	.000	.000	.000	.000	.000	.023
[05] Textile mill products	.001	.237	.012	.016	.031	.000	.013	.005	.010	.001	.000	.000	.002	.000	.000	.000	.000	.000	.000	.000	.011
[06] Pulp and paper products	.001	.005	.279	.013	.013	.000	.016	.008	.002	.001	.000	.000	.001	.000	.000	.000	.000	.000	.000	.000	.016
[07] Printing	.000	.001	.087	.086	.001	.000	.027	.001	.002	.000	.000	.002	.000	.000	.000	.000	.000	.000	.000	.000	.010
[08] Chemical fertilizers and industrial chemicals	.001	.001	.007	.003	.343	.000	.012	.073	.003	.004	.000	.006	.004	.000	.000	.000	.000	.000	.000	.000	.002
[09] Drugs and medicine	.002	.001	.021	.006	.033	.049	.011	.001	.003	.008	.000	.001	.005	.000	.000	.000	.000	.000	.000	.000	.008
[10] Miscellaneous chemicals	.001	.001	.026	.011	.097	.002	.073	.002	.001	.004	.000	.004	.007	.000	.000	.000	.000	.000	.000	.000	.008
[11] Petroleum and coal products	.000	.001	.001	.001	.004	.000	.006	.043	.000	.001	.000	.000	.002	.000	.000	.000	.000	.000	.000	.000	.000
[12] Rubber products	.000	.006	.003	.001	.048	.000	.003	.002	.044	.000	.000	.001	.005	.000	.000	.000	.000	.000	.000	.000	.005
[13] Ceramic, stone and clay products	.001	.003	.019	.004	.012	.000	.009	.014	.005	.094	.005	.005	.006	.001	.000	.000	.000	.000	.000	.000	.005
[14] Iron and steel	.000	.001	.002	.002	.007	.000	.005	.035	.008	.014	.459	.018	.001	.000	.000	.000	.000	.000	.000	.000	.001
[15] Non-ferrous metals and products	.000	.001	.002	.002	.006	.000	.003	.003	.000	.003	.000	.251	.001	.000	.000	.000	.000	.000	.000	.000	.004
[16] Fabricated metal products	.001	.003	.007	.009	.003	.000	.019	.006	.010	.007	.150	.111	.068	.001	.001	.002	.002	.000	.000	.000	.004
[17] General-purpose machinery	.001	.004	.010	.016	.003	.001	.021	.005	.097	.015	.111	.069	.069	.192	.001	.054	.021	.000	.000	.028	.013
[18] Household appliances	.000	.003	.010	.013	.006	.000	.004	.001	.014	.002	.009	.023	.014	.006	.109	.022	.034	.000	.000	.004	.014
[19] Electrical machinery	.001	.003	.014	.005	.006	.000	.007	.002	.021	.009	.022	.098	.018	.006	.000	.145	.013	.000	.000	.004	.013
[20] Info.&com. electronics	.001	.007	.027	.021	.013	.001	.017	.004	.029	.035	.004	.059	.021	.004	.002	.075	.269	.000	.000	.001	.026
[21] Motor vehicles, parts and accessories	.001	.006	.011	.008	.005	.000	.037	.004	.180	.023	.052	.074	.019	.013	.027	.102	.005	.443	.000	.004	.030
[22] Other transportation equipment	.000	.001	.001	.003	.001	.000	.010	.001	.020	.003	.021	.010	.010	.006	.002	.010	.002	.004	.196	.002	.004
[23] Precision instruments and machinery	.000	.001	.004	.002	.001	.000	.002	.001	.007	.007	.002	.011	.004	.002	.000	.005	.007	.000	.000	.101	.006
[24] Miscellaneous manufacturing	.003	.014	.037	.014	.174	.000	.057	.009	.026	.018	.011	.028	.025	.004	.001	.001	.005	.000	.000	.001	.167

