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

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In a Nutshell

- First study to examine simultaneous effect of private (firm) as well as public (university) R&D spillovers on TFP
- Large panel of Japanese plants –matched with R&D survey data, 1984-2007
- Examine factors that attenuate the effects of private R&D spillovers:
  - Technological proximity (R&D by field)
  - Geographic proximity (prefecture & city)
  - Relational proximity (main buyers and suppliers of firms) (very preliminary, cross section)
- Public spillovers: university R&D expenditures
  - Geographic proximity and technological relatedness (relevant science fields)

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 3.1% 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 patterns of R&D spillovers in Japanese manufacturing industries, and possible moderators

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

Approach in Previous Studies

1. 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
2. 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).
3. Limited attention to spillovers through supplier and client 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)
   - Instead, supplier-buyer linkages have been the focus of the literature on FDI spillovers to local firms

Supplier-client Linkages and Spillovers

- 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)

R&D and Spillovers: other issues

- Absorptive capacity (Cohen and Levinthal, 1989): firms' own R&D stock enhances benefits of spillovers (e.g. Aldieri and Cincera, 2009; Lokshin et al. 2008; Griffith et al, 2004)
  - In particular in case of public R&D spillovers from universities (e.g. Cockburn and Henderson, 1998; Cassiman and Veugelers, 2006).
- Market spillovers: fewer productivity benefits expected of other firms' R&D if these firms are direct market competitors, due to compensating 'business stealing' effect of rivals' R&D
  - Bloom et al, 2010; Branstetter and Sakakibara, 2002
- International knowledge spillovers, e.g. through trade or FDI (e.g. Branstetter, 2001; Keller, 2002; Griffith et al. 2004)
- Role of multinational firms:
  - 'Reverse knowledge transfer' from overseas R&D laboratories (Griffith et al., 2008; Todo and Shimizutani, 2008; Iwasa and Odagiri, 2004): spillovers from foreign R&D stocks
  - Affiliates of foreign multinationals tend to have higher TFP levels (e.g. Criscuolo and Martin, 2009; Doms and Jensen, 1998)

Our Research Ambition

Simultaneous consideration of all potential spillovers

Current approach (presentation)

- Technological proximity (R&D by field)
- Geographic proximity (prefecture & city)
- Public R&D (universities)
- Relational proximity (main buyers and suppliers of firms)

Future Plans

- Continuous distance measures & technological proximity measures
- Input-output tables for relational proximity
- Business group spillovers; identification of multinationals and overseas R&D

Data & Sample

Main data sources

- Census of Manufacturers (CM)
  - > 240,000 plants yearly
  - After 2000, only plants > 30 employees with yearly capital stock data; 40,000 plants
  - TFP of manufacturing plants available (JIP productivity project)
- Survey of R&D (SRD)
  - Mandatory yearly survey, ca. 9000 responding firms, response rate > 90%. Corrections for sampling and non-response

Database matching

- Matching keys: firm name, address and capital (no firm codes available)
- On average > 90% of total R&D expenditures by manufacturing firms linked to census plants: allocate to fields and locations. Non-matched R&D allocated to firm HQ location.

➢ Unbalanced panel of > 200,000 plants, 1984-2007

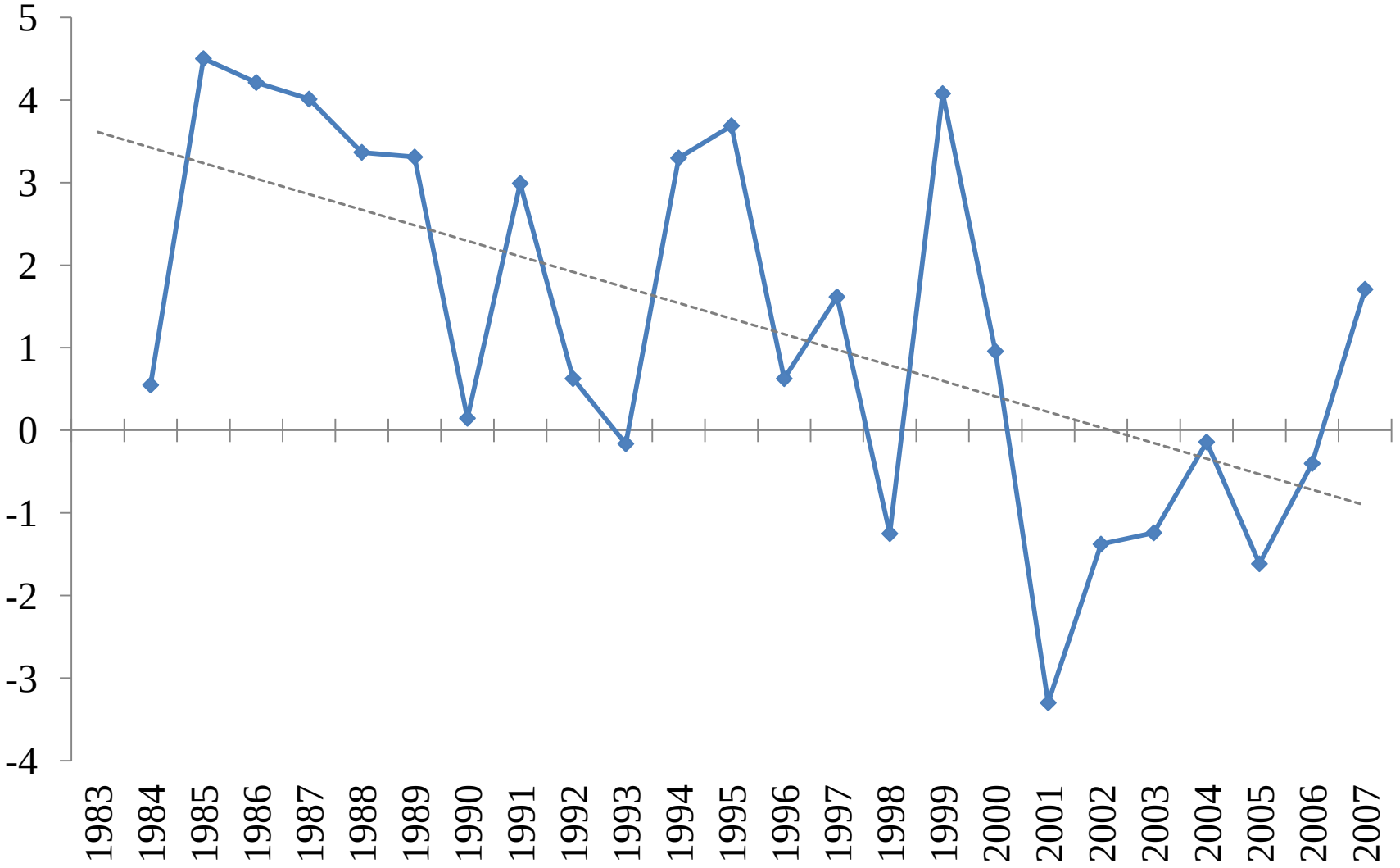
➢ Robustness checks for sample of R&D-active firms (13,000 plants)

