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INNOVATION, COOPETITION AND SPILLOVER EFFECTS IN EUROPEAN REGIONS

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Abstract. Innovation and investment are critical to economic growth. In this article, we address the complex task of evaluating the capacity of regional innovation to increase investment and generate spillovers in regions of the European Union (EU) from both spatial and temporal perspectives. Using panel data estimation methods and exploring the effects of dynamic spatial autocorrelation, our findings show a positive spatial autocorrelation at the level of EU regions. We also observed spatial competition, both in terms of the distribution of investments and in terms of the diffusion of short-term innovation gains. We argue that, in the short term, EU regions tend to behave as competitors for investment fixing, but in the long run, innovation has the potential to generate spillover effects on neighbouring regions. Furthermore, we find that investment patterns were characterized by a significant temporal autocorrelation, showing that shocks to investment in regions tend to be absorbed in a few periods. This paper attempts to fill existing gaps by using estimation methods for dynamic spatial panel data to identify and explore the effects of regional innovation on investment for the 154 European Union regions, and reports original findings as regards the knowledge spillover across European regions.

Keywords: coopetition, regional innovation system, knowledge spillover, investment, dynamic spatial panel model, dynamic spatial Durbin model (DSDM), regional innovation index.

JEL Classification: O33, R11, C23.

Introduction

There is a general agreement in the literature that investment and innovation are fundamental to long-term economic growth and development. The relationship between investment and

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innovation has been explored, first, by the scholars embracing neoclassical growth models that considered technological change to be endogenously determined by the rate of investment expenditure. However, understanding a bidirectional relationship between investment and technological change was emphasized as being of utmost importance since then. Agglomeration is an important contributor in the study of growth, innovation, and investment decisions at regional level. Agglomeration and proximity are also key factors that facilitate knowledge transmission and generate intellectual spillovers in regional economies.

Although there is a consistent body of both theoretical and empirical literature on these topics, as will be further detailed in the next sections, this paper addresses several shortcomings identified in the existing literature. This paper attempts to fill existing gaps by using estimation methods for dynamic spatial panel data to identify and explore the effects of regional innovation on investment for the 154 European Union regions defined by the Nomenclature of Territorial Units for Statistics (NUTS) at the NUTS 2 level over the period 2000–2020. Innovation is measured using the composite regional innovation index given by the Regional Innovation Scoreboard, which is released every two years by the European Commission.

The paper proceeds as follows. In Section 1, we provide a synthesis of the relevant literature to our study. Section 2 illustrates the data set used in the study and the method of analysis. Section 3 provides research results and their discussion. Section 3.1 proposes a panel data model for discussing regional innovation and investment in regions of the European Union. Section 3.2 explores the spillover effects of regional innovation across European regions using a dynamic spatial autoregressive model. Finally, Section 4 follows up with the results and concludes with insights for innovation and investment policy makers.

1. Regional innovation and the role of spillovers

The importance of investment and innovation for economic growth has long been established. There is a consensus that investment is deemed necessary for economic growth, enabling both innovation and long-term economic growth (Mourao & Popescu, 2022; King & Levine, 1993). The role of foreign direct investment (FDI) on innovation and growth processes has also been demonstrated. FDI directly stimulates economic growth and development, but also, impacts indirectly other aspects of the economic activity through spillovers (Bostan et al., 2023; Apostu et al., 2022). FDI plays a crucial role in facilitating knowledge spillovers, as it promotes technology transfer, human capital development, research collaboration, supplier linkages, and competition, all of which contribute to the diffusion of knowledge and the growth of domestic industries (Marques & Morgan, 2021; Kijek & Kijek, 2019; Bostan et al., 2023; Neuländtner & Scherngell, 2022; Popescu & Mourao, 2016).

An extensive body of research has considered innovation to be rooted in regions and their attributes. The concept of the "regional innovation system" (Cooke, 1992; Asheim & Isaksen, 1997; Braczyk et al., 1998) is currently well established and dominates prominently scholarly debates on regional innovation and growth. The framework of regional innovation systems has been used to provide explanations about the uneven spread of innovation at the level of the regions and the endogenous factors and processes that stimulate the creation of knowledge and enhance the innovative capacity of regions (Isaksen et al., 2018). In that sense, innovation is the result of exchanges and interdependencies between organizations, overlooked by a common regional institutional framework determined by the geographical context (Cooke et al., 2004; Mourao & Popescu, 2023). Regional authorities can positively affect the economic benefits for the regions if the cooperation between authorities and local business leads to the development of the investment strategies of the enterprises (Lewandowska et al., 2021), cooperation of enterprises with their competitors, scientific institutions and other business environment entities (Wasiluk & Ginevičius, 2020). Agglomeration and geographic proximity are important to the study of growth, innovation and investment decisions in regions. Localization economies are associated to with specialization within a geographic region (Fracasso & Vittucci Marzetti, 2018). In other words, these externalities embody knowledge spillovers in the regional economy.

The study of spillovers from innovation processes has recently become a major concern of researchers. Knowledge spillovers have a "profound effect" (Huber, 2012), and play a significant role in regional innovation performance (Xu et al., 2022). The generation of spillovers is "geographically confined" and arises from co-location within the innovation ecosystem and from collaborations across different innovation ecosystems (Audretsch et al., 2022; Audretsch & Feldman, 1996). It has been established that the innovation performance is uneven across regions regardless of the analyzed space despite sustained efforts to stimulate regional innovation (Lopes et al., 2021). Furthermore, more innovative regions are more resilient, as they benefit of spillover effects from neighboring regions (Martini, 2020). Recent research showed that regional institutional quality largely drives innovation performance and established the role of spatial spillovers at the level of Italian regions (Peiró-Palomino & Perugini, 2022). Wang et al. (2023) introduced the notion of "re-spillover", arguing that the flow of innovation factors between two regions may exert an influence on the innovation activity of third regions.

