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The long-run relationship between R&D and knowledge in Spanish regions

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Motivation

The estimation of knowledge production functions (KPFs; Griliches, 1979) has been extensively used for the empirical analysis of innovation. At the regional level, this framework permits the study of how local inputs contribute to the generation of knowledge (Jaffe, 1989)

The production of new ideas in a region not only depends on the amount of resources that it devotes to research and development (R&D) but also on the stock of knowledge available in other regions, especially nearby ones

Therefore, KPFs are also used to measure the intensity and spatial extent of these knowledge spillovers that are of interest in the geography of innovation literature (Audrestch and Feldman, 2004)

Given the relevance of the determinants of regional innovation for policy-making, several studies have analysed this issue in European regions within this setting (Botazzi and Peri, 2003; Moreno et al., 2005; Paci et al., 2014; among others)

Motivation

As well as uncovering the factors behind the creation of new ideas and how they flow between regions, KPFs serve as a testing ground to discriminate between alternative endogenous growth theories

Within this setup, the dynamics of the knowledge-generating sector and the long-run relationship between R&D and knowledge permits the testing of different 'ideas-based' growth models through the study of the scale of the effect that the R&D sector exerts on knowledge creation

- This distinction may serve as a basis for the design of regional innovation policies regarding R&D expenditures
- Moreover, it is an empirical check of the assumptions made on the process of technological change in the models currently used to assess the impact of EU regional policies (Brandsma and Kancs, 2015; Brandsma et al., 2015; Lecca et al., 2018)

Our contribution

This paper tries to contribute to the literature on the regional determinants of knowledge generation by introducing time-dependence into the flow of new ideas

More specifically, we adopt a longitudinal perspective by considering that knowledge generation depends on the existing stock of ideas

The main aim is to analyse the long-run dynamic behaviour of regional knowledge (output), R&D employment and external knowledge (inputs) in Spanish regions

- Panel unit root tests and cointegration estimation techniques
- Cross-sectional dependence
- Spatial heterogeneity
- Different types of proximity

Theoretical framework

Our empirical analysis is based on the simple theoretical model proposed by Jones (2005), later adopted by Bottazi and Peri (2007) and Sanso-Navarro and Vera-Cabello (2018)

This framework introduces time-dependence into the flow of new ideas by considering that knowledge is generated by the workers in the R&D sector using their creativity and the available stock of knowledge as inputs

$$I_t = F(R\&D_t, A_t, \tilde{A}_t) \tag{1}$$

- I_t denotes the ideas generated in a given region in period t
- R&D has a strong contemporaneous effect on innovation
- The influence of past resources devoted to R&D on innovation is exerted through the stock of useful knowledge A_t
- Due to knowledge spillovers, a region also benefits from the ideas created in other regions $\tilde{A}_t$

Theoretical framework

In order to make this framework operative, the number of new ideas generated in a region is considered to be proportional to the number of patents for which an application is filed by its residents ($Pat_t = \varkappa I_t$)

- As is common practice in the related literature, patent statistics will allow us to proxy for the generation of new ideas

Furthermore, it will be assumed that

(i) The relationship in (1) is log-linear:

$$\ln(Pat_t) = \ln(\varkappa) + \lambda \ln(R\&D_t) + \phi \ln(A_t) + \xi \ln(\tilde{A}_t) \qquad (2)$$

(ii) The available stock of knowledge increases with the development of new ideas and is continually decreasing at a constant obsolescence rate δ:

$$A_{t+1} = Pat_t + (1 - \delta)A_t \qquad (3)$$

Theoretical framework

After some manipulations, the following long-run relationship is obtained:

$$\ln(g_{A_t} + \delta) - \ln(\varkappa) = (\phi - 1)\ln(A_t) + \lambda \ln(R\&D_t) + \xi \ln(\tilde{A}_t) \quad (4)$$

The LHS will become a region-specific stationary process if the stock of knowledge converges to a stochastic balanced-growth path

