R&D, spillovers, innovation systems and the genesis of regional growth in Europe

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Abstract: Research on the impact of innovation on regional economic performance in Europe has fundamentally followed three approaches: a) the analysis of the link between investment in R&D, patents, and economic growth; b) the study of the existence and efficiency of regional innovation systems; and c) the examination of geographical diffusion of regional knowledge spillovers. These complementary approaches have, however, rarely been combined. Important operational and methodological barriers have thwarted any potential cross-fertilization. In this paper, we try to fill this gap in the literature by combining in one model R&D, spillovers, and innovation systems approaches. A multiple regression analysis approach is conducted for all regions of the EU-25, including measures of R&D investment, proxies for regional innovation systems, and knowledge and socio-economic spillovers. This approach allows us to discriminate between the influence of internal factors and external knowledge and institutional flows on regional economic growth. The empirical results highlight how the interaction between local and external research with local and external socio-economic and institutional conditions determines the potential of every region in order to maximise its innovation capacity. They also indicate the importance of proximity for the transmission of economically productive knowledge, as spillovers show strong distance decay effects.

JEL Classification:

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1. **Introduction**

The capacity to innovate and to assimilate innovation have regularly been considered as two of the key factors behind the economic dynamism of any territory (Feldman and Florida, 1994; Audretsch and Feldman, 1996; Cantwell and Iammarino, 1998; Furman, Porter and Stern, 2002). Yet, despite this agreement, different researchers have tried to untangle the link between research, innovation, and economic growth in very different ways. Three different approaches to this relationship predominate. The first is the so-called 'linear model' (Bush, 1945; Maclaurin, 1953), whereby basic research leads to applied research and to inventions, that are then transformed into innovations, which, in turn, lead to greater growth. Empirically, this type of analysis focuses fundamentally on the link between R&D and patents, in the first instance, followed by that between patents and growth. These types of analysis are fundamentally conducted by 'mainstream economists' and, despite criticisms (e.g. Rosenberg, 1994), the approach remains popular with academics and policy makers. A second group can be classified under the appellations of 'systems of innovation' (Lundvall, 1992) or 'learning region' (Morgan, 1997) approaches. These approaches, associated with evolutionary economics (Dosi et al, 1988; Freeman, 1994), concentrate on the study of territorially-embedded institutional networks that favour or deter the generation of innovation. The capacity of these networks to act as catalysts for innovation depends, in turn, on the combination of social and structural conditions in every territorial, the so-called 'social filter' (Rodríguez-Pose, 1999). These approaches them to be fundamentally qualitative and mainly conducted by geographers, evolutionary economists, and some economic sociologists. Finally, there is a large group of scholars who has mainly concentrated on the diffusion and assimilation of innovation (Jaffe, 1986; Audretsch and Feldman, 1996; Cantwell and

Iammarino 2003; Sonn and Storper 2005). This knowledge spillovers approach has been generally adopted by economists and geographers, using both quantitative and qualitative methods.

Although such a wide variety of approaches contributes significantly to improve our understanding of the process of innovation and of the linkages between innovation and economic development, the theoretical mechanisms developed by these different, but nevertheless, complementary strands of literature have rarely been combined. There has been little cross-fertilisation. Major operational and methodological barriers have hitherto kept any potential interaction to a bare minimum. The main reasons for this lack of interaction are related to the different disciplinary backgrounds of the researchers working on innovation, to the different methods used by different approaches, and to the difficulties in operationalising some of the concepts used by different strands of the literature on the topic.

This paper represents an attempt to try to bridge this gap in the literature by combining in one model linear, innovation systems, and spillover approaches. The aim is to show how factors which have been at the centre of these research strands interact and account for a significant part of differential regional growth performance of the regions of the enlarged EU after 1995. An additional objective is to shed new light on the role of geographical distance in the process of innovation by supporting the idea of there being a "continuing tension between two opposing forces" (Storper and Venables 2004 p.367): the increasingly homogeneous availability of standard 'codified' knowledge and the spatial boundness of 'tacit' knowledge and contextual factors. Such tension is an important force behind the present economic geography of

European regions and which is further accentuated by the underlying socio-economic differences.

In order to achieve this aim, we ground our approach on a series of fundamental theoretical mechanisms which make knowledge and its transmission an important explanation for differential growth performance. First, that, as highlighted by the linear model of innovation, local innovative activities are crucial for the 'production' of new knowledge and the economic exploitation of existing knowledge, given the presence of a minimum threshold of local innovation capabilities (as put forward by evolutionary economics and neo-Schumpeterian strands). Such activities are not geographically evenly distributed and thus become a localised source of competitive advantage for some areas rather than others. Second, that information is not automatically equivalent to economically-useful knowledge (Sonn and Storper, 2005). A successful process of innovation depends on "localised structural and institutional factors that shape the innovative capacity of specific geographical contexts" (Iammarino 2005, p.499), as indicated by the systems of innovation (Lundvall 2001), regional systems of innovation (Cooke et al. 1997) and learning regions (Morgan 2004; Gregersen and Johnson 1996) approaches. And third, that technological improvements in 'communication infrastructures' have not affected all kinds of information in the same way. While 'codified information' can be transmitted over increasingly large distances, 'tacit' knowledge is geographically bound thus determining the increasing concentration of innovation and the geographical boundedness of knowledge spillovers (Audretsch and Feldman 2004; Cantwell and Iammarino 2003; Sonn and Storper 2005).

