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Research Policy 36 (2007) 1357–1371
research policy
www.elsevier.com/locate/respol

Innovation and R&D spillover effects in Spanish regions: A spatial approach

Bernardí Cabrer-Borrás, Guadalupe Serrano-Domingo *

University of Valencia, Department of Economic Analysis, Avda dels Tarongers sn, Valencia 46022, Spain

Received 22 June 2005; received in revised form 28 June 2006; accepted 24 April 2007
Available online 18 June 2007

Abstract

This paper analyses the spatial patterns of innovation, its regional interdependencies and evolution, as well as its role in determining local innovation in Spanish regions. Results indicate the suitability of a trade-based regional proximity when considering spatial spillovers in innovation. In this context, not only local capacity is relevant in determining domestic innovation, but also spatial innovation spillovers, which result mainly from efforts in both higher education and public administration. Moreover, a minimum level of regional development is required to improve the effectiveness of R&D policies. Therefore, it is necessary for R&D policies to act in combination with other policies focused on the improvement of socio-economic and structural determinants of regional innovative performance.

Keywords: Innovation; R&D; Spillover effects; Spatial econometrics; Panel data

1. Introduction

Innovation and technological progress are deemed basic determinants of domestic economic growth (Romer, 1990). In this case, the production–innovation system is considered to be the link between knowledge creation and production systems. Nevertheless, together with the domestic capacity of innovation in a specific area, it has been increasingly recognised in the literature that spillovers of knowledge from external sources may have an important impact on innovation processes and economic growth. In this context, the spatial dimension of the problem becomes a relevant question in determining how those spillovers occur and the effectiveness of such spillovers in the local innovation process (see Acs and Varga, 2002; Feldman, 1999).

The econometric analysis of the role of localised knowledge flows in the process of innovation has been widely applied within a knowledge production function framework. In this paper, we analyse the innovation process in Spanish regions, its spatial distribution and temporal evolution. In specific terms, we focus on the factors that can determine innovation activities and the role that geographical space can play in terms of the dissemination of technological knowledge, both inside and between regions. In the case of geographical space, the factors we take into consideration are not limited to the geographic proximity of one region to another. Other factors are considered when determining the diffusion of innovation between regions to shed new

* Corresponding author at: Dept. de Análisis Económico, Facultad de Economía, U. de Valencia, Avda dels Tarongers sn, Valencia 46022, Spain. Tel.: +34 96 382 82 47; fax: +34 96 382 82 49.

E-mail addresses: bernardi.cabrer@uv.es (B. Cabrer-Borrás), guadalupe.serrano@uv.es (G. Serrano-Domingo).

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doi:10.1016/j.respol.2007.04.012

light on the spatial and temporal aspects of Spanish innovation.

Regarding the importance of space for the diffusion of knowledge, one strand of literature emphasises the domestic nature of knowledge spillovers, which are locally bound, based on the geographic proximity to the innovation producers (Acs et al., 1994; Anselin et al., 1997; Audretsch and Feldman, 1996; Jaffe et al., 1993) and on the structural factors that characterise the knowledge capacity of the local economy. Another body of literature highlights the public nature of knowledge that flows freely across borders. In this case, the importance of regional interaction for the flow of knowledge is stressed (Coe and Helpman, 1995; Grossman and Helpman, 1991). In the same way that geographic proximity to innovation producers can favour knowledge spillovers within the region, proximity to other innovative regions can boost local innovation. Consequently, not only the analysis of the effects of R&D spillovers on innovation, but also the analysis of how important other sources of spillovers are (such as spatial spillovers due to regional proximity) could be the key to innovation policy being successful, by speeding up the diffusion of knowledge through actively promoting R&D activities and stimulating regional interactions and interregional innovation networks (Camagni, 1991). Moreover, Moreno-Serrano et al. (2005) point out that externalities across (European) regions are mostly constrained by national borders. Our analysis will therefore concentrate on the role and characteristics of R&D and spatial spillovers owing to innovation interdependencies among Spanish regions that go beyond merely geographical aspects.

The case of Spanish regions is especially interesting for our analysis. Cuadrado-Roura et al. (1999) and De la Fuente (2002) point to the existence of an aggregate convergence process due to the equalisation of education levels, the homogenisation of productive structures and technological catch-up. Despite this convergence process slowing down at the end of the 1980s, the remarkable transformations in the education system as well as the industrial restructuring and technological development still have not come to an end, which suggests that the regional integration process continues. In the context of Europe, Spanish regions have been considered as technologically peripheral regions that over the 1990s experienced a sharp increase in R&D expenditure relative to the European Union average, undertaken by government and very often within the framework of European Structural Funds. This R&D investment has been linked to a neoclassical and regional policy view focused on reducing technological disparities within the country and with respect to the European core (Bilbao-Osorio and Rodriguez-Pose, 2004; Rodriguez-Pose, 2001). Nevertheless, the technological gap remains significant.

Despite R&D levels in Spain being a long way from allowing significant knowledge spillovers (Rodriguez-Pose, 2001), have those transformations in Spanish regions helped to promote the existence of such technology spillovers? If we consider that Spanish regions are not innovation averse regions in the terms of Bilbao-Osorio and Rodriguez-Pose (2004), with more similar socio-political conditions and commercial interdependencies and lower barriers for technological knowledge to flow, have interregional knowledge spillovers promoted regional innovation? Have public R&D efforts helped to achieve the ‘critical mass of knowledge’ to enhance such technological spillovers and innovation performance in Spanish regions?

The analysis of these questions in the context of the 17 Spanish regions from 1989 to 2001 provides the opportunity to explore both the spatial and the temporal dimension of the problem, by means of panel data techniques, as a novel approach in empirical research.[1] In this panel data framework we use spatial econometric techniques to analyse the spatial interdependencies of innovation among Spanish regions and also to search for the statistically correct specification of the model. In addition to this, we analyse whether or not the similarity in levels of technology across regions is an advantage in the diffusion of knowledge and if different benefits from interregional knowledge spillovers are implied.

The paper is organised as follows. Section 2 briefly reviews different viewpoints concerning the innovation process and its determinants. Section 3 discusses the measurement of innovative activity and its spatial and temporal characteristics in Spanish regions. The econometric model is specified in Section 4, and the main results of the estimation are presented in Section 5. Finally, Section 6 draws the conclusions.