Source: JIP database 2010

Private R&D Spillovers: Relational Proximity – Firm-level

- Buyer-supplier relationship at the firm level
  - R&D stock of firm's main suppliers and customers
  - Distinguishing between suppliers and customers;
    - Suppliers R&D
    - Customers R&D
  - Potential effects of capital relationship;
    - Shareholder suppliers R&D
    - Shareholder customers R&D
    - Affiliates suppliers R&D
    - Affiliates customers R&D

Buyer-Supplier and Capital Relationship

Types of links/relationships	# of firms with links	Mean	S.D.	Median	Min	Max
# of suppliers	112,382	8.4	69.6	4	1	7,475
# of customers	118,044	8.6	49.0	4	1	4,644
# of shareholders	19,142	1.9	1.7	1	1	15
# of affiliates	11,895	3.8	15.6	1	1	592

Source: TSR database 2006

Public R&D stock

R&D expenditures by universities and other public institutes

- Data from R&D survey (~100% response rate): R&D stocks with 15 percent depreciation rate
- Expenditures allocated to science fields based on number of researchers per science field as well as to cities based on location of the research institute or university

Technological relatedness; '*relevant*' public R&D

R&D per science field weighted by its relevance for specific technologies and hence industries:

- Based on citations in patents to scientific literature by academic field (Van Looy et al, 2004): gives concordance between science fields and IPC/technology classes
- Based on IPC/technology class to industry concordance (Smoch et al. 2003)

➢ Examine effects of total relevant public R&D and additional effect of geographic concentration

Science-Industry Concordance (Non-patent Citation of Patents by Industry)

	Field of cited academic papers							
Industry of citing patent	Agriculture	Biology	Chemistry	Engineering	Geology	Mathematics	Medicine	Physics
Drugs and medicines	.0215	.1555	.0704	.0063	.0006	.0004	.0535	.0027
Precision instruments and machinery	.0058	.0367	.0287	.0125	.0030	.0004	.0221	.0151
Chemical fertilizers, industrial inorganic and organic chemicals	.0146	.0390	.0451	.0080	.0013	.0001	.0107	.0029
Information and communication electronics	.0012	.0039	.0089	.0616	.0017	.0026	.0017	.0250
General-purpose machinery	.0103	.0145	.0114	.0086	.0015	.0001	.0034	.0055
Electrical machinery, equipment and supplies	.0002	.0004	.0031	.0067	.0002	.0001	.0002	.0062
Food	.0082	.0047	.0010	.0008	.0000	.0000	.0012	.0001
Ceramic, stone and clay products	.0006	.0007	.0032	.0034	.0003	.0000	.0003	.0019
Iron and steal	.0004	.0003	.0017	.0034	.0003	.0000	.0001	.0023
Non-ferrous metals and products	.0004	.0003	.0017	.0034	.0003	.0000	.0001	.0023
Miscellaneous chemicals	.0012	.0007	.0024	.0015	.0002	.0000	.0001	.0010
Motor vehicles, parts and accessories	.0002	.0007	.0007	.0012	.0002	.0000	.0003	.0005
Fabricated metal products	.0002	.0002	.0011	.0009	.0000	.0000	.0000	.0004
Rubber products	.0001	.0002	.0009	.0009	.0000	.0000	.0002	.0004
Petroleum and coal products	.0002	.0005	.0005	.0004	.0002	.0000	.0001	.0002
Household electric appliances	.0002	.0001	.0005	.0005	.0000	.0000	.0000	.0005
Printing	.0000	.0000	.0005	.0003	.0000	.0000	.0000	.0005
Miscellaneous manufacturing products	.0001	.0002	.0003	.0005	.0000	.0000	.0001	.0002
Pulp, paper and paper products	.0001	.0002	.0002	.0004	.0000	.0000	.0000	.0001
Textile mill products	.0000	.0001	.0002	.0002	.0000	.0000	.0000	.0000
Miscellaneous transportation equipment	.0000	.0000	.0000	.0001	.0003	.0000	.0000	.0001

Source: Van Looy et. al (2004)