The paper is organised into four further sections. In the first section the theoretical framework of the analysis is outlined. The second part introduces the empirical model and provides its theoretical justification. In the third section the empirical results are discussed. The final section concludes with some economic policy implications.

2. R&D, innovation systems and knowledge spillovers

From a pure neoclassical perspective, factors such as the percentage of investment in research and development (R&D) or where the actual research is conducted matter little. The traditional neoclassical view of knowledge as a truly public good (non rivalrous and non excludable) available everywhere and to everybody simultaneously implies that innovation flows frictionless from producers to a full set of intended and unintended beneficiaries (as 'manna from heaven'), contributing to generate a long-term process of convergence between countries and regions (Solow 1957, Borts and Stein 1964). However, this view of innovation as a factor that could be overlooked in the genesis of economic development is now firmly on the retreat. It is not just that innovation is considered as the key source of progress (Fagerberg 1994), but also that technology and innovation have become regarded as essential instruments in any development policy (Trajtenberg 1990). Differences in innovation capacity and potential become thus, from an 'endogenous growth' perspective (e.g. Grossman and Helpman 1991), one of the basic explanations for persistent differences in wealth and economic performance. By bringing innovation to the fore, it is often assumed that greater investment in basic R&D will lead to greater applied research and to an increase in the number of inventions, that when introduced in the production chain become growth-enhancing innovations. This linear perception of innovation process has localised R&D investment has the key factor behind technological progress and, eventually, economic growth. The implications of this approach are that the higher investment in R&D, the higher innovative capacity, and the higher the economic growth. Despite being much derided (e.g. Fagerberg 1988; Verspagen 1991; Rosenberg, 1994; Morgan, 1997), the linear model remains popular with academics and policy makers because of its simplicity and powerful explanatory capacity: nations and regions to invest more in R&D, generally tend to innovate more, and often grow faster. But by focusing on local R&D, the linear model completely disregards key factors about how innovation is actually generated. These factors are related to the context in which innovation takes place and to the potential for territories to assimilate innovation being produced elsewhere.

Regarding the context, it is now widely accepted that the innovation potential of any territory is embedded in the conditions of that territory. Hence innovation is a territorially-embedded process and cannot be fully understood independently of the social and institutional conditions of every space (Lundvall, 1992; Asheim, 1999). The 'territorially-embedded' factors influencing the process of innovation have thus become the focus for differentiated theoretical perspectives: from innovative milieux (Camagni, 1995) and industrial districts (Becattini, 1987) to learning regions (Morgan, 1997) and systems of innovation (Cooke et al., 1997; Cooke, 1998). These approaches have brought with them to powerful insights in order to improve our understanding of how and under which conditions the process of innovation takes place. Some of the most relevant findings related to these approaches are the relevance of proximity, local synergy, and interaction (Camagni, 1995, p.317) and the importance of ‘inter-organization networks, financial and legal institutions, technical agencies and research infrastructures, education and training systems, governance structures, innovation policies’ (Iammarino, 2005, p.499) in shaping innovation. The explanatory capacity of such approaches is, however, somewhat constrained by the problems of operationalising in a relatively homogenous way across territories the territorially-embedded networks, social economic structures, and institutions that are at the heart of these approaches. By nature the systemic interactions between (local) actors are intrinsically unique and thus hard to measure and compare across different systems. A potential solution to this problem is the ‘evolutionary integrated view of the regional systems of innovation’ (Iammarino, 2005). By comparing national (macro-level) and regional (micro-level) systems of innovation, a meso-level emerges characterised by “local structural regularities from past knowledge accumulation and learning” (Iammarino, 2005, p. 503). This implies the existence of a series of “external conditions in which externalised learning and innovation occur” (Cooke 1997, p.485) which can be identified across innovation systems and on which innovation strategies can be based. These conditions act as “conditions that render some courses of action easier than others” (Morgan 2004) or ‘social filters’ or, in other words, the unique combination “of innovative and conservative components, that is, elements that favour or deter the development of successful regional innovation systems” (Rodríguez-Pose, 1999, p. 82) in every space.

Finally territories can rely not just on their internal capacity to produce innovation either through direct inputs in the research process or through the creation of innovation prone systems in the local environment, but also on their capacity to attract and assimilate innovation produced elsewhere. At the micro-level, innovative units

(R&D departments within firms, universities, research centres etc.), as well as local institutions and individuals, interact with each other and with their external environment through the networks described above. Such interactions produce the transmission of knowledge in the form of 'knowledge spillovers' (Jaffe, 1986; Acs, Audretsch and Feldman 1992) that are reaped by local actors. The origin of knowledge spillovers can be local, but they can also be generated outside the borders of the locality or region object of the analysis, as "there is no reason that knowledge should stop spilling over just because of borders, such as a city limit, state line or national boundary" (Audretsch and Feldman, 2003, p.6). If there are internal and external sources of spillovers a important questions arise. The first relate to the balance between internally generated innovation and externally transmitted knowledge and the extent to which a territory can rely on externally-generated knowledge for innovation. The second group of questions concern the local and external conditions that will maximise the diffusion of knowledge. While the final group deals with the capacity of knowledge spillovers to travel and the potential for distance decay effects. In order to address these questions we have to resort to the theoretical distinction between codifiable information and tacit knowledge. According to Leamer and Storper (2001, p. 650) codifiable information "is cheap to transfer because its underlying symbol systems can be widely disseminated through information infrastructure". Hence codifiable information can be disseminated relatively costlessly over large distances and does not suffer from strong distance dacy effects. However, all information is not completely codifiable. The presence of some specific features make, in some cases, codification impossible or too expensive. "If the information is not codifiable, merely acquiring the symbol system or having the physiscal infrastructure is not enough for the successful transmission of a message"