2. Determinants of innovation

Analysing determinants of innovation has developed inside the knowledge production function framework (Griliches, 1979). As empirical evidence has appeared to demonstrate that the relationship between innovative

[1] Some cross-sectional examples include: Feldman and Audrestsch (1999) and Jaffe (1989), in the US; Moreno-Serrano et al. (2005), for the European regions; Fritsch and Franke (2004) and Bode (2004), for Germany.

output and innovative inputs (R&D and human capital inputs) is stronger at broader aggregation levels than in microeconomic studies (Audretsch and Feldman, 2004) and suggested the presence of externalities, we focus on a regional knowledge production function in the tradition of the aggregate one modelled by Griliches (1984) and later revised and extended by Jaffe (1989), to analyse the effects of locally bounded knowledge spillovers linked to university research activities. From this seminal work, Jaffe et al. (1993) found that proximity to innovation producers facilitates the process of information sharing and knowledge diffusion among companies. In this manner, Acs et al. (1994) concluded that not only a firm's own R&D efforts, but also R&D developed by other local research institutions (other domestic industries or public research organisations, which are often the sources of the innovative capacity of many local industries), will be important for innovative activity.

In this context, where knowledge is not transmitted without cost, empirical studies suggest that local R&D and other knowledge spillovers not only generate externalities, but are bound within the region where the new knowledge is generated (Acs et al., 1992; Audretsch and Feldman, 1996; Feldman, 1994; Jaffe, 1989; Jaffe et al., 1993). Thus, as knowledge diffusion takes time, and given the existence of sufficient human capital endowments, R&D efforts in the previous year in the local economy would generate domestic spillovers and favour local innovation:

$$I_{\text{it}} = f(I_{\text{it-1}}, H_{\text{it}}, \text{RD}_{\text{it-1}}, Z_{\text{it}}) \qquad (1)$$

where I is innovative output, RD denotes local R&D efforts and H is human capital endowments. Additionally, the innovative performance of the region and its capacity and singularity in terms of innovation can be determined by structural characteristics of the region (social, local and economic characteristics), and by its innovative tradition. The last is measured by lagged innovative output, $I_{\text{it-1}}$, giving an idea of the region's technological specialisation, which will allow it to maintain its innovative competitiveness. Z_{it} includes the former socio-economic factors that can determine regional innovative performance. All these variables will be relevant factors for determining the local capacity of innovation.[2]

Among the additional factors that may determine innovation, and given the knowledge-intensive nature of innovation, we could think of additional sources of local technological externalities different from those linked to local R&D activities. It has been generally accepted that the underlying structure of regions and its economic activity organisation may facilitate local knowledge spillovers and contribute to differences in the innovative performance in regions, keeping constant other knowledge inputs, R&D and human capital (Audretsch and Feldman, 2004). The debate is focused on how the composition of economic activity can shape agglomeration externalities and foster innovation. Glaeser et al. (1992) denote as specialisation or localisation economies, usually attributed to the Marshall–Arrow–Romer (MAR) externality, those externalities linked to the existence of a pool of skilled labour, the co-location of suppliers and customers and also technology spillovers among firms in the same industry, yielding increasing returns to scale in final production and greater productivity and growth (Lucas, 1993; Romer, 1990; among others). The concentration of one industry in a specific location, i.e. increased regional specialisation in an industry, then facilitates knowledge spillovers among firms in the same industry and local innovative activity.

In contrast, the advantages of diversity externalities or *urban economies*, associated with Jacobs (1969), may arise from exchanging complementary knowledge across firms in different complementary industries and economic agents, yielding a greater return to new economic knowledge and facilitating innovation, and hence fostering growth (see Duranton and Puga, 2000, for a formalised model). Thus, the greater the diversity of economic activity of the local economy (that is, the lower the concentration), the greater innovation would be. Nevertheless, empirical evidence does not offer conclusive results about this debate,[3] which would have different implications in terms of innovation-oriented policies.

Alternatively, if it is assumed that technological knowledge and new ideas are a public good, knowledge spillovers would not be locally bound, but could move freely across regions. From this perspective, not only local R&D but also other economies' R&D efforts could determine local innovation (Keller, 1998). Nevertheless, in some cases it is assumed that the entire foreign pool of knowledge is not transmitted. Trade across regions or

[2] Following Furman et al. (2002) we consider regional innovative capacity as the ability of a region to produce and commercialize innovations over the long run.

[3] Feldman and Audrestsch (1999) find evidence to support the positive effect of diversity on innovation; Glaeser et al. (1992), Henderson et al. (1995) and Combes (2000) find strong evidence of the positive effect of diversity externalities in promoting local economic growth and in attracting newer and more innovative activities. In contrast, Henderson (2003) finds evidence of the positive and relevant effects of specialisation on firms' productivity.

countries, foreign R&D investment, or imports of technological inputs, are just a few of the channels down which part of this new knowledge could flow and thus be available to the local economy (Coe and Helpman, 1995)

As a consequence, we extend specification (1) in considering that local innovation is also determined by the composition of economic activity in the local area, its specialisation or diversity patterns, S_{it} and D_{it}, respectively, and also by interregional spillovers, FS_{it}, stemming from new knowledge developed in other regions[4]:

$$I_{it} = f(Z_{it}, I_{it\text{-}1}, H_{it}, RD_{it\text{-}1}, S_{it}, D_{it}, FS_{it}) \quad (2)$$

3. The quantification of innovation and its characteristics in Spanish regions

Innovation could be understood as the process that determines the capacity to produce new products or new processes and the technological development of a particular economy. Thus, the complexity of innovation explains the difficulty in measuring it. In fact, the quantification of innovative activity has been the object of intense debate in the literature, but there is no general answer to this question (see Rogers, 1998).

From a simplified perspective, Fig. 1 illustrates how the combination of R&D efforts and new ideas developed in universities, firms, research centres and other innovation-oriented organisations results in inventions. Some of those inventions are legally protected in the form of patents, utility models or scientific publications. And some of these outputs and other non-protected inventions, combined with R&D efforts and other innovative inputs, are used in production activities and constitute innovations, that is new products (both intermediate and final ones) or processes that finally will enhance regional technological knowledge and productivity. From this general scheme, innovation has been proxied by means of different indicators from the perspective of the inputs or the outputs of the innovative activity (see Patel and Pavitt, 1995; Rogers, 1998, for more details).

From the perspective of inputs, one of the most common indicators used for quantifying innovation is R&D expenditures. There is no doubt about the interest in R&D activities and their complementarities with innovation activities. Nevertheless, this indicator has been criticized because it is not informative about the results of R&D activities, or about the innovation process.

There is no consensus about the best indicator for an innovation output measure as all of them are partial indicators of the extent of innovation. The technology output indicator that is most used in the literature is patenting. Although not all inventions are patented, patenting activity differs across sectors, and in terms of innovative content, there are patents that are used in different innovations and other patents that are not finally used (Buesa and Molero, 1998; Griliches, 1990); so patents provide a good indicator of the inventive capacity of the economy. Given the stronger and longer protection of patents, it is considered that they protect more significant innovations than shown by other indicators (Beneito, 2006). Moreover, its properties of homogeneity and periodicity have the advantage of allowing both temporal and spatial comparisons of innovative activity to be made (Acosta and Coronado, 2003; Fischer et al., 1994). While other output indicators have been considered, such as scientific publications or patent citations (Harhoff et al., 1999; Narin and Olivastro, 1988), to determine relevant innovations, their use is also subject to limitations, given that they share the disadvantages of patents and would require a deep knowledge of the benefits that each aspect would yield to the society to really identify relevant innovations (Michel and Bettels, 2001).