Knowledge spillovers have been examined in the scientific literature through a variety of econometric methods and techniques, including spatial Durbin models (e.g. Neuländtner & Scherngell, 2022; Wanzenböck et al., 2014; Wanzenböck, & Piribauer, 2018), knowledge production function with similarity matrices based on total factor productivity (e.g. Kijek & Kijek, 2019), OLS estimations of knowledge production function (Bottazzi & Peri, 2003; Moreno et al., 2005; Parent & LeSage, 2008; Varga et al., 2014), or the CDM (Crépon, Duguet and Mairesse) model (Vujanović et al., 2022).

In this study, we intend to proceed with the analysis of the spillover effects triggered by the development of regional innovation at the European level. Many of the current processes linked to innovation are supported by channels that can lead to more distant spaces benefiting more from the advantages of innovation than the closest spaces (Bottazzi & Peri, 2003). However, it is also true that the interconnection with investment dynamics and the profile of innovation policies raises additional reasons why the existence of innovation in a given European NUTS2 region is a reflection of what happens in terms of innovation in neighbouring regions (Halásková & Bednář, 2023).

The study by Rodríguez-Pose and Crescenzi (2008) can be identified as a pioneering study in this line of analysis. According to empirical results obtained by Rodríguez-Pose and Crescenzi (2008), the innovative capacity of regions is determined by a complex interaction between local and external research, and the local and external socioeconomic and institutional landscape. Additionally, they confirm the extremely important role of proximity in the transfer of productive knowledge by establishing strong decay effects of geographical distance on spillovers. In this regard, it is proved by Oliinyk et al. (2021) and Štreimikienė et al. (2022) that regional differences in creating the institutional environment of information and knowledge management can significantly shift the patterns of economic growth. Similar findings are typical for the influence of investments in education and training (Samoliuk et al., 2021; Stachova et al., 2020) and environmental protection (Fendoglu & Konat, 2023).

Moreno et al. (2005) also observed selected European regions in the first decade of the 21st century, i.e. 175 European regions from fifteen EU Member States, Switzerland and Norway. Some of the most relevant conclusions of Moreno et al. (2005) pointed to the relevance of endogenous regional factors (e.g. expenditure for research & development). However, in a critical view of the capacity to influence innovation, Moreno et al. (2005) concluded that "*spillovers are mostly constrained by national borders, within less than 250 km, and that technological similarity between regions also matters*." Furková's study (2019) also used observations following the observations of Rodríguez-Pose and Crescenzi (2008) and Moreno et al. (2005). Although the observations focused on European regions, the period analyzed was limited to the period between 2008 and 2012. Furková's conclusions (2019) were essentially in line with those of Rodríguez-Pose and Crescenzi (2008). The results of Moreno et al. (2005) are similar to the results of Bottazzi and Peri (2003), who used patent and research and development data for European regions collected for the period 1977–1995. Bottazzi and Peri (2003) found that spillovers were significantly localized and tended to exert within a distance of 300 kilometres. Bottazzi and Peri (2003) are clear on this criticism: "*Doubling R&D spending in a region would increase the output of new ideas in other regions by only 2 to 3 %, while it would increase the innovation of the region itself by 80 to 90%.*"

Two of these works (Rodríguez-Pose & Crescenzi, 2008; Furková, 2019) pointed to the virtues of innovation even for neighbouring spaces. However, Boschma's (2005) work presents a more critical reading in line with the limited capacity of spillover generation to influence neighbouring spaces (Bottazzi & Peri, 2003; Moreno et al., 2005). Boschma (2005) recognizes the weight of geographical proximity in innovation processes, but warns about possible negative effects of proximity due to lock-in. In addition, we note the work of Raines (2000), which identifies regional competition in attracting investment. This competition for investment by regions and their economic agents reduces the spillover capacity of the effects of innovation.

Thus, this selection of works focused on the effects of the spatial autocorrelation of innovation shows us the diversity of results, even within the European space. Additionally, we found that most this research did not study a period as long as the one we are observing nor did they study a selection of European regions as large as the present study. Additionally, these studies did not have the possibility of recurring to the RIS dimension that we are now observing. Thus, encouraged to contribute to this discussion, we prepared the following empirical exercise in which we seek to explore the effects of the spatial autocorrelation of innovation on investment expenditure for each European NUTS2 region.

2. Data and method

In this paper, we test the relationship between the capacity for regional innovation to generate investment attractiveness across European regions using the econometric spatial analysis methods. We use data from the Eurostat database (2021a, 2021b) and the European Commission Regional Innovation Scoreboards (2012, 2014, 2016, 2017, 2019) for a set of 154 regions at the NUTS2 level of the European Union during the period 2000–2020. Table 1 presents data variables, indicators, and associated data sources.