(Storper and Venables, 2004, p.354). Thus, in this latter case there is a need to disseminate this tacit knowledge by an intrinsically 'spatial' communication technology, among which face to face interaction is key. Face to face contacts, as discussed in Storper and Venables (2004), do not only act as a communication technology but also pursue other functions (such as generating greater trust and incentives in relationship, screening and socialising, rush and motivation) which make communication not only possible but also more effective, and ultimately ease the innovation process.

However, and in contrast with codifiable information, the process of transmission of tacit knowledge is costly and would suffer from strong distance decay effects. Face to face contacts are maximised within relatively small territories, due to a combination of proximity and the presence of common socio-institutional infrastructure and networks. The potential to reap knowledge spillovers will thus be maximised within the region. Some of this knowledge will nevertheless spill over beyond the borders of the region or locality flowing into neighbouring areas, as a consequence of the existence of different forms of inter-regional contacts. Flows of interregional knowledge are thus important as agents of innovation, but their influence is likely to wane with distance (Anselin et al. 1997; Adams and Jaffe 2002; Adams 2002), as the potential for face to face and other forms of interaction decay.

3. The Model: putting different strands together

The three strands presented above of the process of innovation relies upon three crucial factors: internal innovative efforts, socially and territorially embedded factors, and spatially-bound knowledge spillovers. Although these three factors are complementary, disciplinary and methodological barriers have frequently prevented researchers working on these fields from interacting with one another. The difficulties of operationalising some of the factors in systemic and knowledge spillover approaches, given existing statistical information, provides an additional barrier for cross-fertilisation. In this section we propose a simple model which tries to combine the key factors from these three approaches to the study of the process of innovation and of how innovation influences economic growth. The model is aimed at understanding – and, to a certain extent, discriminating between – the role of the different innovation factors proposed by different strands in order to generate economic dynamism in the regions of the EU-25 after 1995. As presented in Table 1, the model combines inputs in the innovation process (R&D expenditure) with the socio-economic local factors that make the presence of favourable regional systems of innovation more likely and controls for the wealth of European regions. These factors are considered locally, i.e. the R&D and the local conditions in the region studies, and externally, i.e. the conditions in neighbouring regions. Finally we control for the influence of national factors, such as the presence of national systems of innovations, by the introduction of a set of national dummies.

Tab.1 – Structure of the empirical model

	Internal factors	**External factors (Spillovers)**
R&D	Investment in R&D in the region	Investment in R&D in neighbouring regions
Regional systems of innovation	Conditions conducive to the establishment of a regional system of innovation	Conditions conducive to the establishment of a regional system of innovation in neighbouring regions
GDP per capita	As a proxy for initial conditions and potential	Initial conditions in neighbouring Regions

National effect	Controlled for by a set of national dummies

By developing the framework above, obtain the following model:

$$\frac{1}{J}\ln\left(\frac{Y_{i,t}}{Y_{i,t-J}}\right) = \alpha + \beta_1 \ln(y_{i,t-J}) + \beta_2 RD_{i,t-j} + \beta_3 SocFilter_{i,t-J} + \beta_4 Spillov_{i,t-j} + \beta_5 ExtSocFilter_{i,t-J} + \beta_6 ExtGDPcap_{i,t-J} + \beta_7 D + \varepsilon$$

where:

$\frac{1}{J}\ln\left(\frac{Y_{i,t}}{Y_{i,t-J}}\right)$	is the usual logarithmic transformation of the ratio of regional per capita GDP in region *i* at the two extremes of the period of analysis (t-J,t);
α	is a constant;
$\ln(y_{i,t-J})$	is the log of the GDP per capita of region *i* at the beginning of the period of analysis (t-J);
RD_{t-j}	is expenditure in R&D as a % of GDP in region *i* at time (t-J);
$SocFilter_{i,t-J}$	is a proxy for the socio-economic conditions of region *i* representing its 'social filter';
$Spillov_{i,t-j}$	is a measure of accessibility to extra-regional sources of innovation;
$ExtSocFilter_{i,t-J}$	is a measure of the 'social filter' of neighbouring regions;
$ExtGDPcap_{i,t-J}$	is a measure of the GDP per capita in neighbouring regions
D	is a set of national dummy variables;
ε	is the error term.

Initial level of GDP per capita - As customary in the literature on the relationship between innovation and growth, the initial level of the GDP per capita is introduced in the model in order to account for the region's stock of existing knowledge and of its distance to the technological frontier (Fagerberg 1988).

