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Spatial spillovers and innovation activity in European regions

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Aims of the paper

- Explore the evolution of technological activity across European regions and the determinants of innovation diffusion and creation
- Estimate a Knowledge Production Function (KPF) where innovation output is function of R&D, and other internal and external factors.
- Use the spatial econometric methodology to define the correct specification of the KPF and to assess the role of several types of spillovers.
- Analyse the importance of geographical proximity (both within and across national borders) in the diffusion of knowledge.
- Explore the role played by similarity of the technological composition between two regions in the diffusion of knowledge.

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The literature behind us/1

- **From a theoretical point of view:** knowledge and technological progress are engines of economic dynamics in most endogenous growth models (since Romer, 1986).
- In the **spatial context** this implies that local growth depends on the amount of technological activity which is carried out locally and on the ability to exploit external technological achievements known as technological spillovers (Martin and Ottaviano, 2001; Coe and Helpman, 1995).
- Importance of geographical **proximity** for sharing innovations and knowledge and other local advantages (Glaeser et al, 1992; Henderson, 1997, Paci and Usai, 2000, Breschi and Lissoni, 2000)
- Importance of other types of **proximity** and **links** for technological spillovers to operate (Boschma, 2005, Coe, Helpman and Hoffmaister, 1997, Keller, 2000, Verspagen, 2000)

The literature behind us/2

- A useful approach to analyse the process of innovation creation is the estimation of a KNOWLEDGE PRODUCTION FUNCTION (KPF)
  - originally formalised by Griliches, 1979, and mainly applied at the firm level.
  - It has been refocused by Jaffe, 1989, to study the geographic scope of knowledge spillovers through citations.
- Empirical estimations of KPF have been carried out for different levels of aggregation:
  - For the US case (Acs et al, 1994; Audretsch and Feldman, 1996; Anselin et al, 1997, Feldman and Audretsch, 1999)
  - For the EU case: Maurseth and Verspagen, 1999; Bottazzi and Peri, 2003).

CRENoS database on innovation activity

- Updated statistical databank on regional patenting at the European Patent Office
- Patent applications
- 1978-2001
- 17 countries in Europe (the 15 members of the pre-2004 EU plus Switzerland and Norway)
- 175 regions (inventors residence)
- Up to 100 (3digit ISIC) manufacturing sectors

European Regions CRENoS (ID-CRENoS; Region; Nuts level)