Given the aim of our analysis, patent applications are chosen to approximate the innovative output potential in the region because, independently of whether the patent is finally granted or not, the application for this property right involves a significant cost for the proponent and a focus on the relevant novelty and profitability features of the invention (Moreno-Serrano et al., 2005). Eurostat's New Cronos database provides homogeneous data on patent applications to the EPO from European regions yearly available for a relatively long period, 1989–2000, allowing a panel data analysis for Spanish regions. Moreover, the spatial assignment of the patent application according to inventor's address instead of the proponent's address avoids the firm's or institution's headquarters bias that could overestimate innovative activity in regions where such headquarters are located. This spatial assignment is more realistic since patent applications are divided among its inventors, and thus among such inventors' regions.

[4] We could consider international flows of knowledge within this framework, but in general these bilateral trade flows are much lower than interregional ones. Moreover, Moreno-Serrano et al. (2005) point out that externalities across regions are mostly constrained by national borders, thereby suggesting that national innovation systems seem to dominate supra-national systems.

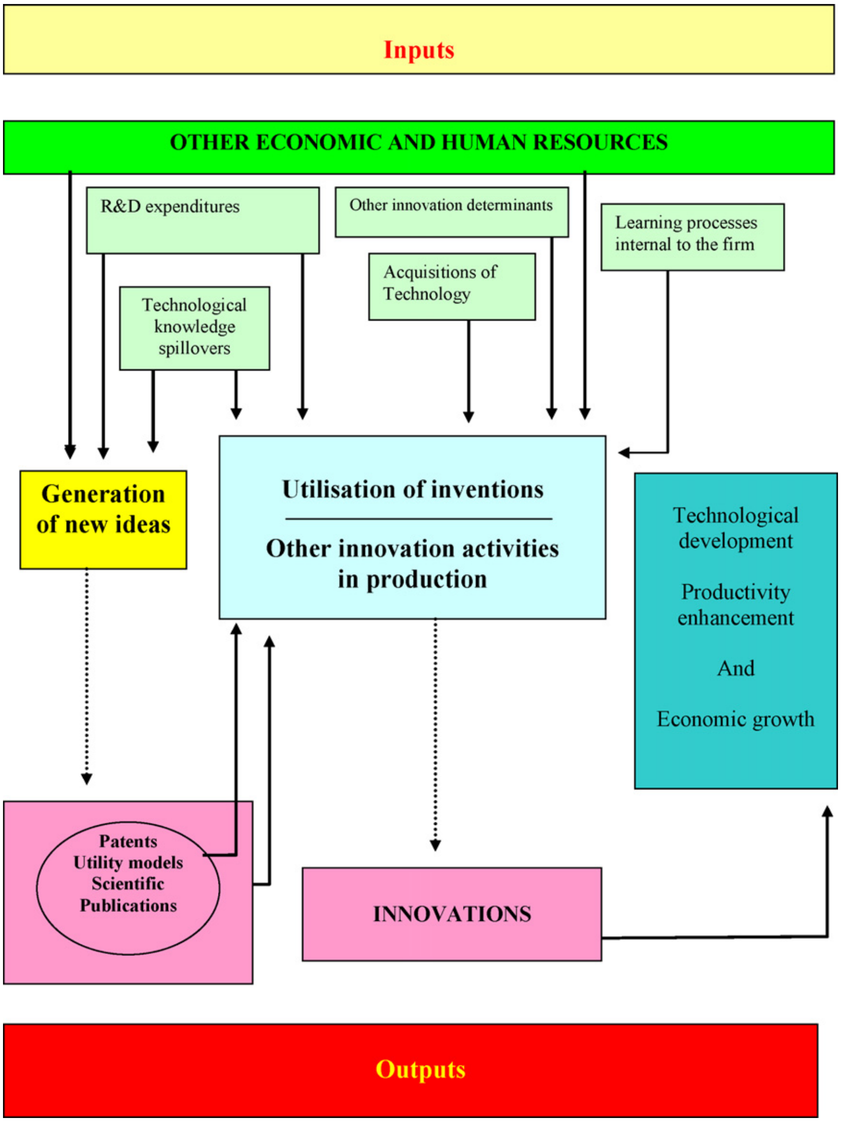

Fig. 1. Inventions, innovations and patent statistics.

3.1. The evolution of innovative activity in Spanish regions

The evolution of innovative activity over the sample period indicates an increasing trend in the number of patent applications, showing a marked upturn in growth in the second half of the 1990s and a positive persistence in innovative activity in the Spanish economy (Fig. 2).

As is the case with R&D expenditures, the geographical distribution of other indicators of innovative activity such as the number of patent applications, patents and utility models are very concentrated, mainly in two regions: Madrid and Catalonia (see Table 1). Moreover,

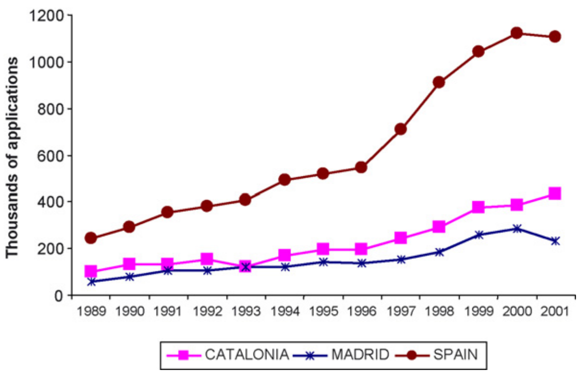

Fig. 2. *Source*: Eurostat 2001 data are provisional.