- There will be a stationary long-run relationship between the resources devoted to R&D and the regional and external stocks of knowledge
- If these variables are non-stationary, there is a cointegration relationship between them
- Standardising by the regional knowledge stock, the cointegration vector is $(-1, \mu, \gamma)$ and can be estimated from:

$$\ln(A_t) = \mu \ln(R\&D_t) + \gamma \ln(\tilde{A}_t) + \varepsilon_t \quad (5)$$

with $\mu = \frac{\lambda}{1-\phi}$ and $\gamma = \frac{\xi}{1-\phi}$

Theoretical framework

This framework allows us to discriminate between alternative 'ideas-based' growth models through the study of

1. The stationarity of the regional knowledge growth rate
2. The presence of a cointegration relationship between the levels of R&D resources and of the regional and external stocks of knowledge

Unit root non-stationarity of the growth rate of the stock of knowledge in a region implies that it is determined by the amount of resources devoted to the research sector and the external and regional knowledge stocks

- The growth rates of regional knowledge and productivity increase with the level of R&D inputs
- R&D has a strong scale effect (1st generation)
- A constant level of R&D resources is enough to sustain long-run growth

Theoretical framework

Alternatively, the stationarity of the growth rate of the regional knowledge stock implies that, in the long-run, the levels of R&D inputs and of external knowledge will determine the level of knowledge in a region and, as a consequence, that of its productivity

- A reallocation of resources to R&D will only affect the level of income
- R&D has weak scale effects (semi-endogenous)
- Long-run growth depends on the growth rate of R&D resources and the elasticities of the KPF
- Higher growth might be achieved with higher investments in education as long as they lead workers in the R&D sector to improve their performance and absorptive capacity to exploit knowledge spillovers

Sample and data sources

Spanish autonomous communities (NUTS2 level; $N = 17$)

Sample period: $1988 - 2012$ ($T = 25$; 425 observations)

Total R&D employment - EUROSTAT

- All sectors (private and public)
- Full-time equivalents

Patent applications to the EPO - OECD REGPAT database (January 2013 edition)

- Classified according to their priority year
- Calculated using fractional counting
- Quality-weighted (Squiccianni et al., 2013)

Variable construction

Following expression (3), the regional stock of scientific and technological knowledge has been constructed from the number of quality-weighted patent applications

Based on a perpetual inventory method (Young, 1995), the initial level of knowledge for a give region has been calculated as

$$A_{i0} = \sum_{t=0}^{\infty} \frac{Pat_{i0}}{(1+\bar{g}_i)^{t+1}}(1-\delta)^t = \frac{Pat_{i0}}{(\bar{g}_i + \delta)} \tag{6}$$

where $\delta = 0.10$ and $\bar{g}_i$ is the average annual growth rate of patent applications during 1988 – 1993 (Botazzi and Peri, 2007)

Variable construction

The stock of ideas in the other regions, which tries to capture the influence of knowledge spillovers, has been constructed as

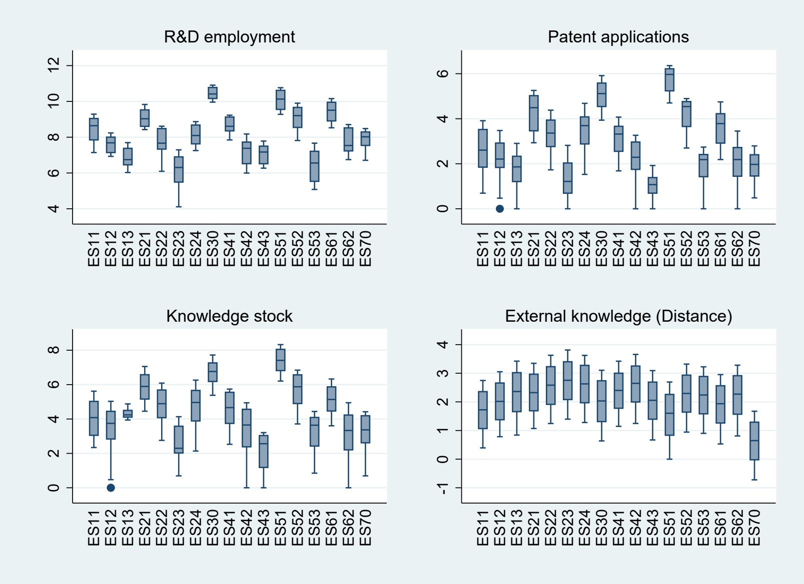
$$\tilde{A}_{it} = \sum_{i \neq j} w_{ij} A_{it} \tag{7}$$