R&D expenditure – As highlighted earlier, the percentage of regional GDP devoted to R&D is the main measure of the economic input in order to generate innovation in each region used by proponents of the linear model of innovation. Local R&D expenditure is also frequently used as a proxy for the local capability to adapt to externally produced innovation (Cohen and Levinthal, 1990; Maurseth and Verspagen, 1999). There are, however, measurement problems associated to this variable that must be borne in mind as they may partially hide the contribution of R&D towards economic performance. First, the relevant time lag structure for the effect of R&D activities on productivity and growth is unknown and may vary significantly across sectors (Griliches 1979). Second, as pointed out by Bilbao-Osorio and Rodriguez-Pose (2004) in the case of European regions, the returns from public and private R&D investments may vary significantly. Furthermore, the fact that not all innovative activities pursued at the firm level are classified as formal 'Research and Development' may be a source of further bias in the estimations. Having acknowledged that, we assume R&D expenditure as a proxy for "the allocation of resources to research and other information-generating activities in response to perceived profit opportunities" (Grossman and Helpman 1991, p.6) in order to capture the existence of a system of incentives (in the public and the private sector) towards intentional innovative activities.

Social Filter - The multifaceted concept of 'social filter' is introduced in the analysis by means of a composite index, which combines a set of variables describing the socio-economic realm of the region. In particular, the variables which seem to be more relevant for shaping the social filter of a regional space are those related to three main domains: educational achievements (Lundvall, 1992; Malecki 1997), productive employment of human resources and demographic structure (Fagerberg et al. 1997; Rodriguez-Pose, 1999). For the first domain, the educational attainment (measured by the percentage of the population and of the labour force having completed higher education) and participation in lifelong learning programmes are used as a measure for the accumulation of skills at the local level. For the second area, the percentage of labour force employed in agriculture and long-term unemployment are included in the analysis. The reasons for choosing these two variables are related to the traditionally low productivity of agricultural employment in relationship to that of other sectors and of the use of agricultural employment, in particular in the new members of the EU, as virtually synonymous of 'hidden unemployment', and to the role of long term unemployment as an indicator of both the rigidity of the labour market and of the presence of individuals whose possibilities of being productively involved in the labour market are persistently hampered by inadequate skills (Gordon, 2001). The percentage of population aged between 15 and 24 was used as our measure of the demographic structure. It represents a proxy for the flow of new resources entering the labour force and thus of the renewal of the existing stock of knowledge and skills.

Problems of multicollinearity prevent the simultaneous inclusion of all these variables in our model. Principal Component Analysis is therefore applied to the set of variables discussed above, in order to merge them into an individual indicator able to preserve as much as possible of the variability of the initial information. The output of the Principal Component Analysis is shown in Table 2a.

[Insert Tables 2A and 2B around here]

The eigenanalysis of the correlation matrix shows that the first principal component alone is able to account for around 43% of the total variance with an eigenvalue significantly larger than 1.

Consequently, the first principal component's scores are computed from the standardised[1] value of the original variables by using the coefficients listed under PC1 in Table 2b. These coefficients emphasize the educational dimension of the social filter by assigning a large weight to the educational achievements of the population (0.576) and of the labour force (0.554) and to the participation in life long learning programmes (0.395). A negative weight is, as expected, assigned to the agricultural labour force (-0.430) and, with a smaller coefficient, to long term unemployment (-0.140). The weight of the population between 15 and 24 is much smaller (0.019) in this first principal component. This procedure provides us with a 'joint measure' for each region's social filter.

Spillovers - In models based on knowledge production functions, spillovers are assessed in terms of their contribution towards the creation of new local knowledge. In our framework, the spillovers' capability to influence regional economic performance, on top of internally-generated innovation, is also assessed. For this purpose we develop a measure of the 'accessibility' to extra-regional innovative activities which we introduce in the analysis by means of a standardised 'index of accessibility to innovation'. The index is a potential measure of the 'innovative

[1] Standardised in order to range from zero to 1

activities' (in terms of nationally weighted millions of Euros invested in R&D activities) that can be 'reached' from each region at a 'cost' which increases with distance.

Our index is based on the customary formula for accessibility indices:

$$A_i = \sum_j g(r_j) f(c_{ij})$$

Where A_i is the accessibility of region i, r_j is the activity R to be reached in region j, c_{ij} is the generalised cost of reaching region j from region I and g(·) and f(·) are 'activity' function (i.e. the activities/resources to be reached) and 'impedance' function (i.e the effort, cost/opportunity to reach the specific activity) respectively. In our index the 'activity' to be reached is R&D expenditure and the 'impedance' is the bilateral trip-time distance between region *i* and region *j*:

$$f(c_{ij}) = w_{ij} = \frac{\frac{1}{d_{ij}}}{\sum_j \frac{1}{d_{ij}}}$$

where d_{ij} is the average trip-length (in minutes) between region *i* and *j*.

We base our analysis on the travel time calculated by the IRPUD (2000) for the computation of peripherality indicators and made available by the European Commission[2]. We chose road distance, rather than straight line distance, as (in particular on a smaller scale) it gives a more realistic representation of the real 'cost' of interaction and contacts across distance. In addition the use of trip-length rather

[2] As the time distance-matrix is calculated either at the NUTS1 or at the NUTS2 level, in order to make it coherent with our data which combine different Nuts levels we relied on the NUTS distance matrix using the NUTS 2 regions with the highest population density in order to represent the corresponding NUTS1 level for Belgium, Germany, and the UK.

than kilometres allows us to take account of “different road types, national speed limits, speed constraints in urban and mountainous areas, sea journeys, border delays (…) as also congestion in urban areas” (IRPUD 2000, p.22), which significantly affect real-world interactions.