Plant TFP and R&D stocks

- TFP levels of each plant
  - Taken from JIP project
  - Calculated for 58 manufacturing industries
  - Non-parametric factor share method (Good et al, 1997) : TFP index
  - Dependent variable: 100* ln (tfp index)

- R&D stock at the plant level
  - Parent firm R&D distributed over 30 fields: mapped into 25 (2-digit) industries
  - Distinguish R&D stock in the plant's 2-digit industry and R&D stock in other industries (e.g. Adams and Jaffe, 1996)
  - Stocks calculated with perpetual inventory method, using 15% depreciation rate and industry deflators

TFP Growth Rate in Overall Manufacturing Industry - Domar weighted - (%)



Private R&D Spillover Pools

Parent R&D and Technological proximity: 2 variables

- Total parent R&D
- Share of the parent's R&D in the 2-digit industry of the plant (tech proximity)

R&D spillovers

Technological proximity

- R&D of plants in the same 2-digit industry versus R&D of plants in other industries

Geographic proximity

- Prefectural R&D stocks versus R&D stocks in the city of the plant

Combining Geographic & technological proximity: four variables

- Prefectural R&D stock in the same industry
- Share of the city in the 'same-industry' R&D stock (proximity)
- Prefectural R&D stock in other industries
- Share of the city in the 'other-industries' R&D stock (proximity)

Public R&D Spillover Pools

R&D expenditures by Universities

- Data from R&D survey (~100% response rate)
- Expenditures allocated to science fields based on number of researchers per science field