Table 1. Variables and data sources

Variable	Indicator	Source
GDP	Gross domestic product (GDP) at current market prices by NUTS 2 regions	Eurostat table[nama_10r_2gdp] 2000–2018
RIS	Regional Innovation Score	Regional Innovation Scoreboards (2019, 2017, 2016, 2014, 2012)
Inv	Gross fixed capital formation at constant prices by NUTS 2 regions	Eurostat table [nama_10r_2gfcf] 1995–2020
terceduc	Percentage population aged 30-34 having completed tertiary education	Regional Innovation Scoreboards (2019, 2017, 2016, 2014, 2012)
lifelongle	Percentage of the population aged 25-64 participating in lifelong learning	Regional Innovation Scoreboards (2019, 2017, 2016, 2014, 2012)
intcopub	International scientific co-publications per million population	Regional Innovation Scoreboards (2019, 2017, 2016, 2014, 2012)
citpub	Scientific publications among the top 10% most cited publications worldwide as a percentage of total scientific publications of the region	Regional Innovation Scoreboards (2019, 2017, 2016, 2014, 2012)
pubrd	R&D expenditures in the public sector as a percentage of GDP	Regional Innovation Scoreboards (2019, 2017, 2016, 2014, 2012)
busrd	R&D expenditures in the business sector as a percentage of GDP	Regional Innovation Scoreboards (2019, 2017, 2016, 2014, 2012)
nonrd	Non R&D innovation expenditures in SMEs as percentage of turnover	Regional Innovation Scoreboards (2019, 2017, 2016, 2014, 2012)
process	SMEs introducing product or process innovations as a percentage of SMEs	Regional Innovation Scoreboards (2019, 2017, 2016, 2014, 2012)
mark	SMEs introducing marketing or organisational innovations as a percentage of SMEs	Regional Innovation Scoreboards (2019, 2017, 2016, 2014, 2012)
sme	SMEs innovating in-house as percentage of SMEs	Regional Innovation Scoreboards (2019, 2017, 2016, 2014, 2012)
innsme	Innovative SMEs that collaborate with others as a percentage of SMEs	Regional Innovation Scoreboards (2019, 2017, 2016, 2014, 2012)
pubpriv	Public-private co-publications per million population	Regional Innovation Scoreboards (2019, 2017, 2016, 2014, 2012)
patent	EPO patent applications per billion regional GDP	Regional Innovation Scoreboards (2019, 2017, 2016, 2014, 2012)

End of Table 1

Variable	Indicator	Source
trademark	Trademark applications per billion regional GDP	Regional Innovation Scoreboards (2019, 2017, 2016, 2014, 2012)
design	Design applications per billion regional GDP	Regional Innovation Scoreboards (2019, 2017, 2016, 2014, 2012)
empl	Employment in medium-high/high-tech manufacturing and knowledge intensive services as percentage of total workforce	Regional Innovation Scoreboards (2019, 2017, 2016, 2014, 2012)
newmark	Sales of new-to-market and new-to-firm innovations in SMEs as percentage of turnover	Regional Innovation Scoreboards (2019, 2017, 2016, 2014, 2012)

Table 2 below reports the descriptive statistics regarding our data.

Table 2. Descriptive statistics (source: own research)

Variable	Obs.	Mean	Std. dev.	Min.	Max.
inv	3,064	9018.183	15567.46	0	176,974
gdp	3,064	22995.87	49964.15	0	733,875
invgdp	3,064	0.112686	0.126289	0	0.79372
lgdp	3,064	4.897508	5.113538	0	13.5009
linvgdp	3,064	0.112686	0.126289	0	0.79372
ris	3,064	20.18373	35.68874	0	169.895
terceduc	3,064	26.97644	50.28228	0	235.002
lifelongle	3,064	22.42488	48.15912	0	306.931
intcopub	3,064	26.0755	48.62942	0	239.487
citpub	3,064	21.53143	38.0076	0	195.453
pubrd	3,064	23.06457	39.97063	0	174.811
busrd	3,064	16.73167	34.6873	0	182.314
nonrd	3,064	27.28001	46.727	0	198.148
process	3,064	22.76373	40.91818	0	194.934
mark	3,064	23.45082	41.48857	0	182.845
sme	3,064	22.8682	41.72945	0	205.831
innsme	3,064	20.81484	42.40911	0	264.072
pubpriv	3,064	17.46835	37.85407	0	256.591
patent	3,064	13.74939	32.00499	0	220.738
trademark	3,064	21.56323	45.68039	0	275.963
design	3,064	19.54172	39.5305	0	197.29
empl	3,064	21.3207	43.11319	0	223.215
newmark	3,064	24.8894	43.05894	0	169.407

3. Results and discussion

3.1. A panel data model for discussing European innovation and regional investment

First, we estimated the value of investment expenses spent on each European region at constant prices depending on the Regional innovation score (Ris) provided for each European NUTS 2 region. Thus, we observe 154 European regions (i) for each year (t) in the period after 2000. We also consider absolute flows and the percentage of these flows in each unit's GDP at constant prices. The empirical model justification is detailed in Corrado et al. (2013). The disturbance term follows Moral-Benito (2009) and Mourao and Stawska (2020). These disturbances have the following components: η_i (related to the unobserved country-specific heterogeneity), γ_t (which suggests the unobserved effect that has a dynamic pattern along the periods but is common for the observed units), and $\varepsilon_{it,}$ which is an independent and identically distributed error term.

Running the tests suggested by the literature (Im et al., 2003; Choi, 2001) we found significant values for δ, the autoregressive parameter. This suggests the use of methods for dynamic panel data, namely the methods of Difference GMM and System GMM. We have also run regressions considering fixed and random effects, whose statistical quality was considered below the one provided by Difference GMM and System GMM; these results are available under request. Therefore, we estimated the system of Equations (1) and (2):

$$Investment_{it} = \alpha + \delta Investment_{it-1} + \theta Innovation_{it} + \beta' X_{it} + \eta_i + \gamma_t + \varepsilon_{it}; \quad (1)$$

$$u_i = \eta_i + \gamma_t + \varepsilon_{it}, \quad (2)$$

for $i = 1,\ldots, N$ and $t = 1,\ldots, T$.