Several specifications for the weights have been considered in order to capture three types of proximity (Boschma, 2005; Caragliu and Nijkamp, 2016; among others)

- Geographical: $\tilde{A}^{dist}$, $\tilde{A}^{3nn}$
- Technological: $\tilde{A}^{tech}$, $\tilde{A}^{lq}$
- Social: $\tilde{A}^{soc}$

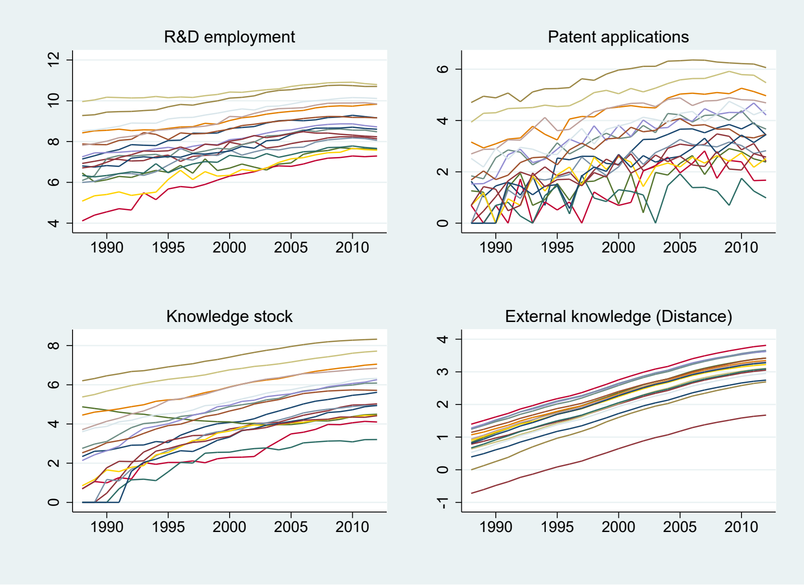
Sample description: Box-plots

(in natural logarithms, 1988-2012)



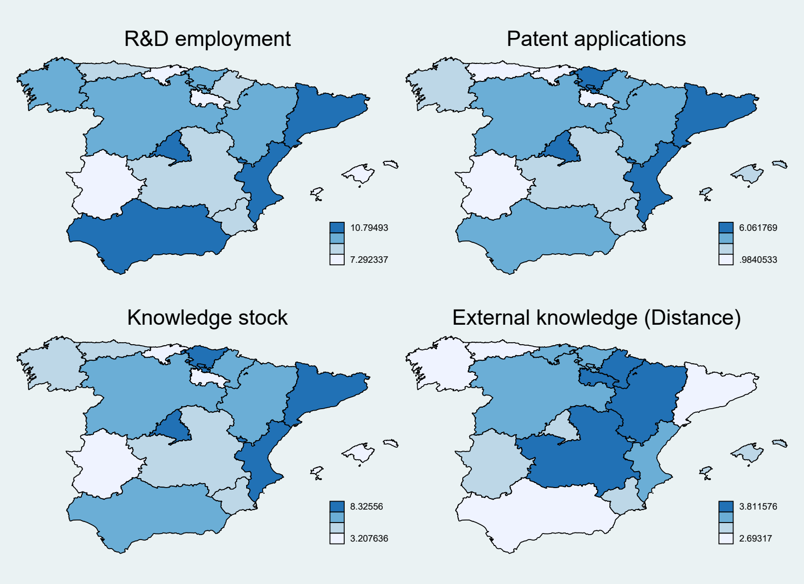
Sample description: Temporal evolution

(in natural logarithms, 1988-2012)



Sample description: Cloropleth maps

(in natural logarithms, 2012)



Cross-sectional dependence testing

(Pesaran, 2015; Bailey et al., 2016)