Table 1
Some indicators of innovation activity in Spanish regions

	Patent application (1995–2001)		European patents (1998–2001)		Patents and U.M. (1998–2001)		GDP (1995–2001)	
	Number	%	Number	%	Number	%	Value	%
Andalusia	268680	5.0	39	2.5	2250	8.1	11419	13.0
Aragón	195810	3.7	78	5.0	1197	4.3	2829	3.2
Asturias	59650	1.1	17	1.1	388	1.4	2029	2.3
Balearic Islands	58060	1.1	14	0.9	311	1.1	2028	2.3
The Canary Islands	76450	1.4	3	0.2	466	1.7	3683	4.2
Cantabria	22640	0.4	5	0.3	191	0.7	1097	1.2
Castille and Leon	144710	2.7	38	2.4	942	3.4	5037	5.7
Castille-La Mancha	69490	1.3	9	0.6	532	1.9	3206	3.6
Catalonia	1942670	36.4	533	34.3	7570	27.3	16743	19.0
Comunidad Valenciana	579260	10.8	174	11.2	4371	15.8	8409	9.5
Extremadura	22600	0.4	3	0.2	174	0.6	1556	1.8
Galicia	99240	1.9	19	1.2	855	3.1	4747	5.4
Madrid	1142800	21.4	337	21.7	5128	18.5	15484	17.6
Murcia	64400	1.2	11	0.7	695	2.5	2050	2.3
Navarre	158980	3.0	53	3.4	644	2.3	1592	1.8
The Basque Country	424760	7.9	219	14.1	1767	6.4	5451	6.2
La Rioja	12770	0.2	3	0.2	264	1.0	708	0.8
Total	5342970	100	1555	100	27744	100	88067	100

Source: New Cronos Eurostat.

if we focus on the technological level according to the use of innovation in the application of a patent (degree of technological complexity involved depending on the destination or use of innovation in the patent application), a high concentration of innovation is observed in Spanish regions, mainly in high-technology innovations, where the values of the concentration index reach around 2.60 and 3.26 for each sub-sample[5] (see Table 2). Only low technology innovations of the others would have concentration levels that approach the average. Nevertheless, a regular decline in these geographical inequalities in the distribution of innovation activity is observed in the second half of the 1990s.

The next question to study is whether this decline in geographical inequalities in the distribution of innovation activity is the result of spatial interdependencies in innovative activity. The degree of spatial dependence can be analysed by Moran's (1948) *I*-statistic which is defined as:

$$I = \frac{N}{\sum_i \sum_j w_{ij}} \frac{\sum_{ij} w_{ij}(X_i - \bar{X})(X_j - \bar{X})}{\sum_i (X_i - \bar{X})^2} \quad \text{if } i \neq j$$

where X_i and X_j are the observations for regions i and j of the variable of interest, $\bar{X}$ the regional average, N the number of observations and w_{ij} is the i–j element of the row-standardised W matrix of weights. As the standardisation factor $\sum_i \sum_j w_{ij}$ equals N in the case of a row-standardised matrix of weights, the first quotient is equal to one in our analysis. This statistic is normal-standard (0.1) distributed (Cliff and Ord, 1981) under the null hypothesis of spatial independence in the variable under analysis. The rejection of the null hypothesis indicates the distribution of that variable in space according to the patterns defined in the matrix of weights.

We have considered the common matrix of weights in the literature based on geographical contiguity among

Table 2
Geographical concentration of innovation activity in Spanish regions

	Herfindhal–Hirschman index	
	1989–1994	1995–2000
High technology	2.60	3.26
Medium technology	4.15	4.70
Low technology	4.41	5.66
Total	4.30	4.87

Note: *I*-statistic values are between 0 and 100. The 0 value indicates maximum concentration and 100 corresponds to maximum dispersion.
Source: New Cronos Eurostat.

[5] In similar studies for Germany, France, the UK and the US it is considered that values of the concentration index lower than 5.0 indicate a very high geographical concentration of innovative activity (Brechi, 1998).

Table 3
Spatial autocorrelation in innovation (Moran's *I*-test, normal approximation)

Weights matrix	Moran index	*Z*-value	*P*-value
Contiguity	0.220	4.102	0.0
Bilateral imports	0.224	6.460	0.0
Bilateral trade flows	0.208	6.127	0.0

regions and for different technological levels of innovation. However, from a more specific perspective, the distance separating two regions could be more than merely geographical (for example: the level of regional integration, personal contacts among economic agents, productive and technological complementarities, etc.). In an industrial context, the innovative contiguity between productive sectors, w_{ij}, is often set equal to 1 if the intensity in their commercial relationships is higher than the average. If we follow this idea, we can define the proximity between regions from a commercial perspective. In this case we can use the intensity of bilateral trade flows as the bilateral weights, w_{ij}, to approximate the intensity of regional interdependences, or more specifically, use the bilateral import shares[6] among Spanish regions, following the seminal work by Coe and Helpman (1995). Considering that more than 50% of regional interactions are trade related, we assume that the more intense the commercial interrelations between regions, the more the innovation exchanges between them.

Table 3 shows the results of computing Moran's *I*-statistic for the three weighting matrices. In all cases the null hypothesis can be rejected, obtaining positive evidence of the existence of spatial autocorrelation in innovative activity among Spanish regions. Moreover, the standardised *Z*-statistic shows that spatial autocorrelation is stronger when commercial proximity (considering either total trade or imports) rather than geographical proximity is considered. These results mean that patent applications in one region tend to be more correlated with the innovation carried out by its commercial partners rather than with its geographical neighbourhood, and, more concretely with the innovation performed by its supplier regions. Thus our preferred weighting matrix will consider commercial proximity between Spanish regions by means of the amount of bilateral import flows.

[6] Intensity of bilateral trade flows = $(X_{ij}+M_{ij})/(X_i+M_i)$ and bilateral import shares = M_{ij}/M_i between regions *i* and *j* are computed from Llano's (2004) data on interregional trade in Spain.

4. The econometric model

The questions and issues analysed in the previous section seem to suggest that, in effect, innovation in a region depends not only on local capacity for innovation and the composition of its economic activity, but also on the innovative activity in nearby regions, which we call foreign spillovers. The incorrect omission of this term when estimating Eq. (2) would generate spatial autocorrelated residuals, implying inefficient estimates and inference problems similar to temporal autocorrelation problems. In this case, spatial econometric methodology provides the techniques to solve these problems (Anselin, 1988).

Following these ideas, we begin to analyse the determinants of innovation by specifying the model according to Eq. (3):

$$I_{\text{it}} = \beta_{i0} + \beta_2 I_{\text{it-1}} + \beta_3 H_{\text{it}} + \beta_4 \text{RD}_{\text{it-1}} + \beta_5 S_{\text{it}} + \beta_6 D_{\text{it}} + u_{\text{it}} \quad (3)$$

where individual effects, β_{i0}, are not measurable or observable factors, fixed over time and specific for each region, the so-called socio-economic factors, that control for institutional and other structural factors that may affect either the innovative capacity of the region or the propensity to protect its results by means of patents. u_{it} is the random effect that could have a spatial dependence problem (see variables and data sources in Table 4).

If spatial statistics applied to estimating Eq. (3) point to the existence of spatial dependence in the model, the next step is to include it in the model's specification. We consider that such spatial autocorrelation in innovation activity is a form of foreign spillovers that can determine the innovation in the local economy (substantive spatial dependence, Anselin and Florax, 1995). Thus, we specify the model as:

$$I_{\text{it}} = \beta_{i0} + \beta_1 \text{WI}_{\text{it}} + \beta_2 I_{\text{it-1}} + \beta_3 H_{\text{it}} + \beta_4 \text{RD}_{\text{it-1}} + \beta_5 S_{\text{it}} + \beta_6 D_{\text{it}} + u_{\text{it}} \quad (4)$$

where *W* is the weight matrix defining the commercial proximity of regions and the foreign spillover variable, WI_{it}, the spatial lag for innovation, is a weighted sum of innovation activity in the regions commercially close to region *i*.