Table 3 presents the results of the estimates considering eight alternative methods according to common specifications in literature (Roodman, 2009; Mourao & Stawska, 2022). The various estimation methods provide converging results. European regions characterized by high values in the composite indicator of innovation tend to register significantly higher values of gross fixed capital formation approximately 3 to 4 years after the reference value for the innovation indicator. Several implications of these results emerge. The first implication concerns the characteristic that innovation, in its multiple aspects and components, is a cause for the investment spent in the regions. As investment is an unavoidable dimension in generating income and jobs, our results prove that it is driven by innovation improvements. This improvement in innovation takes approximately 3 to 4 years to be reflected in the promotion of investment (which favours the causality direction assumed along Equations (1)–(2) (for an enlarged debate of the possible bidirectional causality between investment and innovation, see Spescha & Woerter, 2021). Second, our work subscribes to the standard of high first-order autocorrelation of the investment presented in the works of Caballero and Engel (1999). This pattern is a demanding challenge for the most impoverished regions in terms of investment; however, combined with the results we achieved for the regional innovation score, the same regions that are impoverished in terms of investment have more to gain by betting more on the dimensions of innovation. These dimensions of innovation will tend to capitalize significantly on investments in a short period. Third, most estimates recognize that the estimated coefficients for the first two "lags" of the regional innovation score do not have

Table 3. The effect of European regional innovation on Investment (Dependent variable: logarithmic value of absolute Gross Formation of Fixed Capital, at constant prices)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	P.OLS	Fixed Eff. OLS	Differences GMM (M1)	Differences GMM (M2)	Differences GMM (Endog,)	System GMM (1)	System GMM (2) (Endog)	System GMM (2) (Endog & collapse)
Investment (t-1)	0.981*** (0.005)	0.867*** (0.005)	0.993*** (0.032)	0.992*** (0.041)	0.991*** (0.062)	0.898*** (0.042)	0.990*** (0.089)	0.991*** (0.008)
RIS(t-1)	0.979 (1.362)	0.711 (1.101)	0.342 (1.305)	0.331 (0.328)	0.372 (0.388)	0.187 (0.309)	0.221*** (0.007)	0.234*** (0.073)
RIS(t-2)	0.934 (2.562)	0.827 (2.331)	0.834 (1.198)	0.843 (0.572)	0.543 (0.367)	0.642 (0.872)	0.834 (0.802)	0.821 (0.824)
RIS(t-3)	1.669 (2.471)	0.434 (2.033)	0.533*** (0.037)	0.532*** (0.031)	0.532*** (0.117)	0.632 (0.723)	0.733*** (0.211)	0.634** (0.282)
RIS(t-4)	0.717*** (0.159)	0.734*** (0.301)	0.434*** (0.087)	0.312*** (0.112)	0.566*** (0.116)	0.502*** (0.002)	0.492*** (0.112)	0.730*** (0.238)
RIS(t-5)	0.292*** (0.022)	0.334*** (0.016)	0.334*** (0.142)	0.372*** (0.021)	0.334 (0.235)	0.501*** (0.023)	0.488* (0.242)	0.438 (0.334)
RIS(t-6)	0.552** (0.278)	0.443** (0.193)	0.642*** (0.210)	0.442** (0.197)	0.334* (0.152)	0.334** (0.112)	0.402** (0.201)	0.332 (0.254)
RIS(t-7)	0.383** (0.171)	0.433** (0.152)	0.442*** (0.201)	0.334* (0.134)	0.234** (0.111)	0.217** (0.102)	0.201 (0.281)	0.334*** (0.172)
RIS(t-8)	0.302*** (0.072)	0.334*** (0.032)	0.311*** (0.007)	0.213*** (0.052)	0.177** (0.065)	0.201*** (0.007)	0.172** (0.067)	0.187 (0.192)
Controls	No	No	No	No	No	No	No	Yes
Instruments			38	38	52	63	362	39
Hansen J-test			0.260	0.271	0.272	0.338	0.289	0.320

End of Table 3

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	P.OLS	Fixed Eff. OLS	Differences GMM (M1)	Differences GMM (M2)	Differences GMM (Endog,)	System GMM (1)	System GMM (2) (Endog)	System GMM (2) (Endog & collapse)
Diff-in-Hansen test			0.377	0.166	0.148	0.198	0.251	0.291
AR(1)			0.001	0.001	0.001	0.001	0.001	0.001
AR(2)			0.142	0.212	0.432	0.322	0.355	0.268
Observations	2911	2911	2911	2911	3064	3064	3064	3064
NUTS2	154	154	154	154	154	154	154	154

Notes: Significance levels: *, 10%; **, 5%; ***, 1%. Standard errors between parentheses. Additional details about errors and clustered errors available under request and following Mourao and Stawska (2022).