Public R&D spillovers

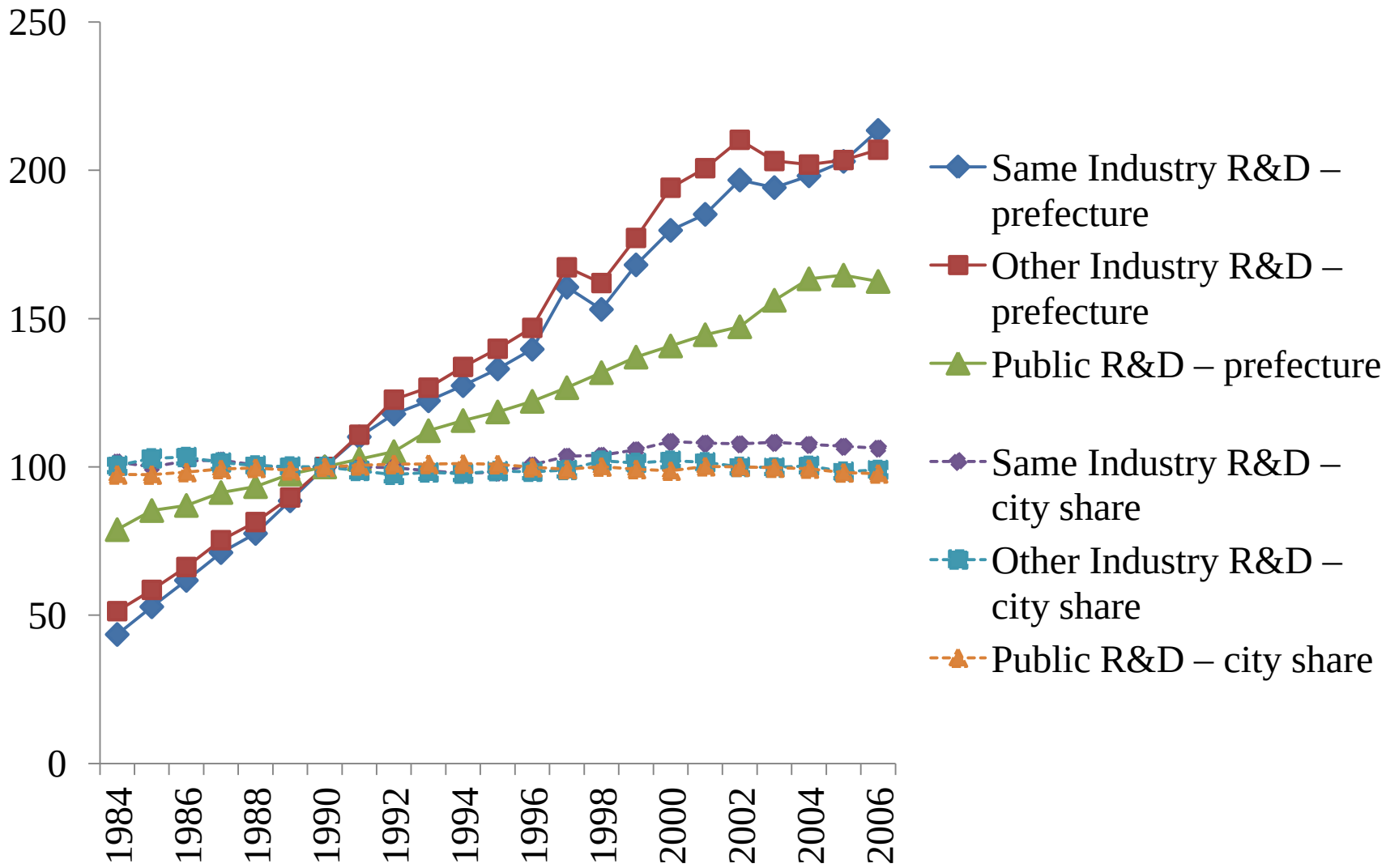
Technological relevance

- R&D per science field weighted by its relevance for specific technologies and industries
- Based on patent citation data (Van Looy et al, 2004): concordance between science fields and IPC/technology classes
- Based on IPC/technology class to industry concordance (Smoch et al. 2003)

Combining geographic & technological relevance: two variables

- Relevant public (university) R&D stock in plant's prefecture
- Share of the plant's city in the public R&D stock of the prefecture

Avg. R&D spillover pools for large plants (Index: 1990=100)



Relational proximity and spillovers

- R&D stock of the firm's main suppliers and customers
- Derived from detailed data on the (maximum) 10 largest suppliers and customers of each firm (Tokyo Shoko Research
- Data for 2006: cross section analysis productivity in 2007
- Potential effect of geographic proximity & difference between suppliers and customers
  - Total relational R&D stock (R&D by suppliers and customers)
  - Share of R&D stock of suppliers
  - Share of R&D stock in the prefecture

Descriptions of R&D stock by industry

Industry (R&D field)	# of unique plants	# of unique firms	Avg. # of plants per firm	Avg. # of plants per year	Avg. # of plants with R&D stock per year	%	Avg. R&D stock per plant/year (bill. of yen)	Avg. # of R&D investing firms per year
Household machinery	3,070	2,762	4.5	747.0	51.3	6.9	214.8	54.4
Information & communication electronics	15,939	13,357	2.8	5529.0	505.7	9.1	162.0	317.3
Automobile	9,458	7,874	2.1	3568.0	402.2	11.3	124.6	170.5
Drugs and medicine	1,065	761	8.2	499.3	226.0	45.3	39.5	215.1
Rubber	2,863	2,491	1.7	1160.1	110.4	9.5	36.2	74.2
Electrical machinery	13,014	11,309	2.5	4354.8	314.9	7.2	33.5	236.8
General machinery	27,870	25,322	1.7	10745.0	654.2	6.1	24.3	421.1
Other transportation equipment	2,985	2,722	1.8	993.4	76.2	7.7	21.2	76.4
Iron and steel	4,875	4,160	2.4	2147.7	186.0	8.7	20.6	62.1
Chemical fertilizers and industrial chemicals	1,708	1,258	3.5	771.2	345.0	44.7	15.7	228.3
Other chemicals	2,228	1,774	2.5	930.0	321.3	34.6	15.3	337.2
Precision instruments and machinery	4,580	4,134	1.6	1452.2	113.7	7.8	11.6	138.3
Printing	12,380	11,384	1.4	5183.2	58.5	1.1	9.7	17.7
Pulp and paper	6,911	5,675	3.3	3238.1	212.9	6.6	9.1	51.3
Non-ferrous metals	3,055	2,588	2.4	1201.7	163.4	13.6	8.2	89.9
Petroleum and coal	587	395	10.5	230.1	51.4	22.3	5.8	32.0
Food	29,280	25,485	1.9	13880.2	732.9	5.3	5.3	227.0
Textile mill	24,188	21,358	1.5	10278.6	175.9	1.7	4.9	85.2
Fabricated metal	27,215	24,627	1.6	10158.1	329.9	3.2	4.5	158.0
Ceramic, stone and clay	12,854	10,575	2.4	6000.2	352.6	5.9	4.2	137.2
Miscellaneous manufacturing	23,654	22,030	1.4	9181.3	162.6	1.8	3.6	173.4
Total over all industries	201,472	172,749	2.0	92249.0	5546.9	6.0	38.2	2,549.4

(Preliminary) Methods

- Fixed effects model regressing ln (tfp) on ln(R&D stock)(t-1) variables and proximity ratios
- Full set of industry-year dummies to control for industry specific shocks
- Time-variant control variables (age of plant, just established plant, size of plant, exiting plant, number of plants of the firm)
- Error terms clustered at the firm level

Fixed effects results: Parent R&D & controls (2,121,727 obs.; 201,472 plants; 172,472 firms)

	[1]		[2]	
ln.Parent R&D	2.398***	[0.498]	2.370***	[0.499]
Parent R&D – same industry share			0.026***	[0.009]
new plant	-0.123	[0.211]	-0.121	[0.211]
exiting plant	-1.832***	[0.149]	-1.832***	[0.149]
ln.parent firm age	2.199***	[0.215]	2.201***	[0.215]
relative plant age	0.255***	[0.044]	0.253***	[0.044]
ln.plant size	-0.332**	[0.139]	-0.337**	[0.139]
multi-product plant	-0.050	[0.121]	-0.046	[0.121]
ln.# of firm plants	-1.513***	[0.362]	-1.502***	[0.362]
Industry-year dummies	Included		Included	
Constant	-15.170***	[0.960]	-15.244***	[0.962]
R-squared	0.193		0.193	
F test	133.5		133.3	

Standard errors adjusted for firm in brackets.
* p<.1, ** p<.05, *** p<.01.