Finally, if we consider that innovative activity in nearby regions can be proxied by outputs (patent applications) but also by inputs (R&D efforts), foreign spillovers could really be due not so much to innovation activity in other regions but to their R&D efforts (Bottazzi and

Table 4
Variables, measurement and data sources

Variable	Measurement and data sources	Expected sign
I_{it}	Number of patent applications over gross added value (GAV) in 1995 constant € for each region and year. *Source*: New Cronos Eurostat database, Spanish Regional Accounts INE and Hispalink	
WI_{it}	Foreign spillovers: spatial lag for innovation. *Source*: own computations with different weight matrix	+
I_{it-1}	Temporal lag for innovation. *Source*: New Cronos Eurostat database, Spanish Regional Accounts INE and Hispalink	+
H_{it}	Relative number of employees that at least began secondary or higher levels of schooling. *Source*: IVIE	+
RD_{it-1}	R&D expenditures over GAV in 1995 contant €. *Source*: INE and own computations	+
WRD_{it-1}	Foreign spillovers: spatial lag for R&D efforts. *Source*: INE and own computations	+
S_{it}	Specialisation index $S_{it} = (1/2)\sum_{j=1}^{J} \left\|(GAV_{ij}/GAV_i) - (GAV_{Nj}/GAV_N)\right\|$, where j are the productive sectors[a] and N refers to the national average. *Source*: INE, Hispalink and own computations	+
D_{it}	Concentration index (Herfindhal–Hirschman) $D_{it} = \sum_{j=1}^{J}(GAV_{ij}/GAV_i)^2$. *Source*: INE, Hispalink and own computations	−

INE: Spanish Statistical Institute (www.ine.es); Hispalink (www.hispalink.org); IVIE: Instituto Valenciano de investigaciones económicas (www.ivie.es).

[a] Agriculture, energy, intermediate goods, capital goods, consumption goods, building, transport and communication services, market services and non-market services.

Peri, 2003):

$$I_{it} = \beta_{i0} + \beta_1 I_{it-1} + \beta_2 H_{it} + \beta_3 RD_{it-1} + \beta_4 WRD_{it-1} + \beta_5 S_{it} + \beta_6 D_{it} + u_{it} \quad (5)$$

where the foreign spillover term is the weighted sum of R&D efforts in nearby regions. In this case, the consideration of foreign R&D spillovers will enable a richer analysis from considering the different sources of public and private R&D efforts and its implications for economic policy.

5. Econometric results

We use a pool of information for the 17 Spanish regions in the period 1989–2000, totalling 204 observations. In this context, the panel data approach allows us fuller exploitation of both the spatial and temporal dimensions of the data. Both R&D allocation and productivity might be affected by time-invariant unobservable regional characteristics, whose omission would cause inconsistent OLS estimates of the coefficients. For this reason, we specify and estimate a fixed effects model[7] by means of the within-groups estimator. Moreover, the presence of an endogenous variable as a regressor of the temporal lag would generate an endogeneity problem, and inconsistent estimates, if there is temporal autocorrelation in u_{it}. Moreover, the characteristics of the endogenous variable, of zero values in some years and regions, generate a censored sample that has to be considered in the estimations.

5.1. Evidence on interregional relations in innovative activity

The econometric results of the censored within-groups estimations are presented in Table 5. The knowledge production function for innovative output holds in the Spanish regions. Both the human capital and own R&D efforts positively determine innovation in a region. Moreover, the innovative tradition or inertia in the region favours local innovative output. Together with these structural factors, the composition of economic activity plays a determinant role in the innovation in the region. Specialisation economies display a positive and significant effect on innovative activity, while diversity externalities, with the negative sign of the concentration index, have no significant effect on it. Thus, this result points to the presence of MAR (Marshall–Arrow–Romer) economies in innovative activity in Spanish regions, in line with previous studies where a positive correlation between specialisation and innovation is found in European regions

[7] The Hausman (1978) test allows testing the adequacy of within-groups versus random effects model.

Table 5
Innovative activity and spatial innovation spillovers

	(i)	(ii)	(iii)
WI_{it}		0.244**	
I_{it-1}	0.256**	0.206**	0.229**
H_{it}	1.171**	0.791**	1.123**
RD_{it-1}	1.605**	1.486**	1.674**
WRD_{it-1}			
S_{it}	0.555**	0.517**	0.536**
D_{it}	−0.426	−0.486	−0.495
λ			0.407**
Scale factor	223.799**	221.167**	219.291**
AIC	13.542	13.523	13.514
Schwarz	13.939	13.936	13.929
LM-ERR	11.834		
LM-LAG	6.684		
LM_{ρ}^{A}	4.559	0.311	0.209
LR test		5.480**	6.880**
Heteroscedasticity	36.250**	22.960	27.930**

Dependent variable: I_{it}. *Note*: significance indicated as ** for 5%. Period 1989–2000.

(Paci and Usai, 2000), and in contrast to Feldman and Audrestsch (1999) who find evidence to support the diversity thesis as promoting local innovation in an industry. These results are robust throughout our analysis. According to Feldman and Audrestsch (1999), we also performed a robustness check of the main econometric results after imposing different R&D lag structures.

Nevertheless, from a deeper analysis of the residuals of the estimation in column (i) we detect the existence of spatial autocorrelation, as shown in Table 3. The tests for spatial autocorrelation (LM-ERR and LM-LAG, see Anselin, 1988) are computed using the bilateral import shares matrix.[8] This matrix has non-zero elements for each pair of commercial partners which are functions of the volume of imports between the two regions and implies that the higher the volume of imports from a region, the higher the volume of knowledge that is accessible for the importing region, and thus the higher the intensity of spillovers. Consequently this matrix widens the assumption largely supported by the literature (see Karlsson and Manduchi, 2001, for an empirical survey) that geographical proximity matters in the interregional flow of knowledge.