Table 4. The effect of European regional innovation on the Investment (Dependent variable: ratio between the value of regional absolute Gross Formation of Fixed Capital and regional GDP, at constant prices)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	P.OLS	Fixed Eff. OLS	Differences GMM (M1)	Differences GMM (M2)	Differences GMM (Endog,)	System GMM (1)	System GMM (2) (Endog)	System GMM (2) (Endog & collapse)
Investment, % GDP (t-1)	0.892*** (0.022)	0.862*** (0.038)	0.748*** (0.029)	0.605*** (0.050)	0.662*** (0.082)	0.707*** (0.061)	0.759*** (0.052)	0.801*** (0.060)
RIS(t-1)	0.853* (0.354)	0.813* (0.322)	0.782 (0.554)	0.535 (0.535)	0.582 (0.770)	0.682 (0.661)	0.735 (0.534)	0.711 (0.622)
RIS(t-2)	0.134* (0.056)	0.146* (0.068)	0.448* (0.210)	0.934* (0.532)	0.892* (0.472)	0.882* (0.401)	0.148*** (0.005)	0.133*** (0.013)
RIS(t-3)	0.144** (0.535)	0.162*** (0.438)	0.500** (0.221)	0.934** (0.434)	0.918** (0.410)	0.907** (0.438)	0.143** (0.051)	0.177** (0.069)
RIS(t-4)	0.141*** (0.048)	0.153*** (0.038)	0.129*** (0.044)	0.134*** (0.038)	0.182*** (0.045)	0.177*** (0.077)	0.165** (0.049)	0.181** (0.062)
RIS(t-5)	0.335 (0.532)	0.371 (0.628)	0.148** (0.057)	0.135** (0.052)	0.164** (0.054)	0.152** (0.055)	0.146*** (0.057)	0.183*** (0.054)
RIS(t-6)	0.135 (0.778)	0.143 (0.829)	0.443 (0.434)	0.558 (0.482)	0.600 (0.572)	0.591 (0.581)	0.856 (0.572)	0.921 (0.703)
RIS(t-7)	0.135 (0.632)	0.155 (0.722)	0.168 (0.232)	0.172 (0.188)	0342 (0.702)	0.439 (0.809)	0.535 (0.989)	0.630 (0.742)
RIS(t-8)	0.635 (0.542)	0.552 (0.449)	0.199 (0.532	0.178 (0.322)	0.201 (0.399)	0.331 (0.404)	0.435 (0.450)	0.502 (0.440)
Controls	No	No	No	No	No	No	No	Yes
Instruments			168	168	172	172	191	159
Hansen J-test			0.408	0.7891	0.772	0.561	0.980	0.901

End of Table 4

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	P.OLS	Fixed Eff. OLS	Differences GMM (M1)	Differences GMM (M2)	Differences GMM (Endog,)	System GMM (1)	System GMM (2) (Endog)	System GMM (2) (Endog & collapse)
Diff-in-Hansen test			0.197	0.114	0.632	0.723	0.971	0.962
AR(1)			0.001	0.001	0.001	0.001	0.001	0.001
AR(2)			0.142	0.517	0.302	0.308	0.655	0.502
Observations	2911	2911	2911	2911	3064	3064	3064	3064
NUTS2	154	154	154	154	154	154	154	154

Notes: Significance levels: *, 10%; **, 5%; ***, 1%. Standard errors between parentheses. Additional details about errors and clustered errors available under request and following Mourao and Stawska (2022).

a statistically significant effect on investment in the region. This result is relevant because it confirms the timeliness of the return generated by policies on innovation; thus, policies on regional innovation are policies that force us to wait for effective returns, posing significant challenges in the management of these returns to local investors, politicians, and companies.

Next, new estimates considering the proportion of investment expenditure in the production value of each European region as a dependent variable were performed. Similarly, the results shown in Table 4 prove that the estimated coefficient associated with the dynamics of the dependent variable is positive and statistically significant. This coefficient varies between 0.898 and 0.993. On the one hand, estimates for the first lag in the relationship between investment and regional output reveal how any shock requires a relatively short period of absorption, converging with traditional readings on investment cycles for most developed economies. However, the various results presented in the columns of Table 4 allow for a different reading than the results in Table 3. In particular, we find that it is now the most recent Ris variable value that has a positive and statistically significant influence on the proportion of investment in production in each European region. Taking into account, for example, the estimated coefficient (0.133 ***) for the second lag of the Ris variable in column (8) of Table 4, we are led to claim that an increase of one unit in the European regional innovation indicator allows the region's proportional investment in production to increase by approximately 0.13 percentage points. For estimations (3)–(8), the exhibited values support the validity of the instrument. Both the Hansen J test and the Diff-in-Hansen test allow simultaneous acceptance of the instrument's validity and refute the issue of instrument proliferation bias (Bruno et al., 2017) when the singular two-step estimated covariance matrix of moments leads to the p-values of Hansen statistics collapsing into unity.

Regional innovation notably influences total future investment (recorded mainly 5 to 8 years later) in each space observed. Reconciling the results in Table 3 and Table 4, our findings are in line with the argument of Archibugi et al. (2013), i.e., that innovation tends to ensure that regions with stagnant or falling production will begin investing (which increases the ratio of investment in the regional product), generating a longer-term effect on global investment, which is more significantly multiplied in the periods ahead.

3.2. Exploring the spillover effects of regional innovation across European regions

Recently developed models allow us to investigate the spatial effects considering direct impacts (from each explicative variable on the dependent variable of a spatial unit) and indirect impacts (from each explicative variable of the neighbouring spatial units on the dependent variable of a spatial unit).

Next, we discuss the estimations of a dynamic spatial Durbin model (DSDM):

$$Investment_{it} = \alpha + \delta Investment_{it-1} + \rho W Investment_{it} + \eta W Investment_{it-1} + \beta' X_{it} + W X_{it} \theta + \varepsilon_{it}, \quad (3)$$

where $i = 1,\ldots, N$ and $t = 1,\ldots, T$. $Investment_{it}$ identifies the vector that has observations for the investment level for a European region $i = 1,\ldots, N$ at time $t = 1,\ldots, T$. X_{it} and WX_{it} are exogenous dimension matrices (for the Regional innovation score of that region and the Regional innovation score of the surrounding NUTS2 region, respectively). β is a vector containing the parameters related to the exogenous dimensions observed in a given spatial unit. θ is another estimated vector of parameters regarding the exogenous dimensions of the neighbouring spaces. The response parameter of the neighbours' value of the investment is given by τ. is The space-time parameter and the spatial autoregressive coefficients are, respectively, η and. ρ. *W* is an NxN matrix of constants. α is a vector with regional time-invariant fixed effects. ε has the estimated disturbances (with the conventional assumptions of zero mean and finite variance σ^2).

To choose the proper spatial weight matrices, we constructed a table of posterior model probabilities, following LeSage and Pace (2014). The values we obtained favoured the option of a first-order contiguity matrix.