Thus, the amount of knowledge flowing from outside the region is proxied by the average magnitude of all other regions’ R&D expenditure weighted by the inverse of the bilateral time-distance. The resulting variable is then standardised by making it range from zero to one, in order to make it perfectly comparable with the social filter index.

Extra regional social filter – Following a similar procedure we calculate, for each region, the distance-weighed average of the social filter index of all the other regions in the EU. The aim of including this variable is to assess whether proximity to regions with adequate social filters and dynamic innovation systems matters, i.e. whether socio-economic and institutional spillovers have a similar role to knowledge spillovers.

GDP in neighbouring regions – Again the same weighing procedure is pursued in order to introduce the initial economic conditions (GDP per capita) of neighbouring regions. This variable accounts for the advantage of proximity to relatively ‘advanced’ regions.

4. Results of the analysis

4.1 Estimation issues and data availability

In this section we estimate the model outlined above by mean of heteroskedasticity-consistent OLS (Ordinary Least Square). In order to minimize the effect of spatial autocorrelation (i.e the lack of independence among the error terms of neighbouring observations) we include in the analysis a set national dummy variables, accounting for the 'national fixed effect' which, in turn, takes into consideration a consistent part of the similarities between neighbouring regions. Furthermore, by including spatially lagged variables in our analysis, we explicitly aim at modelling the interactions between neighbouring regions, thus minimizing their effect on the residuals. Another major problem concerns endogeneity, which we dealt with by including[3] in the model the value of the explanatory variables as a mean over the period (t-J-5) – (t-J), while the average growth rate was calculated over the period from t-J to t. In addition, in order to resolve the problem of different accounting units, explanatory variables are expressed, for each region, as a percentage of the respective GDP or population.

The empirical model was estimated for the period 1995-2003, thus allowing us to include all the EU-25 members for which regional data are available. Because of data constraints but also for reasons of homogeneity and coherence in terms of relevant institutional level, the analysis uses NUTS1 regions for Germany, Belgium, and the UK and NUTS2 for all other countries (Spain, France, Italy, the Netherlands, Greece, Austria, Portugal, Finland, Czech Republic, Hungary, Poland, and Slovakia).

Countries without a relevant regional articulation (Denmark, Ireland, Luxemburg, Estonia, Latvia, Lithuania, Slovenia, Malta, and Cyprus) were necessarily excluded

[3] In the case of the New Member States data availability has prevented us from calculating the mean of the explanatory variables over the five year period (t-T-5) forcing us to use a shorter time span. For some EU 15 countries slightly differential time spans have been used according to data availability for each variable.

from the analysis[4]. In addition, regional data on R&D expenditure are not available in the Eurostat databank for Sweden.

In our analysis EUROSTAT data (stored in the REGIO databank on which we largely relied for our empirical analysis) have been complemented with Cambridge Econometrics (CAMECON) data for GDP. Table A-1 in the appendix provides a detailed definition of the variables included in the analysis.

4.2 Innovation, spillovers and social filter

The estimation results for the empirical model outlined in the previous section are presented in Table 3. The results of different regressions are reported. In Regressions 1-3 the variables for 'social filter' and 'accessibility to external sources of innovation' are progressively introduced. In Regressions 4-9 the individual components of the social filter are introduced separately in order to discriminate among them. In Regressions 10-12 the effect of neighbouring regions endowment in terms of social filter and economic wealth is assessed.

The R^2 confirms the overall goodness-of-fit of all the regressions presented and in all cases the probability of the F-statistics lets us reject the null hypothesis that all of the regression coefficients are zero. V.I.F tests has been conducted for the variables

[4] As far as specific regions are concerned, no data are available for the French Départments d'Outre-Mer (Fr9). Uusimaa (Fi16) and Etela-Suomi (Fi17) were excluded from the analysis due to the lack of data on socio-economic variables. Etela-Suomi (Fi17) and Trentino-Alto Adige (IT31) were excluded from the analysis as they have no correspondent in the NUTS2003 classification, thus preventing us from matching data available only in the new NUTS classification. Due to the nature of the analysis, the islands (PT2 Açores, PT3 Madeira, FR9 Departments d'Outre-Mer, ES7 Canarias) and Ceuta y Melilla (ES 63) were not considered as time-distance information, necessary for the computation of spatially lagged variables, is not available.

included in all the specifications of the model excluding the presence of multicollinearity. There was no spatial autocorrelation in the residuals detected using Moran's I statistic.

[Insert Table 3 around here]

Several implications can be extracted from the results of the empirical analysis. First is that the initial level of the GDP per capita is significant in a few cases only, thus suggesting that for the period under analysis, neither regional convergence, nor divergence can be recorded. Only when social conditions are explicitly controlled for (regressions 3, 10, 11 and 12) there is evidence of a weak degree of regional convergence.