Both the LM-ERR and LM-LAG test reject the null hypothesis of the absence of spatial autocorrelation in the innovative activity of Spanish regions at a 1% level of significance. This result points to the necessity of revising the model specification, including the interdependence of innovation in Spanish regions, to consider the existence of spatial externalities that can affect the level of regional innovative activity. In this case, the LM-ERR test has a higher value than the LM-LAG, pointing to a specification of the spatial dependence by means of a spatial error model (Anselin and Florax, 1995). Thus, the model will stand as:

$$I_{it} = \beta_{i0} + \beta_1 I_{it-1} + \beta_2 H_{it} + \beta_3 RD_{it-1} + \beta_5 S_{it} + \beta_6 D_{it} + u_{it}, \text{ where } u_{it} = \lambda W u_{it} + \varepsilon_{it} \quad (4')$$

Table 5 shows the maximum likelihood estimation results of model (4′) in column (iii). Perturbation normality is not rejected but homoscedasticity is not accepted. As a result, we estimate the spatial lag model in Eq. (4). Results are in column (ii) in Table 5. In this model, specification tests point to normality and homoscedasticity in perturbations, while the LM test suggests that spatial autocorrelation is adequately captured by the spatial lag of the endogenous variable. Moreover, AIC and Schwartz are slightly lower for the spatial lag model, which is the one we prefer. Nevertheless, the rest of the estimates are robust to the different spatial autocorrelation specification, except the human capital and R&D coefficients which are higher when substantive spatial dependence is not considered in the model, capturing part of such spatial spillover effects.

Interregional externalities in local innovative activity have been included in the model (4) by means of the spatial lag of endogenous variable, WI_{it}. In the literature, the general practice to capture spatial dependence is through defining the weight matrix from a geographic perspective. Nevertheless, in this case, interregional proximity is defined, in a wider sense, in terms of commercial interdependencies and according to the Moran test results, in terms of bilateral import shares. Given that Spanish regions trade mainly with geographically neighbouring regions, the two weight matrix definition criteria are not contradictory, but the commercial one is richer given that it provides information about the presence and intensity of interrelations among regions. The objective is to analyse whether or not innovative activity on behalf of import suppliers favours domestic innovation in a region.

[8] Several tests have been carried out to assess the adequacy of the regressions in Table 5. Normality and temporal autocorrelation are not a problem in our regressions, but the distribution of error terms is not homoscedastic. This is important since it can affect efficiency and inference in our estimations. The estimation results with the bilateral import shares weighting matrix allow the null of homoscedasticity to be not rejected. Moreover, the estimated parameters are robust to the consideration of bilateral trade flows weighting matrix. Results can be provided by the authors upon request.

Focusing on the estimates from the censored spatial lag model in column (ii) of Table 5, it is observed that local R&D efforts have a positive and significant effect on domestic innovation. The estimated elasticity of patent applications to own R&D efforts is 0.33,[9] in line with results in previous literature, an elasticity that in the case of European regions ranges from 0.2 to 0.8 (Moreno-Serrano et al., 2005; Bottazzi and Peri, 2003, respectively). Similarly, the innovation to human capital elasticity is estimated at around 0.75, in line with elasticities for this factor obtained in recent growth regressions (Bassanini and Scarpeta, 2001) and in the microeconomic literature (Ashenfelter et al., 1999; Topel, 1999). Conclusions about the effects of economic composition on economic activity remain unaltered.

The spatial lag of the endogenous variable is significant and has a positive effect on innovative activity. This result indicates the importance of innovation performed in trade partners in local innovative activity, which has a similar effect to own R&D efforts given that innovation elasticity in one region to innovative activity in its trade partners is around 0.33. This result is higher than the elasticities obtained with other weighting matrices such as the contiguity measures (Moreno-Serrano et al., 2005) because the bilateral imports weighting matrix considers one region's bilateral trade flows with all the rest of the Spanish regions and its amount to set the range and intensity of spillovers.

Finally, we estimate the model in Eq. (5) where spillover effects are considered to emanate from R&D rather than from innovative activity (Bottazzi and Peri, 2003). Estimation results are shown in the first column of Table 6. The results relating to innovative tradition, human capital, local R&D efforts and external economies due to the composition of economic activity in the region are in line with the previous results. Spillovers emanating from R&D efforts performed by import suppliers affect innovative activity in the region positively and significantly, but to a lesser extent than own R&D efforts. Nevertheless, this R&D spillover effect is not broad enough to capture all interregional spillovers. In fact, spatial autocorrelation tests show that some residual spatial interdependence remains that would affect the efficiency of estimates. The estimation of the corresponding spatial error model is presented in column (ii) in Table 6, confirming previously obtained results.

In short, interregional knowledge spillovers have significant and positive effects on local innovation, regardless of how they are considered. Moreover, on comparing the elasticity of regional innovative activity to innovation or to R&D performed by regional trade partners, we find that the latter is twice the former, indicating the greater effectiveness (in terms of stimulating innovation) of policies enhancing regional R&D activities rather than directly favouring innovation in the productive process.

5.2. The origin of interregional R&D spillovers

According to Rodriguez-Pose (2001) the expansion of R&D efforts observed in countries that are lagging behind in Europe relatively speaking, in technological terms, has been linked to neoclassical and regional policy views. Concretely, in the Mediterranean periphery, and thus in Spain, the public sector has been the driving force behind the increase in R&D effort under a regional policy view focused on reducing technological disparities within the country and with respect to the European core. Given this objective, public R&D efforts[10] have been as important as private.

We analyse this question in light of the importance of its policy implications in terms of the effectiveness of promoting regional innovation, and hence growth and the reduction of regional inequalities. In order to achieve this, we distinguish between the origin of R&D efforts performed in all Spanish regions, considering resources devoted to R&D in the region by firms, that is private R&D efforts ($RDpriv_{it-1}$), and by universities and administrations, that is public R&D efforts ($RDpub_{it-1}$). This differentiation of R&D by its origin occurs both in the analysis of local R&D effects on innovative activity and in the analysis of interregional R&D spillovers. Results are shown in columns (iii) to (vii) in Table 6. As in the previous case, results of the positive and significant effect of the tradition of innovation activity in the region, of human capital endowments and the composition of economic activity, remain unaltered. To avoid serious multicollinearity problems, we first analyse the domestic scope of R&D spillovers depending on their public or private nature. First of all, in columns (iii) and (iv) we check the robustness of results in light of the various specifications of spatial innovative spillovers. In both cases, local R&D performed by firms does not have a

[9] Average values for variables are: R&D = 186.4131; I = 763.47; WI = 1154.22 and H = 720.47.

[10] In Spain in 1995, firm R&D expenditures represented 48.6% of total R&D expenditures. As most universities in Spain are public institutions or at least receive public financial support, we can consider that in general public R&D efforts, from both administrations and universities, have been as important as the private in contributing to R&D levels and growth rates.