Variables in levels (natural logarithms)				
	CD	$\alpha_{0.05}$	α	$\alpha_{0.95}$
RD	52.838***	0.921	1.007	1.092
A	43.526***	0.892	1.006	1.120
$\tilde{A}^{dist}$	55.808***	0.920	1.007	1.094
$\tilde{A}^{3nn}$	53.979***	0.919	1.007	1.094
$\tilde{A}^{tech}$	44.689***	0.906	1.005	1.104
$\tilde{A}^{lq}$	5.429***	0.670	0.779	0.887
$\tilde{A}^{soc}$	30.907***	0.902	1.000	1.098
Variables in first differences (growth rates)				
	CD	$\alpha_{0.05}$	α	$\alpha_{0.95}$
RD	8.912***	0.723	0.851	0.979
A	8.341***	0.751	0.887	1.023
$\tilde{A}^{dist}$	50.776***	0.892	1.007	1.121
$\tilde{A}^{3nn}$	14.141***	0.745	0.861	0.976
$\tilde{A}^{tech}$	6.767***	0.654	0.777	0.900
$\tilde{A}^{lq}$	0.665	0.278	0.421	0.564
$\tilde{A}^{soc}$	4.736***	0.580	0.718	0.856

Unit root testing

(Pesaran, 2007)

Variables in levels (Intercept and trend)				
augm. lags	0	1	2	3
RD	-3.038	-2.436	-1.936	-1.844
A	-2.682	-2.708	-2.116	-2.070
$\tilde{A}^{dist}$	-2.507	-2.693	-2.556	-2.212
$\tilde{A}^{3nn}$	-2.731	-2.876	-2.722	-1.927
$\tilde{A}^{tech}$	-3.861*	-3.257	-2.872	-2.822
$\tilde{A}^{lq}$	-3.876*	-2.892	-1.987	-1.853
$\tilde{A}^{soc}$	-4.337**	-3.002	-2.477	-1.857
Variables in first differences (Intercept)				
augm. lags	0	1	2	3
RD	-5.581***	-3.819**	-2.534	-2.169
A	-4.403***	-3.293*	-2.581	-2.164
$\tilde{A}^{dist}$	-3.703**	-2.877	-2.556	-2.389
$\tilde{A}^{3nn}$	-4.113**	-3.479**	-3.049*	-1.987
$\tilde{A}^{tech}$	-6.108***	-4.380***	-3.365**	-2.897
$\tilde{A}^{lq}$	-6.580***	-4.607***	-2.865	-2.664
$\tilde{A}^{soc}$	-7.400***	-4.487***	-3.723**	-2.990

Long-run cointegration relationship testing
(Banerjee and Carrión-i-Silvestre, 2017)

	Intercept			Intercept and trend		
augm. lags	0	1	2	0	1	2
$\tilde{A}^{dist}$	-3.388***	-3.226***	-2.728	-3.548***	-4.031***	-3.621***
$\tilde{A}^{3nn}$	-3.083***	-3.268***	-2.382	-2.962***	-3.460***	-2.594*
$\tilde{A}^{tech}$	-3.110***	-2.463	-2.242	-3.282***	-3.132***	-2.732**
$\tilde{A}^{lq}$	-3.431***	-2.912*	-2.372	-3.184***	-3.309***	-2.358
$\tilde{A}^{soc}$	-3.634***	-3.090**	-2.719	-3.524***	-3.542***	-2.852***

Long-run cointegration relationship estimation

Common Correlated Effects - Mean Group (Pesaran, 2006)