1	AT11	Burgenland	2	44	DEA2	Koeln	2	88	FR26	Bourgogne	2	131	IT71	Abruzzo	2
2	AT12	Niederoesterreich	2	45	DEA3	Muenster	2	89	FR3	Nord-Pas-De-Calais	2	132	IT72	Molise	2
3	AT13	Wien	2	46	DEA4	Detmold	2	90	FR41	Lorraine	2	133	IT8	Campania	2
4	AT21	Kaernten	2	47	DEA5	Arnsberg	2	91	FR42	Alsace	2	134	IT91	Puglia	2
5	AT22	Steiermark	2	48	DEB1	Koblenz	2	92	FR43	Franche-Comte	2	135	IT92	Basilicata	2
6	AT31	Oberoesterreich	2	49	DEB2	Trier	2	93	FR51	Pays De La Loire	2	136	IT93	Calabria	2
7	AT32	Salzburg	2	50	DEB3	Rheinhessen-Pfalz	2	94	FR52	Bretagne	2	137	ITA	Sicilia	2
8	AT33	Tirol	2	51	DEC	Saarland	2	95	FR53	Poitou-Charentes	2	138	ITB	Sardegna	2
9	AT34	Vorarlberg	2	52	DED1	Chemnitz	2	96	FR61	Aquitaine	2	139	LU	Luxembourg	0
10	BE1	Reg.Bruxelles-Cap	1	53	DED2	Dresden	2	97	FR62	Midi-Pyrenees	2	140	NL1	Noord-Nederland	1
11	BE2	Vlaams Gewest	1	54	DED3	Leipzig	2	98	FR63	Limousin	2	141	NL2	Oost-Nederland	1
12	BE3	Region Wallonne	1	55	DEE1	Dessau	2	99	FR71	Rhone-Alpes	2	142	NL3	West-Nederland	1
13	CH01	Région Lémanique	2	56	DEE2	Halle	2	100	FR72	Auvergne	2	143	NL4	Zuid-Nederland	1
14	CH02	Espace Mittelland	2	57	DEE3	Magdeburg	2	101	FR81	Languedoc-Roussillon	2	144	NO01	Oslo Og Akershus	2
15	CH03	Nordwestschweiz	2	58	DEF	Schleswig-Holstein	2	102	FR82	Provence-Alpes-Cote D'Azur	2	145	NO02	Hedmark Og Oppland	2
16	CH04	Zürich	2	59	DEG	Thueringen	2	103	FR83	Corse	2	146	NO03	Sør-Østlandet	2
17	CH05	Ostschweiz	2	60	DK	Denmark	0	104	GR11	Anatoliki Makedonia, Thraki	2	147	NO04	Agder Og Rogaland	2
18	CH06	Zentralschweiz	2	61	ES11	Galicia	2	105	GR12	Kentriki Makedonia	2	148	NO05	Vestlandet	2
19	CH07	Ticino	2	62	ES12	Asturias	2	106	GR13	Dytiki Makedonia	2	149	NO06	Trøndelag	2
20	DE11	Stuttgart	2	63	ES13	Cantabria	2	107	GR14	Thessalia	2	150	NO07	Nord-Norge	2
21	DE12	Karlsruhe	2	64	ES21	Pais Vasco	2	108	GR21	Ipeiros	2	151	PT11	Norte	2
22	DE13	Freiburg	2	65	ES22	Navarra	2	109	GR22	Ionia Nisia	2	152	PT12	Centro (P)	2
23	DE14	Tuebingen	2	66	ES23	Rioja	2	110	GR23	Dytiki Ellada	2	153	PT13	Lisboa E Vale Do Tejo	2
24	DE21	Oberbayern	2	67	ES24	Aragon	2	111	GR24	Sterea Ellada	2	154	PT14	Alentejo	2
25	DE22	Niederbayern	2	68	ES3	Madrid	2	112	GR25	Peloponnisos	2	155	PT15	Algarve	2
26	DE23	Oberpfalz	2	69	ES41	Castilla-Leon	2	113	GR3	Attiki	2	156	SE01	Stockholm	2
27	DE24	Oberfranken	2	70	ES42	Castilla-La Mancha	2	114	GR41	Voreio Aigaio	2	157	SE02	Oestra Mellansverige	2
28	DE25	Mittelfranken	2	71	ES43	Extremadura	2	115	GR42	Notio Aigaio	2	158	SE04	Sydsverige	2
29	DE26	Unterfranken	2	72	ES51	Cataluna	2	116	GR43	Kriti	2	159	SE06	Norra Mellansverige	2
30	DE27	Schwaben	2	73	ES52	Comunidad Valenciana	2	117	IE01	Border, Midland And Western	2	160	SE07	Mellersta Norrland	2
31	DE3	Berlin	2	74	ES61	Andalucia	2	118	IE02	Southern And Eastern	2	161	SE08	Oevre Norrland	2
32	DE4	Brandenburg	2	75	ES62	Murcia	2	119	IT11	Piemonte	2	162	SE09	Smaaland Med Oearna	2
33	DE5	Bremen	2	76	FI13	Ita-Suomi	2	120	IT12	Valle D'Aosta	2	163	SE0A	Vaestsverige	2
34	DE6	Hamburg	2	77	FI14	Vali-Suomi	2	121	IT13	Liguria	2	164	UKC	North East	1
35	DE71	Darmstadt	2	78	FI15	Pohjois-Suomi	2	122	IT2	Lombardia	2	165	UKD	North West	1
36	DE72	Giessen	2	79	FI16	Uusimaa (Suuralue)	2	123	IT31	Trentino-Alto Adige	2	166	UKE	Yorkshire And The Humber	1
37	DE73	Kassel	2	80	FI17	Etela-Suomi	2	124	IT32	Veneto	2	167	UKF	East Midlands	1
38	DE8	Mecklenburg-Vorpommern	2	81	FI2	Aland	2	125	IT33	Friuli-Venezia Giulia	2	168	UKG	West Midlands	1
39	DE91	Braunschweig	2	82	FR1	Ile De France	2	126	IT4	Emilia-Romagna	2	169	UKH	Eastern	1
40	DE92	Hannover	2	83	FR21	Champagne-Ardenne	2	127	IT51	Toscana	2	170	UKJ	South East	1
41	DE93	Lueneburg	2	84	FR22	Picardie	2	128	IT52	Umbria	2	171	UKI	London	1
42	DE94	Weser-Ems	2	85	FR23	Haute-Normandie	2	129	IT53	Marche	2	172	UKK	South West	1
43	DEA1	Duesseldorf	2	86	FR24	Centre	2	130	IT6	Lazio	2	173	UKL	Wales	1
				87	FR25	Basse-Normandie	2					174	UKM	Scotland	1
												175	UKN	Northern Ireland	1