Fixed effects results: Private & public R&D spillovers

	[1]	[2]	[3]	[4]
ln.Parent R&D	2.370***	2.357***	2.358***	2.358***
	[0.499]	[0.495]	[0.495]	[0.495]
Parent R&D – same industry share	0.026***	0.026***	0.026***	0.026***
	[0.009]	[0.009]	[0.009]	[0.009]
ln.Same Industry R&D – prefecture		0.180***	0.248***	0.241***
		[0.038]	[0.039]	[0.041]
Same Industry R&D – city share		-0.001	-0.001	-0.001
		[0.003]	[0.003]	[0.003]
ln.Other Industry R&D – prefecture			1.376***	1.395***
			[0.175]	[0.177]
Other Industry R&D – city share			-0.003	-0.004
			[0.007]	[0.007]
ln.Relevant Public R&D – prefecture				0.053
				[0.066]
Relevant Public R&D – city share				0.025
				[0.017]
Plant and industry-year controls	Included	Included	Included	Included
Constant	-15.244***	-15.870***	-25.653***	-26.482***
	[0.962]	[0.971]	[1.584]	[1.768]
R-squared	0.193	0.193	0.193	0.193
F test	133.3	132.8	132.7	132.3

Fixed effects results: Absorptive capacity & structural changes

	[1]		[2]	
ln.Parent R&D	0.415	[0.556]	0.733*	[0.414]
Parent R&D – same industry share	0.025**	[0.012]	0.027***	[0.009]
ln.Same Industry R&D – prefecture	0.226***	[0.041]	0.082**	[0.042]
Same Industry R&D – city share	-0.001	[0.003]	-0.001	[0.003]
ln.Other Industry R&D – prefecture	1.387***	[0.177]	0.539***	[0.180]
Other Industry R&D – city share	-0.003	[0.007]	-0.002	[0.007]
ln.Relevant Public R&D – prefecture	-0.035	[0.069]	0.173***	
Relevant Public R&D – city share	0.025	[0.017]	0.032*	[0.017]
ln.Parent R&D – same industry x ln.Same Industry R&D – prefecture	0.018	[0.012]		
ln.Parent R&D – other industry x ln.Other Industry R&D – prefecture	0.016	[0.010]		
ln.Parent R&D x ln.Relevant Public R&D – prefecture	0.102***	[0.025]		
Trend x ln.Parent R&D			0.020***	[0.003]
Trend x ln.Same Industry R&D – prefecture			0.018***	[0.004]
Trend x ln.Other Industry R&D – prefecture			-0.075***	[0.007]
Trend x ln.Public R&D – prefecture			-0.054***	[0.006]
Plant and industry-year controls	Included		Included	
Constant	-25.063***	[1.768]	-26.251***	[1.741]
R-squared	0.193		0.194	
F test	131.7		131.4	

Fixed effects results: R&D performing firms
(146,472 obs.; 13,082 plants; 5,155 firms)

	[1]		[2]		[3]	
ln.Parent R&D	0.988**	[0.412]	-1.541	[1.031]	0.640	[0.408]
Parent R&D – same industry share	0.026***	[0.009]	0.027**	[0.013]	0.027***	[0.009]
ln.Same Industry R&D – prefecture	0.437**	[0.174]	0.496**	[0.219]	0.232	[0.175]
Same Industry R&D – city share	0.007	[0.009]	0.007	[0.009]	0.003	[0.009]
ln.Other Industry R&D – prefecture	1.774**	[0.728]	1.854**	[0.734]	0.896	[0.722]
Other Industry R&D – city share	0.017	[0.028]	0.018	[0.028]	0.014	[0.028]
ln.Relevant Public R&D – prefecture	0.021	[0.295]	-3.224**	[1.317]	0.551*	[0.322]
Relevant Public R&D – city share	-0.035	[0.080]	-0.034	[0.079]	-0.031	[0.079]
ln.Parent R&D – same industry x ln.Same Industry R&D – prefecture			-0.005	[0.016]		
ln.Parent R&D – other industry x ln.Other Industry R&D – prefecture			-0.002	[0.010]		
ln.Parent R&D x ln.Relevant Public R&D – prefecture			0.242**	[0.097]		
Trend x ln.Parent R&D					0.047***	[0.016]
Trend x ln.Same Industry R&D – prefecture					0.004	[0.016]
Trend x ln.Other Industry R&D – prefecture					-0.031	[0.035]
Trend x ln.Public R&D – prefecture					-0.085***	[0.025]
Plant and industry-year controls	Included		Included		Included	
Constant	-35.354***	[11.408]	-1.961	[15.941]	-33.179***	[11.065]
R-squared	0.292		0.292		0.293	
F test	28.2		28.9		28.9	

Cross section analysis (2007): Relational spillovers
(R&D performing firms: 6,236 plants)