Empirical Methods

- Relate ln(tfp) to ln(R&D stocks)in t-1
- Two approaches:
  1. Panel data analyses with IO table based relational proximity at the industry-level
     - Use long difference model to reduce influence of measurement error and cyclical effects (e.g. Haskell et al, 2007; Branstetter, 2000)
       - 5-year difference, starting 1987, leaves max. 4 non-overlapping observations per plant
     - Control for initial TFP level; gradual convergence of TFP
  2. Cross section analysis (OLS) with firm specific buyer-supplier relationship data
     - Private and public R&D with geographic and tech proximity

Results : Relational proximity at the industry-level (Long difference 1987-2007; IO table based)

	(1)	(2)	(3)	(4)
ln.Parent R&D stock	5.425	5.422	5.425	5.425
	[0.543]***	[0.542]***	[0.543]***	[0.542]***
ln.Supplier industry R&D stock		0.806		0.823
		[0.182]***		[0.183]***
ln.Customer industry R&D stock			0.020	0.096
			[0.147]	[0.148]
ln.Tech-related industry R&D stock	1.510	1.256	1.531	1.354
	[0.217]***	[0.223]***	[0.273]***	[0.276]***
ln.Public R&D stock	0.687	0.922	0.677	0.880
	[0.157]***	[0.165]***	[0.174]***	[0.179]***
(Lagged) ln.TFP * 100	-0.493	-0.493	-0.493	-0.493
	[0.00275]***	[0.00275]***	[0.00276]***	[0.00276]***
R-squares	0.347	0.347	0.347	0.347

5-year difference; # of obs. = 213,698, # of plants = 105423.
Controls not reported: Industry dummies, year dummies, # of sister plants, firm size, plant size, plant age and multi-product dummy. Firm-level clustered robust standard errors in brackets. ***p<0.01, **p<0.05, *p<0.1.

Results: Buyer-Suppliers linkage at the firm-level (Cross section 2007)

	(1)	(2)	(3)
ln.Parent R&D stock	1.300	1.357	1.322
	[0.188]***	[0.184]***	[0.186]***
ln.Suppliers R&D stock	-0.005		-0.068
	[0.0899]		[0.0914]
ln.Customers R&D stock		0.651	0.646
		[0.0812]***	[0.0816]***
ln.Tech-related industry R&D stock < 50km	0.907	0.837	0.865
	[0.117]***	[0.117]***	[0.117]***
ln.Public R&D stock < 10km	0.115	0.098	0.090
	[0.0486]**	[0.0486]**	[0.0486]*
R-squares	0.621	0.623	0.623

OLS; # of obs. = 22,252 plants. Controls not reported: Industry dummies, dummies for zero R&D stocks, # of sister plants, # of (matched/unmatched) suppliers and customers, firm size, plant size, plant age and multi-product dummy. Robust standard errors in brackets. ***p<0.01, **p<0.05, *p<0.1.

Results: Shareholders R&D at the firm-level (Cross section 2007)

	(1)	(2)	(3)
ln.Parent R&D stock	1.567	1.522	1.524
	[0.181]***	[0.177]***	[0.177]***
ln.Shareholders R&D stock	0.302		
	[0.152]**		
ln.Suppliers R&D stock - shareholders		0.421	
		[0.202]**	
ln.Customers R&D stock - shareholders			-0.014
			[0.171]
ln.Tech-related industry R&D stock < 50km	0.863	0.853	0.857
	[0.117]***	[0.117]***	[0.117]***
ln.Public R&D stock < 10km	0.126	0.124	0.123
	[0.0486]***	[0.0486]**	[0.0486]**
R-squares	0.621	0.621	0.621

OLS; # of obs. = 22,252 plants. Controls not reported: Industry dummies, dummies for zero R&D stocks, # of sister plants, # of (matched/unmatched) shareholders, shareholding suppliers and customers, firm size, plant size, plant age and multi-product dummy. Robust standard errors in brackets. ***p<0.01, **p<0.05, *p<0.1.