Second, local R&D expenditure generally shows a positive and significant relationship with economic growth in all regressions, in line with similar research (Fagerberg et al. 1997; Rodríguez-Pose, 1999, 2001; Cheshire and Magrini, 2000; Bilbao-Osorio and Rodríguez-Pose, 2004; Crescenzi 2005). For the European regions considered, investing in R&D seems to be a more important source for economic development than relying of knowledge spillovers from investing in R&D in neighbouring regions. When considering both factors together (Regression 1) the coefficient of local R&D expenditure is positive and significant, while access to extra-regional innovation is insignificant. Relying exclusively on local R&D inputs is, however, not a guarantee for achieving greater growth, as such relationship proves to be not always robust when the social filter variable is introduced. As highlighted in Regression 2, the local socio-economic conditions – the 'social filter' – are a better predictor of economic growth than investment in R&D. The social filter variable is always positively associated with economic growth and statistically significant. The relevance of the 'social filter' is enhanced when R&D investment and access to knowledge spillovers are considered in conjunction with local conditions (Regression 3). The results point out that having a good 'social filter' enhances the potential of European regions to assimilate spillovers, making local R&D expenditure irrelevant. These results highlight that while investing in R&D locally enhances economic growth, relying of knowledge spillovers is a viable alternative for regions with adequate socio-economic structures that would guarantee the reception and assimilation of those spillovers. This does not mean that local innovative efforts are unimportant for regional economic performance. However, as far as knowledge may flow also from outside the region (both in the form of codified knowledge and spillovers), local socio-economic conditions may prove the true differential competitive factor by enabling the translation of all source of knowledge into successful innovation and economic growth.

Introducing the individual the individual sub-components of the social filter uncovers the specific importance of the educational endowment of both the population and the labour force (regressions 4 and 5). The role of life-long learning, the percentage of the labour force working in agriculture, the level of long term unemployment, and the demographic structure of the population, is, in contrast, not significant and, in the cases of agricultural employment and long-term unemployment, limit the capacity of regions to assimilate knowledge spillovers (Regressions 6 and 7). In these cases, relying on knowledge spillovers is no substitute of local investment in R&D.

The results underscore that accessibility to extra-regional innovation, our proxy for knowledge spillovers, is related in a positive and statistically significant way to regional growth performance, in particular when associated to an appropriate measure for socio-economic conditions. This confirms that knowledge spillovers, by increasing the 'amount of knowledge' available in the region, reinforce the effect of local innovative activities, and, to a certain extent, may even compensate for a weak contribution of the innovative activities pursued locally. Thus, other things being equal, a region within an innovative neighbourhood is more advantaged than one located close to less innovative areas. On the contrary both the socio-economic endowment (Regression 11) and the level of economic wealth (Regression 12) of neighbouring regions seem to have no significant effect on local economic performance. The extra-regional social filter is significant only when considered jointly with internal features, as in Regression 10 where the total accessibility to innovation prone space is considered by including in a single variable both the region's features and that of its neighborhood.

On the basis of these results, the potential of a region in terms of economic performance is maximized when an appropriate social filter is combined with local investment in R&D. The reception of R&D spillovers from neighbouring regions is an important additional source of advantage which, in any case, requires an appropriate social infrastructure in order to be productively translated into new innovation and economic growth. In this framework the analysis of the spatial scope of such spillovers, which we will discuss in the next subsection, becomes particularly important for the understanding of the role of geography in a knowledge based economy.

4.3 The spatial boundness of innovative spillovers

The understanding of the spatial scope of knowledge spillovers is extremely relevant from both a theoretical and a political point of view. As discussed in section 2, some streams of literature cast doubt on the role of geography in the transmission of knowledge flows while other provided significant evidence in support of the role of proximity as a relevant condition for the transmission of knowledge. Our empirical results provide additional support for the latter hypothesis. In what follows, we focus in more details upon the relevant 'spatial scale' for the transmission of growth-enhancing knowledge spillovers, by attempting to quantify the concept of 'proximity' for the regions of the EU.

[Insert Table 4 around here]

In Table 4 we present various estimations of our empirical model in which regional spillovers' proxies are calculated by mean of different 'spatial weights'. As in the case of the regressions presented in Table 3 all usual diagnostic statistics confirm the robustness of our results.

Regression 1, which we use as a benchmark, shows our estimation results when regional spillovers are proxied by the index of accessibility to extra-regional innovation as in all regressions in the previous table. The regression not only confirms that knowledge flowing from neighbouring regions improves regional growth performance, as was underlined before, but also shows that spillovers are geographically bounded and that they decay with distance. The weighing mechanism on which the variable is based makes the importance of other regions' innovative activities decrease with distance thus emphasizing the effect of innovative activities pursued in closer regions. More precisely, regions can rely upon the research strength of regions within a three hour drive (ca 200 kms) as shown by the increase in significance of the spillover variable once a 180 minute cut off is introduced in the weighing matrix (Regression 2). When more remote regions are taken into consideration, by fixing the cut off trip length at 300 and 600 minutes (Regressions 3 and 4 respectively), the variable is no longer significant thus showing that beyond a 180 minute trip-time the returns to extra-regional innovative activities are inexistent. These results are confirmed also where total accessibility to innovative activities is considered by introducing a variable capturing both internal and distance-weighed R&D expenditure (Regressions 5-12). In this second case the 'institutional' borders of the region are overcome by focusing upon a 'continuous' space which results from the aggregation, in an individual variable, of the total R&D expenditure that can be reached from a certain location regardless of regional borders. In doing this, we aim to measure the total impact of R&D agglomeration on economic performance.

Our results show once again that only the variables combining the strength of internal efforts with those pursued in more proximate (within the 180 minutes limit) areas produce a positive and significant effect on regional growth performance.