	[1]	[2]	[3]	[4]	[5]
ln.Parent R&D	3.230***	3.259***	3.200***	3.246***	3.186***
	[0.339]	[0.341]	[0.338]	[0.339]	[0.340]
Parent R&D – same industry share	0.054***	0.054***	0.053***	0.054***	0.053***
	[0.014]	[0.014]	[0.014]	[0.014]	[0.014]
Supplier&Buyer R&D – all	0.509**	0.460*	0.637**	0.505**	0.631**
	[0.253]	[0.257]	[0.263]	[0.253]	[0.264]
Supplier&Buyer R&D – prefecture share		0.018			
		[0.012]			
Supplier&Buyer R&D – supplier share			0.021*		0.020*
			[0.012]		[0.012]
Supplier&Buyer R&D – capital relational share				0.026	
				[0.020]	
ln.Same Industry R&D – prefecture					-0.124
					[0.350]
Same Industry R&D – city share					0.010
					[0.018]
ln.Other Industry R&D – prefecture					0.628
					[0.763]
Other Industry R&D – city share					0.024
					[0.041]
ln.Relevant Public R&D – prefecture					-0.607
					[0.543]
Relevant Public R&D – city share					-0.014
					[0.033]
Industry dummies – 2digit	Included	Included	Included	Included	Included
Constant	-44.719***	-44.756***	-47.196***	-45.188***	-45.168***
	[7.488]	[7.496]	[7.611]	[7.523]	[9.684]
R-squared	0.552	0.552	0.552	0.552	0.552
F test	158.3	153.1	154.1	153.3	131.1

Robust standard errors in brackets. * p<.1, ** p<.05, *** p<.01. All the other control variables are also included but not reported. The number of firms in the sample is 2,884 for all specifications.

Preliminary Results

- Positive effect of parent firm R&D stock on plants' TFP, with larger effects of parent firm R&D in the same industry/field. Multiple plants relying on the same R&D reduces TFP
- Positive effects of R&D spillovers in the same industry in the prefecture. No evidence of further proximity effects at the city level
- Positive effects of other industry spillovers at the prefecture level, no further proximity effects
- Public R&D spillovers: only effects noticeable in interaction with own R&D. Indication that absorptive capacity matters
- Positive effects of relational spillovers. In particular supplier spillovers. These spillovers are not attenuated by distance (prefecture).

- Effects work *simultaneously*
- Spillover effects substantial compared to own R&D effects
- Public and other industry spillover effects are *declining* over time: preliminary evidence that reduced spillovers are responsible for declining aggregate returns to R&D?
  - Are results robust to better specified and inclusive models
  - Challenge for future research is then to find out why

Limitations and Future Research I

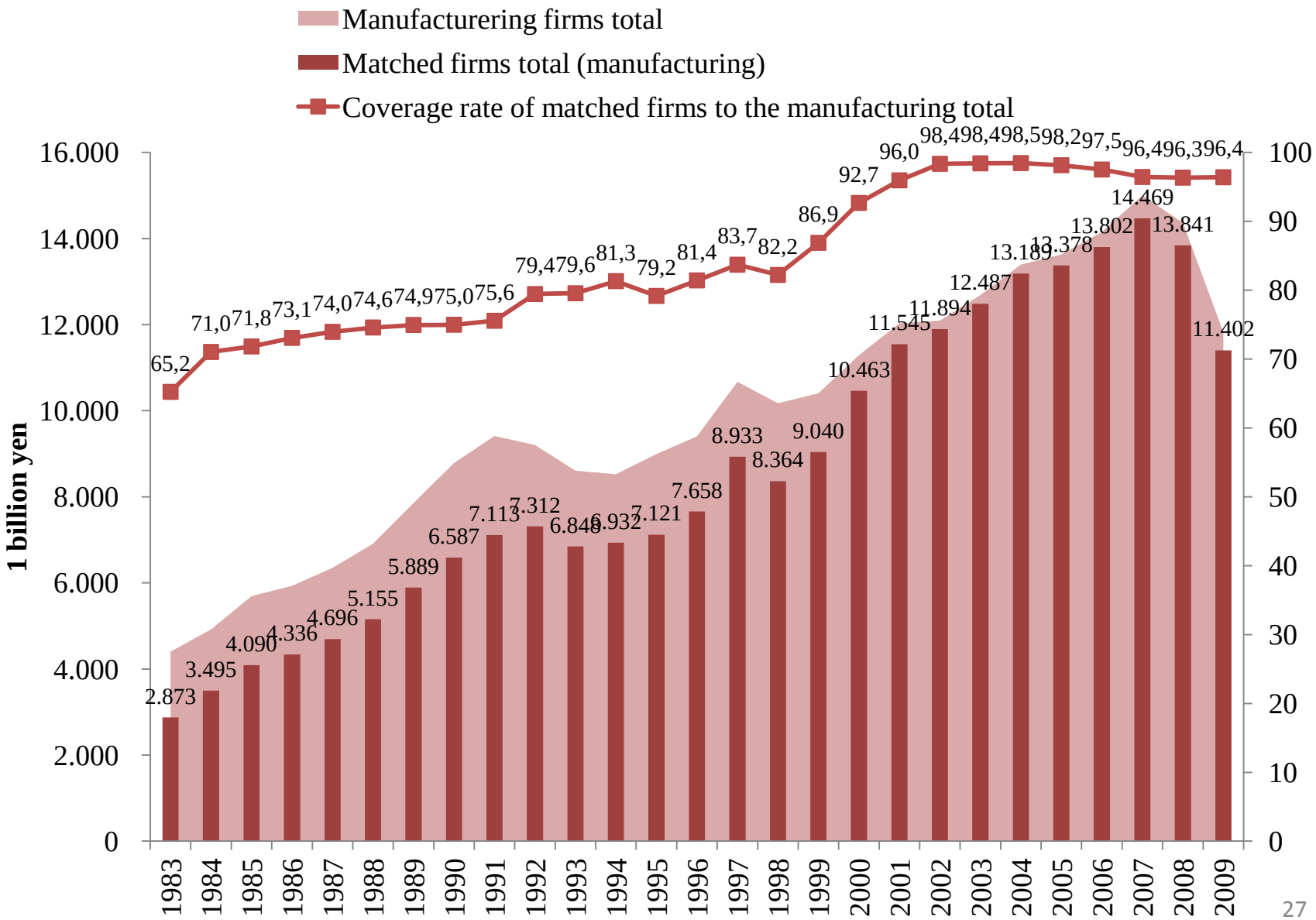
- **Improve binary representation of related and unrelated R&D**
  - Apply weighting scheme for relatedness of the R&D fields, to calculate a relevant R&D stock.
    - E.g. Based on joint occurrence of R&D in firms (Bond et al, 2010), or citation-based measure of relationships between technologies (Leten et al., 2007)
- **Geographic proximity ignores spillovers from other (adjacent) prefectures**
  - Use distance weighted proximity measures (latitude & longitude of plants)
- **Relational spillovers in panel**
  - **Extending firm-specific measure to panel may be difficult**
  - Use input-output tables instead
- **Spillover disaggregation in more detail**
  - Calculate R&D stocks a the 3-digit level
  - Examine role of competition (negative market spillovers) at the 4-digit level