Table 6
Innovative activity and R&D spillovers depending on R&D origin and regional level of development

	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)	(ix)	(x)	(xi)	(xii)	(xiii)	(xiv)	(xv)	(xvi)	(xvii)
WI_{it}			0.27**					0.25**							0.28**		
I_{it-1}	0.23**	0.19**	0.25**	0.28**	0.25**	0.23**	0.19**	0.20**	0.22**	0.18**	0.20**	0.18**	0.21**	0.19**	0.23**	0.26**	0.23**
H_{it}	0.95**	0.83**	0.70**	0.92**	0.83**	0.75**	0.60**	0.82**	0.99**	0.83**	0.98**	0.84**	0.78**	0.65**	0.82**	1.04**	0.91**
R&D	1.51**	1.61**				1.45**	1.56**				1.50**	1.58**	1.46**	1.53**			
R&D rich								1.55**	1.59**	1.66**							
R&D poor								1.00	0.92	1.24							
R&D pub			2.35**	2.28**	2.67**												
R&D pub-rich															3.19**	3.32**	3.58**
R&D pub-poor															2.15	1.45	2.07
R&D priv			−0.16	−0.30	−0.266												
R&D priv-rich															−0.57	−0.74	−0.66
R&D priv-poor															−4.36	−1.50	−2.45
W R&D	1.05*	1.25**		1.09*4	0.99				1.09*	1.44**						1.09*	1.17*
W R&D rich											1.67**	1.78**					
W R&D poor											0.43	0.95					
W R&D pub						3.49**	4.22**										
W R&D pub-rich													3.32*	4.07**			
W R&D pub-poor													3.24*	3.71**			
W R&D priv						−0.25	−0.70										
W R&D priv-rich													0.90	0.54			
W R&D priv-poor													−1.03	−0.50			
S_{it}	0.45*	0.47*	0.62**	0.60**	0.59**	0.51**	0.49*	0.52**	0.49*	0.47*	0.44	0.44	0.49*	0.47*	0.59**	0.58**	0.57**
D_{it}	−0.49	−0.541	−0.492	−0.51	−0.47	−0.96**	−1.06**	−0.44	−0.43	−0.57	−0.36	−0.48	−0.88	−0.94**	−0.52	−0.50	−0.52
λ		0.37**			0.31**		0.39**			0.42**		0.38**		0.34**			0.36**
Scale factor	223.05**	218.92**	225.13**	227.33**	224.476	220.63**	215.72**	221.05**	222.80**	217.84**	221.85**	218.08**	219.84**	216.59**	224.00**	226.42**	222.83**
AIC	13.537	13.512	13.562	13.579	13.565	13.528	13.5	13.533	13.545	13.514	13.535	13.514	13.539	13.525	13.575	13.593	13.573
Schwartz	13.951	13.944	13.994	14.106	14.014	13.960	13.949	13.965	13.977	13.963	13.967	13.963	14.005	14.009	14.042	14.060	14.056
LM error	12.12**			10.67**		7.50**			10.42**		8.52**		6.33**			8.87**	
LM lag	2.99*			4.11**		3.63*			2.80*		2.48		2.93*			4.16**	

Dependent variable: I_{it}. Period 1989–2000. *Note*: significance indicated as ** for 5% and * for 10%.

significant effect on innovation while public R&D in the region has a significant and positive effect on local innovation, confirming the key role of the public sector in terms of both increasing R&D capacity and promoting innovation in the region. Nevertheless, the spatial autocorrelation test in the estimation in column (iv) clearly rejects the null hypothesis, while the LM-ERR points to the adequacy of the estimation of the spatial error model, so some kind of innovation spillovers apart from those emanating from R&D interdependencies must be considered to further improve the efficiency of our estimations. In this case, estimates in column (v) confirm that basically public (both high education and government) R&D efforts are relevant in promoting innovation, providing evidence in line with results in Acs et al. (1994) and Bilbao-Osorio and Rodriguez-Pose (2004) for European peripheral regions.

Similarly, the public R&D efforts performed by regional trade partners contribute to increasing domestic innovation, as shown in the more efficient estimation in column (vii) in Table 6. This result provides evidence of the importance of public initiatives, when it comes both to spurring local innovation and the innovative activity of commercially related regions (supporting the statements made by Rodriguez-Pose (2001) concerning the general orientation of public R&D in Mediterranean countries, and hence in Spain), and also to reducing technological disparities within the country and its technological dependency with respect to the European core.

5.3. Innovative spillovers and the level of economic development

Another interesting question related to R&D spillovers and their positive effect on promoting innovation and technological development can be found in Rodriguez-Pose (2001). The author states that R&D levels in Spain are a long way from being those which would allow significant knowledge spillovers and in fact reflect an unfavourable productive structure with large agricultural and service sectors.

Empirical literature has suggested the existence of threshold effects in the factors determining economic growth (Azariadis and Drazen, 1990). In particular, Durlauf and Johnson (1995) obtain evidence regarding the existence of threshold effects of local knowledge (measured by human capital) on output growth depending on the level of development, using as one of the control variables the initial output per capita. In other threshold analyses, Sorensen (1999) obtains evidence on the positive effects of R&D on innovation only when human capital reaches a minimum level; and Lopez-Bazo et al. (2006) find that the intensity of the effects of internationalisation and local knowledge depends on the level of each region's economic development, proxied by its relative TFP level.

Following these ideas, we analyse if innovative spillovers from trade partners have homogeneous effects on domestic innovation depending on the level of development. In this sense, Acosta and Coronado (2003, p. 1786) emphasise the relevance of "environmental and institutional factors that, in a particular territory, foster certain kinds of collective learning (tacit local knowledge) that favour innovative activity." Thus the threshold variable, GAV per capita, proxies the innovation capacity, namely the tacit local knowledge that determines the ability of an economy to translate its aggregate knowledge endowments into innovation and technological development. Developed regions are, in words of Rodriguez-Pose (1999, p. 82), 'innovation prone' economies that are "capable of transforming a larger share of their own R&D into innovation and economic growth" while less developed or 'innovation averse' regions are not capable of doing it to the same extent.

The group of less developed regions[11] coincides with those that have GDP per capita less than 75% of the EU average, designated as 'objective 1' regions for the distribution of European development funds, and with those in Acosta and Coronado (2003). This coincidence allows characterising its innovation-enhancing features in a wider and richer perspective rather than its R&D efforts. So, relative to the advanced regions, less developed regions contribute about 32% to total R&D, and their R&D/GDP ratio is less than 35% of the European average. Moreover, they are specialised in medium–low technological sectors, where few are involved with scientific research to promote innovation and are more implicated in tacit knowledge of previous specific innovations. In order to avoid estimation problems, we define a dummy variable that has a value of one if a region's average GAV per capita is lower than the national average, that is the group of poor regions, and a dummy variable for rich regions that has the value one when a region's average GAV per capita is higher than the national average. By interacting R&D variables with such dummy variables, we incorporate the R&D differential effect stemming from the level of development into the model.

[11] The regions with the lowest levels of GAV per capita are Andalucia, Asturias, Canary Islands, Cantabria, Castille and Leon, Castille-La Mancha, Community of Valencia, Extremadura, Galicia and Murcia. The more developed regions are the Balearic Islands, Catalonia, Madrid, Navarre, the Basque Country and La Rioja.