5. Conclusions

The objective of this paper has been to analyse for regions in the EU the role played by the different combinations factors identified by different approaches to the study of innovation, and to allow us to discriminate among them. The results of the empirical analysis uncover the importance not only of traditional linear model local R&D innovative efforts, but also of local socio-economic conditions for the genesis and assimilation of innovation and its transformation into economic growth across European regions. In addition, it shows the importance of proximity for the transmission of economically productive knowledge. The results highlight that not only knowledge flowing from neighbouring regions improves regional growth performance, but also that spillovers are geographically bound and that there is a strong distance decay effect, which is the European case expands to more or less a 200 km radius. These outcomes shed additional light on the role of geography in the process of innovation, by supporting the idea an existing tension between two forces: the increasingly homogeneous availability of standard 'codified' knowledge and the spatial boundness of 'tacit' knowledge and contextual factors. Such tension is an important force behind the present economic geography of European regions and its role is further accentuated by the underlying socio-economic differences.

The analysis also has important regional policy implications. When innovation is recognized as the key source of sustained economic growth, the mechanics of its contribution to economic performance becomes crucial for an effective policy targeting. In this respect our analysis has showed that in terms of innovation a region can rely upon both internal and external sources of innovation, but that the socio-economic conditions in order to maximize the innovation potential of each region are necessarily internal, as socio-economic conditions in neighbouring regions do not have any substantial impact on local economic performance.

Consequently, policies based on innovation may deliver, at a regional level in Europe, very different results, according to the possibility of every region of benefiting from knowledge spillovers (location advantage) and favorable underlying socioeconomic conditions (internal conditions). Thus R&D investment in core regions, which benefits from both a location and social filter advantage, are overall more conducive to economic growth due to their impact on both local and neighboring regions' performance. Conversely, in peripheral regions investment in R&D may not yield the expected returns. Their limited R&D investment capacity, their inadequate social filters, and their lower exposure to R&D spillovers, because of their location, are likely to undermine the R&D effort conducted within the borders of these regions. Does this mean that it is not worth investing in innovation in these regions? Our results indicate that very different policies to those of the core may be needed in order to render peripheral societies in Europe more innovative. These policies will need to rely less of R&D investment and much more on enhancing the local social and economic barriers that prevent the reception and assimilation of external innovation. Any incentive for local innovative activities would have to be complemented by reinforcing the local endowment in terms of education and skills in order to guarantee the greatest returns from innovation policies. The emphasis on skills is also likely to set the foundations for a future transformation of these regions into innovation prone societies, in which the returns of any investment in R&D will yield substantially higher results than at present.

Overall, our analysis supports the idea that while the neo-Schumpeterian threshold of expenditure is an important source of innovation, for most regions in the EU the capacity of the local population to assimilate whatever research is being generated locally or in neighbouring regions and to transform it into innovation and economic activity may be a better short term solution in order to generate greater economic growth.

Tab.2a - Principal Component Analysis: Eigenanalysis of the Correlation Matrix

	PC1	*PC2*	*PC3*	*PC4*	*PC5*	*PC6*
Eigenvalue	2.5886	1.2723	0.9083	0.6418	0.5661	0.0229
Proportion	0.431	0.212	0.151	0.107	0.094	0.004
Cumulative	0.431	0.643	0.795	0.902	0.996	1

Tab2b - Principal Component Analysis: Principal Components's Coefficients

Variable	*PC1*	*PC2*
Education Population	0.576	-0.224
Education Labour Force	0.554	-0.313
Life-Long Learning	0.395	0.26
Agricultural Labour Force	-0.43	-0.285
Long Term Unemployment	-0.14	-0.459
Young People	0.019	0.701

Table 3 - H-C OLS estimation of the empirical model. R&D, social filter and knowledge spillovers