Limitations and Future Research II

- **Improve data & methods**
  - Weak exogeneity, endogeneity, autocorrelation
  - ➢ Long difference analysis; GMM or IV analysis using (changing) R&D policies as instruments
- **We assume that all parent R&D is available at each plant and that spillovers occur at the plant location**
  - ➢ Control for location of parent firm laboratories (Adams and Jaffe, 1986): using R&D facility directories
  - ➢ Public spillovers, in particular, may occur at the laboratory level
- **Business group effects**
  - ➢ Include business group/ capital ownership ties: match with Basic Survey
- **Control for international spillovers and overseas R&D**
  - ➢ Use Basic Survey information on overseas activities and foreign ownership (Japanese affiliates of foreign firms)

OTHER RESULTS & TABLES

Matched sample coverage of the R&D expenditure)



Descriptive statistics of the variables

	Overall				Within		
	Mean	S.D.	Min	Max	S.D.	Min	Max
ln.TFP * 100	2.587	34.007	-331.337	332.948	19.995	-290.199	281.613
ln.Parent R&D	0.896	3.350	0.000	19.712	0.112	-3.342	6.150
Parent R&D – same industry share	4.265	18.846	0.000	100.000	3.621	-91.387	99.918
ln.Same Industry R&D – prefecture	3.791	2.246	-10.642	9.153	0.784	-9.633	13.932
Same Industry R&D – city share	9.474	21.864	0.000	100.000	8.720	-86.178	105.126
ln.Other Industry R&D – prefecture	7.885	1.197	-4.175	9.941	0.418	3.011	10.740
Other Industry R&D – city share	7.194	12.291	0.000	100.000	3.461	-69.838	100.037
ln.Public R&D – prefecture	10.324	2.173	4.707	17.648	0.443	4.348	16.037
Public R&D – city share	8.229	17.532	0.000	97.271	1.596	-30.592	50.913
ln. # of firm plants	0.284	0.614	0.000	4.890	0.110	-1.488	2.555
new plant	0.017	0.130	0.000	1.000	0.110	-0.483	0.974
exiting plant	0.016	0.125	0.000	1.000	0.114	-0.484	0.972
ln.firm age	2.300	0.618	0.000	3.258	0.471	-0.248	3.976
relative plant age	0.111	1.783	-21.417	20.909	0.942	-10.817	19.920
ln.plant size	3.483	0.930	2.303	10.109	0.211	0.358	6.451
multi-product plant	0.173	0.379	0.000	1.000	0.190	-0.783	1.130

Correlation matrix

		[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]
[1]	ln TFP * 100	1.000								
[2]	ln.Parent R&D	0.167	1.000							
[3]	Parent R&D – same industry share	0.134	0.792	1.000						
[4]	ln.Same Industry R&D – prefecture	0.220	0.108	0.095	1.000					
[5]	Same Industry R&D – city share	0.020	0.082	0.072	-0.028	1.000				
[6]	ln.Other Industry R&D – prefecture	0.112	0.076	0.064	0.421	-0.074	1.000			
[7]	Other Industry R&D – city share	-0.009	0.020	0.016	-0.067	0.189	-0.120	1.000		
[8]	ln.Relevant Public R&D – prefecture	0.215	0.110	0.100	0.623	-0.043	0.330	-0.106	1.000	
[9]	Relevant Public R&D – city share	-0.012	-0.010	-0.006	-0.147	0.252	-0.201	0.302	-0.166	1.000

Fixed effects results: Balanced panel sample
(278,162 obs.; 12,094 plants; 10,594 firms)