Spatial distribution of innovation

***Early eighties**:*

- strong centre-periphery distribution of innovation activity

Late nineties:

- the intensity to innovate has increased considerably over the two decades in all countries
- the innovations have been spreading to some more regions in the South of Europe (Spain, Southern Italy and Finland)
- the degree of disparities in the regional distribution of innovative activities has decreased

Geography of innovative activity / countries

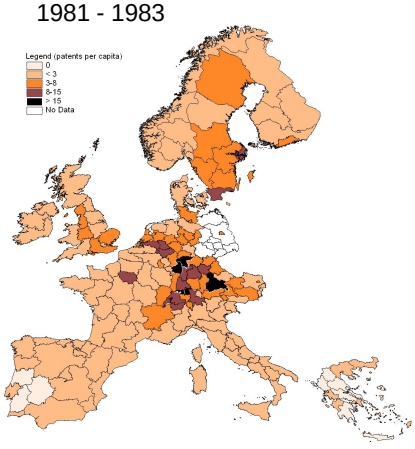
		patents per 100.000 inhabitants (annual average)								variation (annual average)		
Country	**no of regions**	**81-83**	***rank***	**88-90**	***rank***	**95-97**	***rank***	**99-01**	***rank***	**82-90**	**90-96**	**96-00**
Switzerland	7	17,6	*1*	26,1	*1*	26,3	*1*	34,4	*1*	5,6	0,1	6,7
Germany	40	10,6	*2*	19,2	*2*	16,8	*3*	25,2	*2*	8,5	-1,9	10,1
Finland	6	1,9	*11*	6,7	*7*	14,5	*4*	24,7	*3*	17,8	11,1	13,3
Sweden	8	8,5	*4*	10,8	*3*	17,7	*2*	24,1	*4*	3,4	7,1	7,8
Netherlands	4	5,6	*5*	10,6	*4*	11,6	*5*	18,4	*5*	9,1	1,3	11,5
Luxembourg	1	9,3	*3*	6,2	*9*	8,8	*8*	15,6	*6*	-5,8	5,0	14,3
Denmark	1	3,0	*9*	5,6	*10*	10,0	*6*	15,2	*7*	8,9	8,2	10,6
Austria	9	4,2	*7*	8,4	*6*	8,8	*9*	13,0	*8*	9,7	0,7	9,8
France	22	4,9	*6*	8,4	*5*	9,1	*7*	11,9	*9*	7,6	1,1	6,8
Belgium	3	2,8	*10*	5,6	*11*	8,4	*10*	11,9	*10*	9,9	6,0	8,6
United Kingdom	12	4,2	*8*	6,7	*8*	6,6	*11*	9,0	*11*	6,6	-0,1	7,7
Norway	7	1,5	*12*	3,5	*13*	5,3	*12*	7,8	*12*	11,4	6,1	9,5
Italy	20	1,4	*13*	3,7	*12*	4,6	*13*	6,3	*13*	14,5	2,9	7,9
Ireland	2	0,6	*14*	1,6	*14*	2,8	*14*	5,2	*14*	14,2	7,4	15,9
Spain	15	0,1	*15*	0,5	*15*	1,1	*15*	1,8	*15*	19,0	9,3	13,3
Greece	13	0,1	*16*	0,2	*16*	0,3	*16*	0,5	*16*	12,4	6,0	12,1
Portugal	5	0,0	*17*	0,1	*17*	0,2	*17*	0,4	*17*	17,1	9,8	19,0