		R&D employment					External knowledge				
		Adist	A3nn	Atech	Alq	Asoc	Adist	A3nn	Atech	Alq	Asoc
ES	Spain	0.159**	0.252***	0.237**	0.320***	0.308***	1.284	0.172	-0.006	0.004	-0.001
		(0.067)	(0.065)	(0.096)	(0.093)	(0.077)	(2.974)	(0.425)	(0.023)	(0.006)	(0.003)
ES11	Galicia	-0.018	0.304	-0.038	-0.245	-0.025	-3.229	0.706	-0.022	0.015	-0.003
		(0.293)	(0.283)	(0.375)	(0.355)	(0.393)	(6.199)	(0.475)	(0.092)	(0.020)	(0.015)
ES12	Asturias	0.162	0.279	-0.314	-0.375	-0.273	4.748	0.883	0.005	0.015	0.001
		(0.237)	(0.247)	(0.314)	(0.332)	(0.320)	(4.351)	(0.602)	(0.059)	(0.037)	(0.017)
ES13	Cantabria	0.527***	0.423***	0.425***	0.533***	0.454***	6.327*	-2.149**	0.016	0.038***	-0.006
		(0.096)	(0.091)	(0.160)	(0.135)	(0.159)	(3.421)	(0.836)	(0.036)	(0.012)	(0.016)
ES21	País Vasco	-0.069	0.215	1.138***	1.142***	1.077***	-1.018**	-0.043	-0.034	0.006	-0.009
		(0.182)	(0.183)	(0.138)	(0.124)	(0.119)	(0.426)	(0.057)	(0.043)	(0.004)	(0.007)
ES22	Navarra	0.023	0.079	0.089	0.078	0.140**	-10.224***	-0.333	-0.070	-0.001	0.002
		(0.065)	(0.086)	(0.064)	(0.067)	(0.059)	(3.329)	(0.622)	(0.079)	(0.007)	(0.008)
ES23	La Rioja	0.286	0.448	-0.513	0.184	0.117	11.969	3.531***	-0.080***	-0.043**	0.008
		(0.455)	(0.404)	(0.431)	(0.424)	(0.434)	(11.728)	(1.355)	(0.028)	(0.020)	(0.018)
ES24	Aragón	0.242	0.067	-0.134	0.100	0.240	-1.575	0.306	0.149***	-0.001	0.019***
		(0.245)	(0.235)	(0.130)	(0.205)	(0.171)	(2.010)	(0.329)	(0.027)	(0.008)	(0.007)
ES30	Com. Madrid	-0.042	0.377***	0.540**	0.615***	0.535**	-2.253***	-0.424***	-0.178*	0.006	-0.025
		(0.042)	(0.131)	(0.219)	(0.227)	(0.241)	(0.114)	(0.094)	(0.091)	(0.004)	(0.020)
ES41	Castilla y León	-0.090	-0.120*	0.027	-0.053	0.074	-5.008***	-1.560***	0.105	-0.003	0.002
		(0.074)	(0.068)	(0.171)	(0.182)	(0.186)	(0.546)	(0.153)	(0.104)	(0.011)	(0.013)
ES42	Castilla-La Mancha	0.276	0.277	0.363	0.442	0.278	-0.745	-0.647	-0.049	0.004	0.024
		(0.225)	(0.246)	(0.271)	(0.297)	(0.244)	(2.988)	(1.519)	(0.035)	(0.020)	(0.026)
ES43	Extremadura	0.085	0.100	0.001	0.294	0.102	-16.516**	-2.840**	-0.022	-0.058*	-0.027*
		(0.314)	(0.319)	(0.387)	(0.398)	(0.387)	(6.770)	(1.407)	(0.022)	(0.030)	(0.015)
ES51	Cataluña	0.319***	0.225	0.233	0.473**	0.490**	-1.018***	-0.039	0.218*	0.012	-0.008
		(0.071)	(0.143)	(0.209)	(0.192)	(0.209)	(0.230)	(0.090)	(0.127)	(0.008)	(0.008)
ES52	Com. Valenciana	0.519***	0.601***	0.564**	0.562***	0.602***	-6.274***	0.123	0.038	0.018**	-0.004
		(0.179)	(0.225)	(0.242)	(0.194)	(0.205)	(2.167)	(0.313)	(0.096)	(0.008)	(0.007)
ES53	Baleares	0.115	0.074	0.136	0.108	0.008	6.641*	4.389***	-0.096**	0.030	0.018
		(0.219)	(0.196)	(0.214)	(0.243)	(0.220)	(3.768)	(1.571)	(0.044)	(0.028)	(0.014)
ES61	Andalucía	-0.345	-0.296	0.451	0.199	0.287	-3.181	-0.040	-0.045	0.013*	0.005
		(0.233)	(0.249)	(0.532)	(0.392)	(0.414)	(2.658)	(0.071)	(0.088)	(0.007)	(0.009)
ES62	Reg. Murcia	0.771*	0.852**	0.542	0.787**	0.608*	1.865	0.759	-0.043	0.018	-0.014
		(0.395)	(0.415)	(0.332)	(0.337)	(0.327)	(5.007)	(1.080)	(0.049)	(0.026)	(0.014)
ES70	Canarias	-0.062	0.372	0.511**	0.600**	0.531**	41.318***	0.303	0.009	-0.006	-0.002
		(0.295)	(0.298)	(0.260)	(0.245)	(0.246)	(13.517)	(0.772)	(0.050)	(0.021)	(0.012)
RMSE		0.108	0.106	0.123	0.124	0.125					
CD		-2.235**	-0.913	-2.660***	-2.002**	-2.258**					
CIPS		-3.687***	-4.001***	-3.032***	-3.567***	-2.771***					