	[1]		[2]		[3]	
ln.Parent R&D	2.309***	[0.571]	0.639	[0.695]	0.920	[0.574]
Parent R&D – same industry share	0.029*	[0.016]	0.006	[0.020]	0.031*	[0.017]
ln.Same Industry R&D – prefecture	0.282**	[0.115]	0.224*	[0.118]	0.097	[0.119]
Same Industry R&D – city share	0.006	[0.006]	0.008	[0.006]	0.006	[0.006]
ln.Other Industry R&D – prefecture	1.714***	[0.420]	1.712***	[0.420]	1.126***	[0.421]
Other Industry R&D – city share	-0.023	[0.015]	-0.022	[0.015]	-0.022	[0.015]
ln.Relevant Public R&D – prefecture	-0.107	[0.181]	-0.332	[0.205]	0.053	[0.185]
Relevant Public R&D – city share	0.113***	[0.037]	0.115***	[0.037]	0.115***	[0.037]
ln.Parent R&D – same industry x ln.Same Industry R&D – prefecture			0.030	[0.020]		
ln.Parent R&D – other industry x ln.Other Industry R&D – prefecture			-0.014	[0.017]		
ln.Parent R&D x ln.Relevant Public R&D – prefecture			0.093**	[0.037]		
Trend x ln.Parent R&D					0.013***	[0.004]
Trend x ln.Same Industry R&D – prefecture					0.022**	[0.009]
Trend x ln.Other Industry R&D – prefecture					-0.064***	[0.016]
Trend x ln.Public R&D – prefecture					-0.036***	[0.013]
Plant and industry-year controls	Included		Included		Included	
Constant	-15.992***	[5.915]	-12.529**	[5.929]	-15.708***	[5.858]
R-squared	0.340		0.340		0.341	
F test	41.2		39.9		41.6	

Standard errors adjusted for firm in brackets. * p<.1, ** p<.05, *** p<.01.
All the other control variables are also included but not reported.

Fixed effects with AR(1) disturbance [1]
(1,920,255 obs.; 186,444 plants)

	[1]		[2]	
ln.Parent R&D	1.476***	[0.115]	0.650***	[0.178]
Parent R&D – same industry share	0.013***	[0.005]	0.015**	[0.007]
ln.Same Industry R&D – prefecture	0.142***	[0.028]	0.134***	[0.028]
Same Industry R&D – city share	-0.002	[0.002]	-0.002	[0.002]
ln.Other Industry R&D – prefecture	1.002***	[0.108]	0.994***	[0.108]
Other Industry R&D – city share	-0.008	[0.005]	-0.008	[0.005]
ln.Relevant Public R&D – prefecture	0.143***	[0.043]	0.099**	[0.044]
Relevant Public R&D – city share	0.023**	[0.011]	0.023**	[0.011]
ln.Parent R&D – same industry x ln.Same Industry R&D – prefecture			0.011*	[0.006]
ln.Parent R&D – other industry x ln.Other Industry R&D – prefecture			0.016***	[0.006]
ln.Parent R&D x ln.Relevant Public R&D – prefecture			0.052***	[0.011]
Plant and industry-year controls	Included		Included	
Constant	-2.417***	[0.169]	-2.396***	[0.169]
F test	413.9		411.6	
Rsq. (within)	0.106		0.106	
Bhargava et al. Durbin-Watson	1.059		1.059	
autocorrelation coefficient	0.490		0.490	

Robust standard errors adjusted in brackets. * p<.1, ** p<.05, *** p<.01.
All the other control variables are also included but not reported.

Fixed effects with AR(1) disturbance [2] (1,920,255 obs.; 186,444 plants)

ln.Parent R&D	0.894***	[0.123]
Parent R&D – same industry share	0.015***	[0.005]
ln.Same Industry R&D – prefecture	0.027	[0.031]
Same Industry R&D – city share	-0.002	[0.002]
ln.Other Industry R&D – prefecture	1.100***	[0.111]
Other Industry R&D – city share	-0.007	[0.005]
ln.Relevant Public R&D – prefecture	0.280***	[0.046]
Relevant Public R&D – city share	0.023**	[0.011]
Trend x ln.Parent R&D x Pre-2000	0.025***	[0.002]
Trend x ln.Parent R&D x Post2000	0.021***	[0.002]
Trend x ln.Same Industry R&D – prefecture x Pre-2000	0.019***	[0.004]
Trend x ln.Same Industry R&D – prefecture x Post2000	0.022***	[0.004]
Trend x ln.Other Industry R&D – prefecture x Pre-2000	-0.089***	[0.007]
Trend x ln.Other Industry R&D – prefecture x Post2000	-0.073***	[0.007]
Trend x ln.Public R&D – prefecture x Pre-2000	-0.034***	[0.005]
Trend x ln.Public R&D – prefecture x Post2000	-0.030***	[0.005]
Plant and industry-year controls	Included	
Constant	-2.392***	[0.169]
F test	408.9	
Rsq. (within)	0.106	
Bhargava et al. Durbin-Watson	1.060	
autocorrelation coefficient	0.490	

Robust standard errors in brackets. * p<.1, ** p<.05, *** p<.01.
All the other control variables are also included but not reported.

Pseudo-fixed effects results [1]: Parent R&D, spillovers & absorptive capacity (1,437,899 obs.)