As a first step, we run a global spatial autocorrelation test to analyze the spatial autocorrelation of the Gross formation of fixed capital across European regions. For this analysis, we refer to Global Moran's I (Table 5). Table 5 shows that the Moran I values are positive and statistically significant between 2000 and 2020. Therefore, we can claim that investment from a European regional perspective can be characterized by a positive spatial autocorrelation, meaning that it is unlikely that a European region has significant values of investment if it is not surrounded by regions that also have significant investment values. Throughout the period, Moran's I values show a stable pattern, indicating that spatial autocorrelation has not changed particularly in the period.

Table 5. Global Moran I test (logarithmized value of absolute Gross Formation of Fixed Capital, at constant prices)

Year	Moran I	Year (cont.)	Moran I	Year (cont.)	Moran I
2000	0.689***	2007	0.635***	2014	0.602***
2001	0.681***	2008	0.627***	2015	0.612***
2002	0.610***	2009	0.618***	2016	0.622***
2003	0.624***	2010	0.605***	2017	0.634***
2004	0.619***	2011	0.608***	2018	0.615***
2005	0.611***	2012	0.629***	2019	0.632***
2006	0.612***	2013	0.617***	2020	0.636***

Note: Legend ****, statistically significant at 1%.

Following the established literature in the field of spatial panel econometric models (Elhorst, 2010), we analyzed general specifications of spatial econometric models for the logarithmic value of investment observed in each European region (Table 6).

Following Eilers (2016), in a first step for assessing the quality of the estimations, we observed the statistical significance of Lagrange multipliers (LM) and robust-LM. Following Anselin's criteria (2005, pp. 198–200), we have a suggestion to favour the estimation of panel lag models. Table 6 also details these supporting statistics (LM and R-LM).

Then, we observed which fixed effects (space fixed effects or time-fixed effects) improved the quality of the models. For this purpose, we refer to a joint LR test. This test (see Table 6) suggests the preference for space-fixed effects.

Table 6. Results for the LM & joint LR tests (logarithmized value of absolute gross formation of fixed capital, at constant prices)

Variable	Panel OLS	Space Fixed Eff	Time Fixed Eff	Space-time Fixed Eff
Investment, (t-1)	0.951*** (0.055)	0.817*** (0.015)	0.901*** (0.003)	0.911*** (0.004)
RIS(t-1)	0.959 (1.365)	0.721 (1.121)	0.902 (1.472)	0.812 (1.821)
RIS(t-2)	0.944 (2.542)	0.823 (2.333)	0.913 (3.211)	0.932 (2.781)
RIS(t-3)	1.664 (2.474)	0.444 (2.433)	0.642 (2.710)	0.766 (2.512)
RIS(t-4)	0.716*** (0.169)	0.735*** (0.351)	0.729*** (0.201)	0.743*** (0.252)
RIS(t-5)	0.297*** (0.072)	0.336*** (0.016)	0.301*** (0.018)	0.312*** (0.027)
RIS(t-6)	0.558** (0.288)	0.447** (0.197)	0.488** (0.258)	0.503** (0.261)
RIS(t-7)	0.389** (0.179)	0.438** (0.158)	0.414** (0.199)	0.401** (0.198)
RIS(t-8)	0.300*** (0.070)	0.339*** (0.092)	0.391*** (0.062)	0.382*** (0.062)
R2	0.954	0.904	0.914	0.935
Corrected R2	0.902	0.882	0.881	0.891
Sigma^2	0.032	0.019	0.011	0.025
Durbin-Watson	1.823	2.191	2.005	1.923
LM Panel lag	4.612 (0.021)	0.466 (0.038)	67.991 (0.032)	0.832 (0.823)
R-LM Panel lag	7.551 (0.052)	0.420 (0.721)	67.812 (0.052)	0.727 (0.863)
LM Panel error	6.602 (0.088)	0.710 (0.888)	65.102 (0.066)	0.778 (0.852)
R-LM Panel error	8.521 (0.981)	0.671 (0.320)	76.902 (0.102)	0.823 (0.867)
LR ratio joint test	Fixed	Stats	DOF	p-value
	Space	572.992	148	0.000
	Time	5.921	23	0.877

Notes: standard errors in parentheses. For the LM tests (LM Panel lag, R-LM Panel lag, LM Panel error, R-LM Panel error), p-values are in brackets. DOF: degree of freedom. Significance level: *, 10%; **, 5%; ***. 1%.

Table 7 shows the result for the estimation of a spatial Durbin panel model considering the variable "logarithmized value of absolute gross formation of fixed capital, at constant prices" as the dependent variable. Results shown by Table 7 highlight the following three aspects: the confirmation of positive spatial autocorrelation, the promoting effect of investment expenditures arising from regional innovation, and the importance of innovation for the growth of investment expenditures in the entire area surrounding the innovative European region.

Table 7. Results of the spatial Durbin panel model (logarithmized value of the absolute Gross Formation of Fixed Capital, at constant prices)

Variable (*X*)	*X*	*W*×*X*	Long Run – Direct	Long Run – Indirect	Total
Investment (*t* – 1)	0.061*** (0.02)	–0.088*** (0.008)	0.063*** (0.026)	0.014** (0.005)	0.077*** (0.006)
RIS (*t* – 1)	0.104*** (0.021)	–0.021*** (0.007)	0.100*** (0.021)	0.001 (0.337)	0.123* (0.063)
Rho	1.659*** (0.023)				
R^2	0.362				
$Sigma^2$	0.033*** (0.007)				
Theta	–4.775*** (0.551)				
Log-likelihood	132.9179				

First, we see how our estimate reached a Rho value of 1.659, which was positive and statistically significant. This value of Rho shows the importance of high and significant values in the allocation of investment expenses in the area surrounding a European region, so that the same European region tends to present higher investment values as well. In a practical sense, this means that the distribution of investments across European regions tends to be concentrated on some well-defined areas; conversely, the existence of a region with significant amounts of investment expenses is unlikely if it is not surrounded by other European NUTS2 regions with robust investment values. This result follows the evidence reported by the pioneering works of Scott (1988) and Fagerberg (1987).