Long-run cointegration relationship estimation

Augmented Mean Group (Bond and Eberhardt, 2013; Eberhardt and Teal, 2017)

		R&D employment					External knowledge				
		Adist	A3nn	Atech	Alq	Asoc	Adist	A3nn	Atech	Alq	Asoc
ES	Spain	0.190***	0.260***	0.256*	0.257**	0.245*	-3.271**	-0.406	0.009	0.004	0.004
		(0.070)	(0.081)	(0.138)	(0.128)	(0.128)	(1.516)	(0.274)	(0.021)	(0.005)	(0.005)
ES11	Galicia	0.123	0.321	0.531	0.628	0.082	3.284***	0.870***	0.062	0.033	0.033*
		(0.230)	(0.213)	(0.528)	(0.488)	(0.532)	(0.752)	(0.091)	(0.131)	(0.031)	(0.017)
ES12	Asturias	-0.162	-0.244	-0.968***	-1.070***	-1.060***	-8.345***	-1.100***	0.071	0.010	0.009
		(0.246)	(0.229)	(0.300)	(0.034)	(0.300)	(0.762)	(0.167)	(0.054)	(0.041)	(0.019)
ES13	Cantabria	0.435***	0.405***	0.521***	0.049***	0.517***	8.007***	0.573**	-0.005	0.029***	-0.006
		(0.126)	(0.131)	(0.128)	(0.108)	(0.129)	(2.129)	(0.262)	(0.028)	(0.010)	(0.015)
ES21	País Vasco	0.313**	0.652***	0.875***	0.847***	0.859***	0.468	0.120	-0.031	0.003	-0.007
		(0.146)	(0.110)	(0.072)	(0.053)	(0.056)	(0.419)	(0.074)	(0.046)	(0.004)	(0.008)
ES22	Navarra	0.099*	0.136**	0.142**	0.132*	0.142**	-1.838***	0.140	-0.027	0.006	0.011
		(0.056)	(0.060)	(0.065)	(0.067)	(0.062)	(0.323)	(0.116)	(0.079)	(0.007)	(0.008)
ES23	La Rioja	0.319	0.332	0.456	0.552	0.528	3.170*	1.052***	-0.022	-0.051**	0.022
		(0.425)	(0.390)	(0.510)	(0.462)	(0.501)	(1.773)	(0.270)	80.0359	(0.024)	(0.021)
ES24	Aragón	0.350	-0.399***	-0.320***	-0.253***	-0.232***	-7.181***	0.391	0.097***	-0.002	0.014*
		(0.251)	(0.087)	(0.065)	(0.076)	(0.072)	(1.046)	(0.320)	(0.030)	(0.007)	(0.016)
ES30	Com. Madrid	0.228**	0.627***	0.624***	0.469***	0.526***	-0.800***	-0.508***	-0.179**	0.006	-0.015
		(0.094)	(0.069)	(0.091)	(0.089)	(0.086)	(0.207)	(0.105)	(0.072)	(0.004)	(0.016)
ES41	Castilla y León	0.144	0.349**	0.431***	0.378**	0.423**	-1.696***	0.029	0.138	0.008	0.007
		(0.136)	(0.176)	(0.163)	(0.190)	(0.170)	(0.346)	(0.190)	(0.116)	(0.014)	(0.016)
ES42	Castilla-La Mancha	0.359	0.322	0.049	0.139	0.292	-14.086***	-2.974	-0.015	-0.020	0.050*
		(0.327)	(0.227)	(0.328)	(0.303)	(0.309)	(2.643)	(0.584)	(0.034)	(0.019)	(0.028)
ES43	Extremadura	0.144	0.167	-0.456	-0.377	-0.333	-10.948***	-2.632***	-0.014	-0.028	-0.029*
		(0.297)	(0.287)	(0.358)	(0.355)	(0.337)	(1.406)	(0.529)	(0.023)	(0.030)	(0.015)
ES51	Cataluña	0.473***	0.817***	0.700***	0.855***	0.838***	-0.705**	-0.370***	0.198	0.018**	-0.002
		(0.060)	(0.061)	(0.119)	(0.068)	(0.075)	(0.335)	(0.104)	(0.135)	(0.008)	(0.007)
ES52	Com. Valenciana	0.569***	0.490***	0.300*	0.351***	0.331***	-3.550***	0.337**	0.022	0.014*	-0.005
		(0.148)	(0.150)	(0.160)	(0.114)	(0.126)	(0.408)	(0.146)	(0.094)	(0.007)	(0.007)
ES53	Baleares	-0.004	-0.049	-0.158	-0.060	-0.120	-4.619***	-0.486	-0.039	0.020	-0.001
		(0.242)	(0.214)	(0.179)	(0.194)	(0.183)	(1.557)	(0.515)	(0.035)	(0.025)	(0.012)
ES61	Andalucía	-0.357*	0.228	1.380***	0.947***	1.096***	2.006***	-0.271***	-0.087	0.012**	0.011
		(0.208)	(0.232)	(0.319)	(0.216)	(0.209)	(0.515)	(0.055)	(0.091)	(0.006)	(0.008)
ES62	Reg. Murcia	-0.374	-0.232	-0.313	-0.260	-0.248	-14.883***	-1.723**	-0.013	0.015	-0.015
		(0.343)	(0.244)	(0.280)	(0.245)	(0.243)	(3.583)	(0.819)	(0.049)	(0.033)	(0.015)
ES70	Canarias	0.579**	0.501**	0.555**	0.595**	0.526**	-3.890***	-0.349	-0.005	-0.008	-0.009
		(0.236)	(0.242)	(0.241)	(0.234)	(0.245)	(1.360)	(0.263)	(0.047)	(0.020)	(0.011)
RMSE		0.133	0.124	0.158	0.153	0.155					
CD		-2.000**	-1.186	-1.478	-1.440	-1.141					
CIPS		-2.822***	-3.080***	-2.414***	-2.847***	-2.543***					