Geography of innovative activity /regions

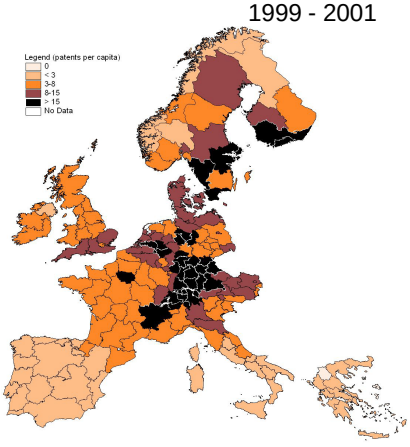
Region	Nation	Period							
		1981-83		1988-90		1994-96		1999-01	
		Pat pc	ranking	Pat pc	ranking	Pat pc	ranking	Pat pc	ranking
Oberbayern	DE	18,08	3	29,1	2	26,9	2	50,4	1
Stuttgart	DE	9,50	13	21,8	7	23,9	6	43,3	2
Nordwestschweiz	CH	34,13	1	38,9	1	32,8	1	42,4	3
Zuid-Nederland	NL	8,15	18	18,4	12	15,5	18	36,8	4
Zurich	CH	18,40	2	27,4	3	24,7	5	36,6	5
Uusimaa	FI	3,48	49	9,4	30	19,5	10	35,5	6
Rheinhessen-Pfalz	DE	18,01	4	24,9	5	26,0	4	32,5	7
Darmstadt	DE	17,90	5	26,8	4	26,0	3	32,2	8
Mittelfranken	DE	9,95	12	22,3	6	17,8	12	31,0	9
Stockholm	SE	10,28	11	13,0	21	20,3	7	30,8	10
Karlsruhe	DE	12,09	8	21,0	8	19,9	8	29,6	11
Freiburg	DE	8,50	17	16,3	15	18,7	11	29,3	12
Tubingen	DE	6,39	25	14,4	18	16,7	15	28,6	13
Vorarlberg	AT	2,52	64	11,3	25	13,3	22	25,8	14
Ostschweiz	CH	9,44	14	19,0	11	17,2	14	25,5	15
Koln	DE	14,97	6	19,9	10	17,4	13	24,8	16
Zentralschweiz	CH	7,39	19	17,4	13	19,9	9	24,5	17
Unterfranken	DE	5,42	29	10,7	26	14,7	21	23,2	18
Braunschweig	DE	3,12	55	8,0	39	6,6	57	23,2	19
Sydsverige	SE	9,13	16	9,2	32	12,4	25	23,1	20

Map 1. Distribution of innovative activity in European regions, (patents per capita, annual average)

1981 - 1983



1999 - 2001



Spatial dependence of innovative activity

Presence of a **strong and positive spatial autocorrelation** process in the innovative activity among contiguous areas

Tab. 3 Spatial autocorrelation in the innovative activity (Moran's I test, normal approximation)

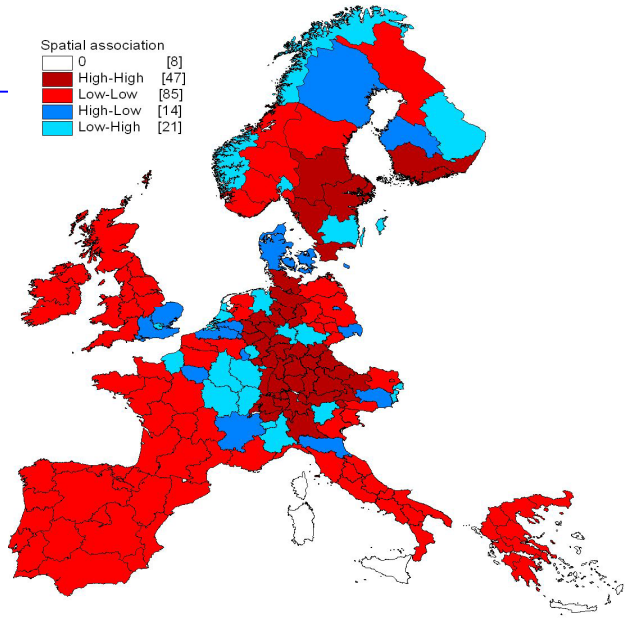
		1981-83		1988-90		1994-96		1999-01	
	contiguity	Z-value	Prob	Z-value	Prob	Z-value	Prob	Z-value	Prob
Total manufacturing	1st- order	3.4	0.0	4.1	0.0	4.3	0.0	4.5	0.0
	2nd-order	2.8	0.0	3.6	0.0	4.2	0.0	4.3	0.0
	3rd-order	3.4	0.0	3.4	0.0	3.7	0.0	3.5	0.0