Second, the results shown by Table 7 align with those in Table 3. There is a significant effect of regional innovation on the levels of economic investment reported in each NUTS2 region. This effect is especially noticeable in the long run and as a direct effect. It should be remembered that, in accordance with LeSage and Pace (2004), the direct effect can be interpreted as the effect of "the impact of changing an explanatory variable on the investment level of each spatial unit itself". The long-term effect follows the interpretations of LeSage and Pace (2014); it designates the expected effect considering the model's constraints and considering a steady-state equilibrium in the estimated parameters.

Finally, we observe from Table 7, that there is a substitutability relationship between the effects arising from innovation on the investment of neighbouring relationships in the short term, although the same relationship becomes a complementary relationship in the long term. The estimated coefficient for $W \times Investment_{t-1}$ indicates that if investment increases in a period in a neighbouring NUTS2 region, it tends to subtract the expected value of investment spent in the following period in a given region. Thus, our evidence yields the conclusions of Bottazzi and Peri (2003) and Moreno et al. (2005).

These conclusions suggest that there is "spatial competition" in attracting investment, leading neighbouring areas to behave like competitors to attract investment. As a corollary, if the investment increases in a space, the remainder available for neighbouring spaces tends to be scarce. A similar conclusion is reached for the estimated coefficient for $W * Ris_{t-1}$, proving that, in the short term, increasing the level of innovation in a region tends to subtract investment from the surrounding spaces. However, in the long run (see the estimated coefficient for $W \times Investment_{t-1}$), neighbouring spaces tend to generate investment for the surrounding spaces, generating spillover effects in line with those found by Bottazzi and Peri (2003).

Therefore, it was demonstrated that, in the short term, European regions tend to behave as competitors for investment fixing, but in the long run innovation has the potential to generate spillover effects on the neighbours of the region, which is consistent with Rodríguez-Pose and Crescenzi (2008). We list this result as strategic behaviour, typical of the phenomenon studied as a "coopetition" (Blonigen & Kolpin, 2007; Ibarra, 2018) by which competing agents gain in the long term due to strategic behaviours.

As we obtain estimates for the variable Logarithmized value of the absolute gross formation of fixed capital, at constant prices, we proceed to analyze the global Moran I and we will study the LM and joint LR tests for the dependent variable Ratio between the value of the absolute regional formation of fixed capital and regional GDP, at constant prices. Tables 8 and 9 reflect this effort considering the percentage of investment in production in each European region as a relevant variable.

Table 8. Global Moran I test (ratio between the value of regional absolute Gross Formation of Fixed Capital and regional GDP, at constant prices)

Year	Moran I	Year (cont.)	Moran I	Year (cont.)	Moran I
2000	0.302***	2007	0.338***	2014	0.309***
2001	0.311***	2008	0.327***	2015	0.312***
2002	0.310***	2009	0.318***	2016	0.322***
2003	0.324***	2010	0.304***	2017	0.334***
2004	0.315***	2011	0.318***	2018	0.315***
2005	0.316***	2012	0.327***	2019	0.337***
2006	0.317***	2013	0.318***	2020	0.337***

Note: Legend ****, statistically significant at 1%

Table 9. Results for the joint LM & joint LR tests (ratio between the value of the regional absolute gross formation of fixed capital and regional GDP, at constant prices)

Variable	Panel OLS	Space Fixed Eff	Time Fixed Eff	Space-time Fixed Eff
Investment (t-1)	0.886*** (0.022)	0.862*** (0.038)	0.839*** (0.049)	0.810*** (0.041)
RIS(t-1)	0.814* (0.354)	0.813* (0.322)	0.809* (0.321)	0.807* (0.308)
RIS(t-2)	0.124* (0.046)	0.146* (0.068)	0.148* (0.069)	0.147* (0.068)
RIS(t-3)	0.145** (0.534)	0.162*** (0.438)	0.152*** (0.551)	0.158*** (0.548)

End of Table 9

Variable	Panel OLS	Space Fixed Eff	Time Fixed Eff	Space-time Fixed Eff
RIS(t-4)	0.142*** (0.047)	0.153*** (0.038)	0.158*** (0.043)	0.155*** (0.044)
RIS(t-5)	0.338 (0.582)	0.371 (0.628)	0.342 (0.572)	0.348 (0.522)
RIS(t-6)	0.136 (0.777)	0.143 (0.829)	0.140 (0.799)	0.142 (0.801)
RIS(t-7)	0.138 (0.638)	0.155 (0.722)	0.140 (0.640)	0.142 (0.659)
RIS(t-8)	0.636 (0.549)	0.552 (0.449)	0.589 (0.503)	0.572 (0.504)
R2	0.932	0.915	0.904	0.899
Corrected R2	0.911	0.900	0.881	0.892
Sigma^2	0.002	0.003	0.012	0.005
Durbin-Watson	1.845	1.998	2.109	2.002
LM Panel lag	4.142 (0.025)	0.467 (0.035)	59.562 (0.033)	0.078 (0.002)
R-LM Panel lag	7.671 (0.057)	0.422 (0.723)	58.098 (0.067)	0.088 (0.003)
LM Panel error	6.722 (0.089)	0.756 (0.889)	57.065 (0.033)	0.099 (0.004)
R-LM Panel error	6.544 (0.941)	0.641 (0.324)	56.822 (0.102)	0.083 (0.007)
LR ratio joint test	Fixed	Stats	DOF	p-value
	Space	574.115	145	0.000
	Time	7.881	21	0.917

Notes: standard errors in parentheses. For the LM tests (LM Panel lag, R-LM Panel lag, LM Panel error, R-LM Panel error), p-values are in brackets. DOF: degree of freedom. Significance level: *, 10%; **, 5%; ***. 1%.