Our hypothesis assumes that the benefits of innovative spillovers on domestic innovation will be greater in those regions in which a certain level of development has already been reached, as there will be suitable incentives and structural factors that determine its capacity to generate and assimilate innovation and fully exploit their opportunities.

Results are shown in Table 6, columns (viii) to (xii). When we analyse the differential effect of domestic R&D depending on the level of development, this variable is found to have a positive and significant effect on domestic innovation in the rich regions with respect to the poor' regions, irrespective of how spatial innovative spillovers are considered; by a spatial lag model (in column (viii)), by including the trade partners' R&D term (in column (ix)), or by the estimation of this last model's spatial error specification (in column (x)).[12] Thus, given the human capital endowments and productive structures in the region, the effect of domestic R&D expenditures is greater in rich regions, confirming the necessity of a certain degree of development in order to benefit more from R&D accumulation. In this sense, human capital has a positive and significant effect on innovation in all the estimations. Analysing the composition of the regions' economic activity, we obtain evidence supporting the presence of MAR externalities in innovation. Only the consideration of the origin of R&D efforts and effects depending on the regional development (in columns (vii) and (xiv) in Table 6, respectively) give the result of specialisation and diversity economies (that is the combination of MAR and diversity externalities) having a positive effect on innovation.

As far as commercial openness is concerned, import suppliers' R&D efforts have a positive and significant effect on domestic innovation in rich regions in relation to poor regions (column (xii)). Thus, the direct effect of local R&D accumulation is much greater in the case of the more advanced Spanish regions and this phenomenon is reinforced when the interrelations among these regions and their commercial partners is considered.

Differences arise when we analyse the source of those R&D expenditures. In the rich regions, benefits from own R&D efforts would emanate basically from public R&D expenditures (that is from universities and government R&D investment) but have no effect on poor regions. On the other hand, private R&D expenditures would not have a significant effect on local innovation in either rich or poor regions (see column (xvii) in Table 6). These results are in line with Acosta and Coronado (2003) and add more precision to Bilbao-Osorio and Rodriguez-Pose's (2004) results for peripheral regions in the European Union. While less developed regions are 'innovation averse' economies where scientific research is little involved in the innovative process, Spanish developed regions, which are on the technological periphery of Europe, would have better structural conditions to enhance scientific (public) research-technology links, a result that reinforces the idea of the necessity of a certain level of development to achieve sufficient innovation capacity.

Nevertheless, the consideration of R&D spillovers emanating from public versus private R&D expenditures in trade partners points to the positive effects of public R&D spillovers both in the rich and poor regions, as in column (xiv) in Table 6, which confirms the importance of public initiatives in terms of enhancing innovation and technological development and the general scope of R&D policies in Spain, in line with Rodriguez-Pose (2001). Moreover, the higher effect of public R&D spillovers in the developed regions reinforces the idea that the effectiveness of innovation-enhancing policies needs a minimum level of economic development, in line with Furman and Hayes (2004), or more generally, an innovation-favourable socio-economic structure.

6. Conclusions

Innovation activity in Europe shows an innovative centre, located in north and central Europe and a low innovative periphery in southern Europe, and more precisely in Mediterranean countries. Nevertheless, this centre-periphery pattern of innovation has weakened over time as the largest expansion of R&D activity has occurred in precisely the southern European countries such as Greece, Portugal and Spain, promoted by public initiatives. In Spain, the expansion of R&D expenditure has occurred at the same time as a decline in geographical inequalities in the distribution of innovation activity among regions. This reduction of interregional innovative inequalities can be due, in part, to the presence of spatial knowledge flows in the process of innovation. In this case, innovative activity in the region would be determined by its own capacity of innovation and by innovation performed in the remaining regions, and thus interregional inequalities in innovation tend to decline.

In this paper we analyse the effect of such interregional externalities on innovation from a temporal and spatial perspective, by means of a within-groups

[12] We tested for the existence of neo-Schumpeterian R&D threshold effects by splitting the sample of Spanish regions according to relative R&D per capita levels. While results on own R&D effects slightly differ, strong multicollinearity problems cast serious doubts on R&D spillover effects.

censored model and the use of spatial econometric techniques.

The econometric analysis shows that innovation in a region depends on its own R&D efforts, its innovative tradition and its human capital endowments. Moreover, the composition of economic activity has a positive effect on innovation pointing to the presence of positive MAR (Marshall–Arrow–Romer) externalities in innovative activity in Spanish regions, in such a way that, the more specialised the region is, the more innovative activity the region boasts. These results are robust to different specifications of externalities. Only when we consider the origin of R&D spillovers or its differential effects combining its origin and differences in the level of regional development, do we obtain the presence of a mixture of MAR and diversity economies in the innovation process. Then, the prevalence of specialisation economies would suggest the implementation of specific regional and industrial policies oriented towards the development of relevant sectors in the region to enhance innovation.

Local R&D efforts and in particular public R&D efforts (considered as the aggregation of R&D performed by universities and governments) positively determine domestic innovation. Thus, R&D policies play a relevant role in shaping a region's innovative capacity. Moreover, the consideration of the level of development of the region points to the positive effect of local public R&D efforts in regions with higher levels of GAV per capita, most of which exhibit higher R&D expenditure levels. This confirms the necessity of a minimum level of development in order to better benefit from R&D accumulation. Similarly, empirical evidence on the positive effect of R&D spillovers in more developed regions reinforces the direct effect of local R&D accumulation on innovation in those rich regions.

Interregional spillovers emanating from trade with other regions enhance domestic innovation. Spillovers emanating from R&D are more effective than those from innovation performed by import suppliers. This result indicates that policies enhancing R&D activities would more effective than those directly favouring productive innovations. Again, trade partners' public R&D expenditures are relevant in increasing domestic innovation, providing evidence of the importance of public institutions, governments and universities, both for boosting local innovation and for trade-related innovative activity in general, and in high relative to low GAV per capita regions in particular.

These results confirm the importance of universities and government R&D initiatives for enhancing innovation in Spain, and the necessity of a minimum level of development to improve the effectiveness of such innovation-enhancing activities. Nevertheless, and given the relevance of socio-economic factors for the innovative performance of regions, it would be necessary to combine such general policies with other industrial, scientific and technological policies, both general and regional in scope, focused on the improvement of the population's level of education, the technological intensity of relevant sectors in the region and the links between the scientific research and the technological requirements of such relevant sectors. That is to say, what are needed are general and regional-specific policy measures oriented to creating and consolidating an innovation prone environment.

Acknowledgements

The authors are grateful to The Ministry of Education and Science of Spain (SEJ2004-07924/ECON) for financial support.

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