	[1]		[2]	
First 5 years average productivity for each plant	0.609***	[0.001]	0.609***	[0.001]
ln.Parent R&D	1.293***	[0.045]	1.429***	[0.067]
Parent R&D – same industry share	0.023***	[0.002]	0.010**	[0.004]
ln(Same Industry R&D – prefecture + 1)	0.349***	[0.018]	0.348***	[0.018]
Same Industry R&D – city share	0.008***	[0.001]	0.008***	[0.001]
ln(Other Industry R&D – prefecture + 1)	0.196***	[0.026]	0.204***	[0.026]
Other Industry R&D – city share	0.002	[0.002]	0.002	[0.002]
ln(Relevant Public R&D – prefecture + 1)	0.112***	[0.022]	0.112***	[0.023]
Relevant Public R&D – city share	0.001	[0.001]	0.001	[0.001]
ln.Parent R&D – same industry x ln(Same Industry R&D – prefecture + 1)			0.002	[0.004]
ln.Parent R&D – other industry x ln(Other Industry R&D – prefecture + 1)			-0.016***	[0.003]
ln.Parent R&D x ln(Relevant Public R&D – prefecture + 1)			0.000	[0.004]
Zero Parent R&D	12.871***	[0.609]	12.780***	[0.654]
Plant and industry-year controls	Included		Included	
Constant	-38.696***	[0.766]	-38.673***	[0.801]
R-squared	0.438		0.438	
F test	1311.2		1315.9	

Pseudo-fixed effects results [2]: Structural change

First 5 years average productivity for each plant	0.608***	[0.001]
ln.Parent R&D	1.151***	[0.045]
Parent R&D – same industry share	0.023***	[0.002]
ln(Same Industry R&D – prefecture + 1)	0.230***	[0.021]
Same Industry R&D – city share	0.008***	[0.001]
ln(Other Industry R&D – prefecture + 1)	0.508***	[0.029]
Other Industry R&D – city share	0.002	[0.002]
ln(Relevant Public R&D – prefecture + 1)	0.346***	[0.025]
Relevant Public R&D – city share	0.001	[0.001]
Trend x ln.Parent R&D x Pre-2000	0.031***	[0.002]
Trend x ln.Parent R&D x Post2000	0.011***	[0.001]
Trend x ln(Same Industry R&D – prefecture + 1) x Pre-2000	0.036***	[0.005]
Trend x ln(Same Industry R&D – prefecture + 1) x Post2000	0.023***	[0.005]
Trend x ln(Other Industry R&D – prefecture + 1) x Pre-2000	-0.090***	[0.007]
Trend x ln(Other Industry R&D – prefecture + 1) x Post2000	-0.068***	[0.007]
Trend x ln(Public R&D – prefecture + 1) x Pre-2000	-0.059***	[0.005]
Trend x ln(Public R&D – prefecture + 1) x Post2000	-0.061***	[0.006]
Zero Parent R&D	12.640***	[0.608]
Plant and industry-year controls	Included	
Constant	-46.564***	[0.819]
R-squared	0.439	
F test	1301.8	

Pseudo-fixed effects with AR(1) [1]: R&D & absorptive capacity (1,562,627 obs.; 165,012 plants; 121,845 firms)

	[1]		[2]	
First 5 years average productivity for each plant	0.634***	[0.003]	0.634***	[0.003]
ln.Parent R&D	0.826***	[0.169]	0.936***	[0.231]
Parent R&D – same industry share	0.009	[0.006]	0.006	[0.010]
ln(Same Industry R&D – prefecture + 1)	-0.028	[0.035]	-0.027	[0.035]
Same Industry R&D – city share	0.002	[0.002]	0.002	[0.002]
ln(Other Industry R&D – prefecture + 1)	0.843***	[0.059]	0.845***	[0.059]
Other Industry R&D – city share	0.001	[0.004]	0.001	[0.004]
ln(Relevant Public R&D – prefecture + 1)	-0.056	[0.044]	-0.053	[0.045]
Relevant Public R&D – city share	0.003	[0.003]	0.003	[0.003]
ln.Parent R&D – same industry x ln(Same Industry R&D – prefecture + 1)			-0.002	[0.008]
ln.Parent R&D – other industry x ln(Other Industry R&D – prefecture + 1)			-0.005	[0.008]
ln.Parent R&D x ln(Relevant Public R&D – prefecture + 1)			-0.004	[0.011]
Zero Parent R&D	7.566***	[2.015]	7.827***	[2.015]
Plant and industry-year controls	Included		Included	
Constant	-37.251***	[2.103]	-37.577***	[2.099]
R-squared	0.198		0.198	
F test	267.2		267.3	
D.W. (transformed)	1.998		1.998	
D.W. (untransformed)	0.483		0.483	
Auto-correlation coefficient	0.752		0.752	

Standard errors adjusted for firm in brackets. * p<.1, ** p<.05, *** p<.01.

All the other control variables are also included but not reported.

Pseudo-fixed effects with AR(1) [2]: Structural changes (1,562,627 obs.; 165,012 plants; 121,845 firms)

First 5 years average productivity for each plant	0.634***	[0.003]
ln.Parent R&D	0.706***	[0.169]
Parent R&D – same industry share	0.008	[0.006]
ln(Same Industry R&D – prefecture + 1)	-0.115***	[0.037]
Same Industry R&D – city share	0.002	[0.002]
ln(Other Industry R&D – prefecture + 1)	1.080***	[0.056]
Other Industry R&D – city share	0.002	[0.004]
ln(Relevant Public R&D – prefecture + 1)	0.081*	[0.044]
Relevant Public R&D – city share	0.003	[0.003]
Trend x ln.Parent R&D	0.016***	[0.002]
Trend x ln(Same Industry R&D – prefecture + 1)	0.022***	[0.006]
Trend x ln(Other Industry R&D – prefecture + 1)	-0.067***	[0.009]
Trend x ln(Public R&D – prefecture + 1)	-0.039***	[0.007]
Zero Parent R&D	7.365***	[2.022]
Plant and industry-year controls	Included	
Constant	-43.656***	[2.175]
R-squared	0.198	
F test	268.9	
D.W. (transformed)	1.995	
D.W. (untransformed)	0.484	
Auto-correlation coefficient	0.752	

Standard errors adjusted for firm in brackets. * p<.1, ** p<.05, *** p<.01.
All the other control variables are also included but not reported.