From Tables 8 and 9 we note the preferences for space-fixed effects considering the joint LR test. We now estimate a spatial Durbin panel model considering the ratio between the value of the absolute regional gross formation of fixed capital and the regional GDP, at constant prices as the dependent variable. We have established three specific comments related to Table 10. The first is related to the temporal autocorrelation of the dependent variable (in line with our comments after Table 4). Thus, if in scenarios of economic stability, the ratio of investment to product for each European region shows a small variation, the estimated high-end value for the first lag (0.901) suggests that sudden changes will also be characterized by a rapid adjustment in the values of this ratio for regional investment.

Second, as reported in Table 10, we observed a significant spatial competition effect from the impact of investment expenses. The estimated coefficient for W * Investment shows that if the ratio between investment and regional product increases in a European area, then there is a downward movement in the value observed by this indicator in the surrounding area. This result converges with that achieved for Table 7. For its part, still in this second line of discussion, we highlight the contribution of direct effects on the part of Investment, still

Table 10. Results of the spatial Durbin panel model (ratio between the value of the regional absolute gross formation of fixed capital and the regional GDP, at constant prices)

Variable (X)	*X*	*W*×*X*	Long Run – Direct	Long Run – Indirect	Total
Investment, % GDP (*t* – 1)	0.901*** (0.078)	–1.406*** (0.037)	0.897*** (0.008)	–0.039*** (0.014)	0.858*** (0.177)
RIS (*t* – 1)	0.252*** (0.036)	0.728 (1.022)	0.118** (0.052)	0.131 (0.297)	0.253* (0.123)
Rho	1.555*** (0.027)				
R^2	0.452				
$Sigma^2$	0.005*** (0.001)				
Theta	–1.421*** (0.072)				
Log-likelihood	4373.504				

showing a marked constraint on European investment to generate regional spillovers. This is in line with the criticism of Moreno et al. (2005) and Bottazzi and Peri (2003).

Third, we highlight the stimulus effect by increasing Regional innovation score. Once again, European innovation was shown to stimulate higher values in indicators related to the investment applied in each NUTS2 region, also convergent with that previously achieved in Tables 3, 4, and 7. However, when we consider the investment ratio in the regional product (Table 10), we find that the direct effects of regional innovation are responsible for the total spatial effects, which leads us to emphasize the importance of innovation as an investment factor at the level of European NUTS2 regions.

Conclusions

The competitiveness of economic agents and their spaces, particularly their regions, has highlighted the importance of innovation processes in sustaining competitive standards. In turn, investment dynamics has long been highlighted as promoters of economic growth. Economic agents spend investment expenses to improve production processes, the living conditions of households, and their strategic position as agents of long-term socioeconomic development.

In this context, this work developed a detailed analysis of the relevance of innovation for investments located in European regions. Using estimation methods with panel data and exploring the effects of spatial autocorrelation, the results achieved allow for challenging readings. We find that there is spatial autocorrelation at the NUTS2 level, but in the sense of spatial competition in terms of the distribution of investments and of the diffusion of short-term innovation gains. However, in convergence with classical theory, investment patterns were characterized by significant temporal autocorrelation, showing that shocks to investment in regions tend to be quickly absorbed, which requires careful management of investment cycles.

Thus, in our view, these results have three implications in terms of policy making and in the reorganization of the innovation effort in Europe. First, it is important to leverage the short-term spillover capacity of European regional innovation. Therefore, we suggest that the innovation gains of a region must be more evident for neighbouring regions in the short term. The presence of spatial competition in the distribution of investment, if not managed, introduces the second implication of our results. We understand the need to avoid the accumulation/concentration of investment in certain NUTS2 regions in order to minimize the impoverishment of neighbouring regions and to reduce costs in the labour markets as well as the forced mobility of affected groups. Finally, as a third implication, we need a greater capacity for innovation at the level of European regions to generate more significant incentives for investment in the same spaces.

The limitations of this work are also opportunities for further research. We identify four limitations at the moment: the observed natures of investment and innovation, the aggregation process of the components of the "Regional Innovation Score", the concentration of our observations in Europe, and the differences ways of accounting for Research and Development expenses in European accounts.

In terms of future work, we designed four emerging lines. The first refers to the challenge of exploring other dimensions, both investment and innovation, in this discussion. We think, above all, about social innovation and social investment. The second line relates to the possibility of exploring each of the components of our "Regional Innovation Score" indicator as a unique explanatory variable of the investment's three aggregates (besides Gross Fixed Capital Formation, discussed here, we also focus on Stock Variation and Amortizations). The third proposal for the emergence of works relates to the possibility of observing the presence of these relations between innovation and investment for other economic spaces (namely, North America, Southeast Asia or Latin America) to deepen the role of institutions in these spaces to explain the relationships between investment and innovation. For a fourth challenge, we recognize that the way R&D expenditures are accounted for by ESA (European System of National and Regional Accounts) changed over time, during the period under analysis. In particular, in 2010, ESA started considering R&D expenditures as business sector investment in intangible assets, which are thus a component of gross fixed capital. Since R&D expenditure is also a component of the RIS Index, a differential analysis for the two periods (2000–2010, 2010–2020) is also recommended, at least as a further challenge.

Disclosure statement

The authors declare no conflict of interest.

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