Map3.

Scatter for innovative activity in the European regions,

1999-01

(patents per capita, annual average; number of regions in parenthesis)



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The determinants of innovative activity

the main determinants of the local process of innovative activity are on a blend of:

internal factors

- production factors (R&D)
- externalities within the region (agglomeration economies, knowledge not codified, institutions)

external regional factors

(spillovers through trade across sectors, common markets for skilled labour,…).

$$I_i = RD_i^{\partial_1} \; Z_{1i}^{\partial_2} \; Z_{2i}^{\partial_3} \; e_i$$

Estimation strategy

- OLS to check for the presence of spatial dependence (R&D, control variables)
- If any, ML estimation of spatial dynamic models (spatially lagged dependent variable, spatially lagged R&D)
- Check for different weight matrices (contiguity, distance)

Basic regression

$$\log I_{i,t} = \beta_1 \log RD_{i,t-q} + \beta_2 \log DENS_{i,t-s} + \beta_3 \log MAN_{i,t-s} + \sum_{c=1}^{17} \delta_c NAT_{ic} + \varepsilon_{i,t}$$

I = patents per capita (annual average 1999-2001)

- RD = share of GDP devoted to R&D (1989-96)
- DENS = density of population (1997-99)
- MAN = share of manufacturing employment (1997-99)
- NAT = national dummies

Extensions:
Spatial lag dependent variable
Spatial lag R&D with distance decay effects
Spatial spillovers within and across national borders
Spatial spillovers and technological similarities

Estimation of innovative activity.
Dependent variable: Log (I).

	OLS estimation (equation 3)		ML estimation (equation 4)	
Variables	Wbin	Wdist	Wbin	Wdist
Log (RD)	0.244		0.225	0.257
	(0.000)		(0.000)	(0.000)
Log (DENS)	0.286		0.319	0.265
	(0.000)		(0.000)	(0.000)
Log (MAN)	0.741		0.455	0.434
	(0.000)		(0.007)	(0.010)
W Log (I)			0.051	0.086
			(0.000)	(0.000)
NAT dummies	Yes		Yes	Yes
R^2-adj	0.853		0.883	0.885
AIC	376.9		357.3	354.3
LM-ERR	10.733	5.473		
	(0.001)	(0.019)		
LM-LAG	23.522	26.238		
	(0.000)	(0.000)		
LR Test			21.639	24.549
			(0.000)	(0.000)

Innovative activity with distance decay effect

Dependent variable: Log (I).

	OLS estimation (equation 6)				
Log (RD)	0.2779	0.294	0.287	0.253	0.260
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Log (DENS)	0.242	0.239	0.240	0.279	0.277
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Log (MAN)	0.660	0.641	0.639	0.707	0.699
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
W_1 Log (RD)	0.056	0.051	0.0498		
	(0.005)	(0.011)	(0.013)		
W_2 Log (RD)		0.032	0.031		
		(0.047)	(0.056)		
W_3 Log (RD)			-0.011		
			(0.489)		
$W_{0\text{-}250}$ Log (RD)				0.049	0.053
				(0.000)	(0.000)
$W_{250\text{-}500}$ Log (RD)					0.007
					(0.516)
NAT dummies	Yes	Yes	Yes	Yes	Yes
R^2-adj	0.876	0.879	0.862	0.863	0.863
AIC	369.9	367.4	368.9	365.6	367.1
LM-ERR	0.035	0.574	0.281	0.641	0.505
	(0.852)	(0.448)	(0.596)	(0.423)	(0.477)
LM-LAG	10.566	7.446	8.765	8.918	8.551
	(0.001)	(0.006)	(0.003)	(0.002)	(0.003)