Results: Affiliates R&D at the firm-level (cross section 2007)

	(1)	(2)	(3)
ln.Parent R&D stock	1.457	1.486	1.626
	[0.207]***	[0.205]***	[0.210]***
ln.Affileates R&D stock	-0.108		
	[0.291]		
ln.Suppliers R&D stock - affiliates		0.414	
		[0.350]	
ln.Customers R&D stock - affiliates			0.366
			[0.353]
ln.Tech-related industry R&D stock < 50km	0.875	0.875	0.870
	[0.117]***	[0.117]***	[0.117]***
ln.Public R&D stock < 10km	0.122	0.123	0.124
	[0.0486]**	[0.0486]**	[0.0486]**
R-squares	0.621	0.621	0.621

OLS; # of obs. = 22,252 plants. Controls not reported: Industry dummies, dummies for zero R&D stocks, # of sister plants, # of (matched/unmatched) affiliates, affiliated suppliers and customers, firm size, plant size, plant age and multi-product dummy. Robust standard errors in brackets. ***p<0.01, **p<0.05, *p<0.1.

Conclusions: Effects of R&D stocks on plant TFP

- Robust impact of parent firm R&D stock
- Simultaneous positive spillovers effects from;
  - R&D by firms with plants in technologically related industries
  - R&D in relevant fields by public institutes and universities
- Relational spillovers of private R&D stock:
  - Industry-level relational spillovers measured by IO table:
    - Positive impact of supplier industry R&D
      → pecuniary externality?
    - No effects of customer industry R&D
  - Inter-firm relational spillovers:
    - Significant R&D spillovers effects from customer firms
    - R&D spillovers from supplier firms limited to within business groups (only from shareholder suppliers)
    - No significant spillovers from R&D of affiliates

Discussions and Future Research: Decline in R&D spillovers?

- Reduced (domestic) inter-firm relationship through:
  - Increased vertical trades with low-tech foreign suppliers matter?
    - Consistent story with our results: Importance of supplier industry R&D spillovers and supplier spillovers within business group
  - Weakened capital ties with suppliers matter? (e.g. Nissan's case)
    - NOT consistent with our results: No evidence of positive spillovers effects from shareholder customers.

➢ We need long panel data for inter-firm relationships as well as overseas activities to conclude 'changes' in relational spillovers and its consequence.

- Other evidences for decline in R&D spillovers in our project:
  - Reduced agglomeration of R&D 'performing' plants in relevant sectors
  - Increased distance of plants from universities
  - Reduced co-specialization of science and industry
  - Reduced spillover effects of public R&D after 2002

Results: Geographic and Relational Proximity (Cross section 2007)

	(1)	(2)	(3)	(4)	(5)
ln.Parent R&D stock	1.284	1.291	1.308	1.329	1.324
	[0.184]***	[0.184]***	[0.185]***	[0.185]***	[0.185]***
ln.Private R&D stock < 50km	0.883	0.846	0.775	0.831	0.872
	[0.119]***	[0.123]***	[0.122]***	[0.118]***	[0.118]***
ln.Public R&D stock < 10km	0.103	0.104	0.110	0.116	0.116
	[0.0487]**	[0.0486]**	[0.0486]**	[0.0486]**	[0.0487]**
ln.Suppliers&customers R&D < 25km	0.025				
	[0.0239]				
ln.Suppliers&customers R&D < 50km		0.042			
		[0.0239]*			
ln.Suppliers&customers R&D < 100km			0.105		
			[0.0258]***		
ln.Suppliers&customers R&D < 250km				0.141	
				[0.0305]***	
ln.Suppliers&customers R&D < 500km					0.133
					[0.0357]***
R-squares	0.621	0.621	0.622	0.622	0.622

OLS; # of obs. = 22,252 plants. Controls not reported: Industry dummies, dummies for zero R&D stocks, # of sister plants, # of (matched/unmatched) affiliates, affiliated suppliers and customers, firm size, plant size, plant age and multi-product dummy. Robust standard errors in brackets. ***p<0.01, **p<0.05, *p<0.1.