Concluding remarks

This paper studies the long-run relationship between R&D and knowledge - two key ingredients of the 'Europe 2020' strategy - at the regional level in Spain

After introducing time-dependence into the flow of new ideas within a KPF framework, the empirical analysis is based on the application of panel unit root tests and cointegration techniques

- Different types of proximity have been considered: Geographical, technological and social
- Heterogeneity across regions has been explored

Concluding remarks

The levels (growth rates) of R&D employment and of the regional and external knowledge stocks are non-stationary (stationary). Moreover, there exists a long-run cointegration relationship between these three variables

Within the simple theoretical framework proposed by Jones (2005), these results may be interpreted as evidence favourable to semi-endogenous growth models

- Any policy supporting the level of resources devoted to R&D will only have transitory effects on the knowledge stock and, hence, productivity growth
- Empirical foundation to the assumptions made regarding technological change in the models used to assess the impact of regional policies in the EU

Concluding remarks

Estimated long-run elasticities from the cointegration relationship show that the level of R&D employment is positively related to the regional stock of knowledge

- A ‘fishing-out’ effect prevails when geographical proximity is taken into account
- Weak evidence of the presence of knowledge spillovers when technological and social proximities are considered

Therefore, it can be concluded that policies should aim at enhancing knowledge diffusion and regional absorptive capacity

- The establishment of research networks should be encouraged
- Improvements in the educational level of the labour force will favour the capacity of regions to absorb external knowledge

THANK YOU FOR YOUR ATTENTION

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