Innovative activity within and across countries

Dependent variable: Log (I)

	OLS estimation		ML estimation		OLS estimation
Variables	Wwithin	Wacross	Wwithin	Wacross	
Log (RD)	0.244		0.246	0.240	0.277
Log (DENS)	(0.000)		(0.000)	(0.000)	(0.000)
	0.286		0.271	0.299	0.243
	(0.000)		(0.000)	(0.000)	(0.000)
Log (MAN)	0.741		0.486	0.668	0.677
	(0.000)		(0.000)	(0.000)	(0.000)
W – Log (I)				0.043	
				(0.007)	
Spatial error term			0.107		
(λ)			(0.000)		
W_{within} Log (RD)					0.056
					(0.021)
W_{across} Log (RD)					0.049
					(0.240)
NAT dummies	YES		YES	YES	YES
R^2-adj	0.853		0.839	0.874	0.859
AIC	376.9		363.1	372.1	372.4
LM-ERR	5.098	0.043			1.385

Technological proximity

WTech: matrix calculated by means of patent application data (1978-01) disaggregated into 101 sectors (energy and manufacturing, 3-digit Ateco91) for each region, where fik is the share of a particular patent class k in the total of patents of region i.

$$P_{ij} = \frac{\sum_{k=1}^{K} f_{ik} f_{jk}}{\left(\sum_{k=1}^{K} f_{ik}^2 \sum_{k=1}^{K} f_{jk}^2 \right)^{1/2}}$$

P_{ij} equal to unity for regions whose technological characteristics are identical
P_{ij} is zero for regions whose vector of characteristics are orthogonal

The closer to unity the greater the degree of similarity of the two regions' technological structure is.
The spatial lag of patents constructed with this weight matrix, would imply a weighted sum of other regions' patents with weights proportional to the proximity of the firms in technological space

Innovative activity with tech-distance matrices

Dependent variable: Log (I).

	OLS estimation			ML estimation		
Variables	W_{tech}	$W_{tech\text{-}contiguity}$	$W_{tech\text{-}distance}$	W_{tech}	$W_{tech\text{-}contiguity}$	$W_{tech\text{-}distance}$
Log (RD)		0.244		0.222	0.222	0.234
		(0.000)		(0.000)	(0.000)	(0.000)
W_{tech}				0.053		
				(0.000)		
$W_{tech\text{-}contiguity}$ Log (I)					0.028	
					(0.000)	
$W_{tech\text{-}distance}$ Log (I)						0.041
						(0.000)
Controls						
Log(DENS)		0.286		0.321	0.322	0.303
		(0.000)		(0.000)	(0.000)	(0.000)
Log(MAN)		0.741		0.525	0.474	0.430
		(0.000)		(0.000)	(0.005)	(0.011)
NAT dummies		YES		YES	YES	YES
R^2-adj		0.854		0.881	0.883	0.886
AIC		376.9		361.1	357.9	353.4
LM-ERR	1.972	1.547	1.776			
	(0.162)	(0.214)	(0.183)			
LM-LAG	10.871	13.365	19.235			
	(0.001)	(0.000)	(0.000)			
LR Test				17.777	20.975	25.474
				(0.000)	(0.000)	(0.000)

Summary of main results/1

- Importance of internal R&D expenditure on innovation activity, with a highly significant and stable coefficient.
- Important role played by other internal factors reflecting agglomeration economies and national characteristics.
- Presence of spatial association and necessity to take into account innovation spillovers arising from other regions both through patenting activity and R&D efforts.
- Such spatial spillovers decay with distance:
  strong impact of the 1st and 2nd order neighbours, or, using distance, up to 250 kilometres.

Summary of main results/2

- Knowledge spillovers occur mainly between regions of the same country:
  national innovation systems seem to dominate the European one.
- Technological similarity between two regions positively influence innovation spillovers with a magnitude comparable to geographical proximity.
- Thus, interregional knowledge spillovers exist between regions which are “close” both geographically and technologically.