	1	2	3	4	5	6	7	8	9	10	11	12
Constant	0.09406***	0.12284***	0.12182***	0.1126***	0.10707***	0.09655***	0.08491***	0.08989***	0.10777***	0.12054***	0.12187***	0.12059***
	(0.02572)	*(0.02814)*	*(0.02796)*	*(0.02563)*	*(0.02561)*	*(0.02671)*	*(0.03019)*	*(0.0292)*	*(0.02709)*	*(0.02802)*	*(0.02805)*	*(0.02809)*
Log GDP 95	-0.003098	-0.005756	-0.00663*	-0.00574*	-0.005112	-0.003359	-0.00196	-0.002733	-0.004345	-0.006577*	-0.006349*	-0.007705*
	(0.003255)	*(0.00353)*	*(0.003543)*	*(0.003267)*	*(0.003268)*	*(0.003346)*	*(0.003803)*	*(0.003478)*	*(0.003339)*	*(0.003571)*	*(0.003668)*	*(0.003929)*
R&D expenditure	0.2682**	0.1424	0.1791	0.1366	0.166	0.2556**	0.2664**	0.2653**	0.2548**	0.1883	0.177	0.1909
	(0.1174)	*(0.1207)*	*(0.1218)*	*(0.1212)*	*(0.1208)*	*(0.1229)*	*(0.1177)*	*(0.1182)*	*(0.1172)*	*(0.1213)*	*(0.1223)*	*(0.1234)*
Social Filter Index		0.01052**	0.010787**								0.010538**	0.011422**
		(0.004626)	*(0.004598)*								*(0.004682)*	*(0.004713)*
Accessibility to ExtraRegional Innovation	0.013236		0.01387*	0.013157*	0.013733*	0.012717*	0.012262	0.013353	0.013807*	0.014184*	0.013936*	0.014229*
	(0.008148)		*(0.008031)*	*(0.007908)*	*(0.007975)*	*(0.0083)*	*(0.008336)*	*(0.008182)*	*(0.008119)*	*(0.008052)*	*(0.008059)*	*(0.008067)*
National Dummies	x	x	x	x	x	x	x	x	x	x	x	x
Social Filter Individual Components:												
Education Population				0.017003***								
				(0.005341)								
Education Labour Force					0.019224***							
					(0.006986)							
Life-Long Learning						0.00385						
						(0.01076)						
Agricultural Labour Force							0.003802					
							(0.006528)					
Long Term Unemployment								0.001892				
								(0.006205)				
Young People									-0.009089			
									(0.005882)			
Extra-Regional Social Filter												
Total accessibility to innovation prone space										0.012617***		
										(0.005656)		
Accessibility to Innovation Prone Extra-Regional areas											-0.00808	
											(0.0261)	
Accessibility to wealth neighbouring regions												8.8E-07
												(0.00000138)
R-Sq	0.659	0.665	0.672	0.681	0.676	0.66	0.66	0.659	0.665	0.67	0.672	0.672
R-Sq (adj)	0.62	0.626	0.631	0.642	0.636	0.618	0.618	0.618	0.624	0.63	0.629	0.63
F	16.84	17.27	16.7	17.45	17.03	15.82	15.85	15.81	16.19	16.61	15.72	15.77
Moran's I	-0.0193012	-0.0185667	-0.0189041	-0.0194612	-0.0198153	-0.0193265	-0.0198503	-0.0195195	-0.0199182	-0.0188243	-0.0188376	-0.0189403

*, ** and *** denote significance a to 10%,5% and 1% level respectively. SE in parentheses

Table 4 - H-C OLS estimation of the empirical model: accessibility to innovation

	1	2	3	4	5	6	7	8	9	10	11	12
Constant	0.12182***	0.134***	0.12317***	0.12551***	0.12107***	0.12176***	0.1216***	0.12116***	0.09082***	0.09202***	0.08063***	0.09103***
	(0.02796)	*(0.02838)*	*(0.02822)*	*(0.02844)*	*(0.028)*	*(0.02799)*	*(0.02799)*	*(0.028)*	*(0.02532)*	*(0.02533)*	*(0.02512)*	*(0.02533)*
Log GDP 95	-0.00663	-0.007635**	-0.006016*	-0.005813	-0.005554	-0.005661	-0.005642	-0.005572	-0.001745	-0.001913	-0.000093	-0.001779
	(0.003543)	*(0.003612)*	*(0.003571)*	*(0.003537)*	*(0.003506)*	*(0.003506)*	*(0.003505)*	*(0.003506)*	*(0.003166)*	*(0.003168)*	*(0.003078)*	*(0.003168)*
R&D expenditure	0.1791	0.1486	0.1458	0.1475								
	(0.1218)	*(0.1194)*	*(0.1211)*	*(0.1211)*								
Social Filter Index	0.010787**	0.01074**	0.01101**	0.010379**	0.01081**	0.010656**	0.010685**	0.010782**				
	(0.004598)	*(0.004579)*	*(0.004724)*	*(0.004638)*	*(0.00455)*	*(0.004538)*	*(0.004538)*	*(0.00455)*				
Accessibility to ExtraRegional Innovation												
Continous Space	0.01387*											
	(0.008031)											
180 minutes cutoff		0.00983**										
		(0.00481)										
300 minutes cutoff			0.002556									
			(0.004712)									
600 minutes cutoff				-0.005154								
				(0.007263)								
Total accessibility to Innovation (Extra+Intra regional)												
Continous Space					0.005349				0.008264*			
					(0.004505)				*(0.004401)*			
180 minutes cutoff						0.006191				0.009091**		
						(0.004619)				*(0.004518)*		
300 minutes cutoff							0.006103				-0.000643	
							(0.004628)				*(0.004707)*	
600 minutes cutoff								0.005447				0.00836*
								(0.004506)				*(0.004402)*
National Dummies	x	x	x	x	x	x	x	x	x	x	x	x
R-Sq	0.672	0.674	0.666	0.666	0.665	0.666	0.666	0.665	0.652	0.653	0.644	0.652
R-Sq (adj)	0.631	0.634	0.625	0.625	0.626	0.627	0.627	0.627	0.615	0.616	0.606	0.615
F	16.7	16.89	16.25	16.28	17.27	17.34	17.33	17.28	17.46	17.55	16.84	17.47
Moran's I	-0.0189041	-0.0196286	-0.0186123	-0.019055	-0.0189909	-0.0192397	-0.0191901	-0.0189931	-0.0188665	-0.0191502	-0.0165446	-0.0188604

*, ** and *** denote significance a ta 10%,5% and 1% level respectively. SE in parentheses

Appendix

Table A-1 – Description of the variables

Variable	**Definition**
Innovation	
R&D	Expenditure on R&D (all sectors) as a % of GDP
Social Filter	
Life-Long Learning	Rate of involvement in Life-long learning - % of Adults (25-64 years) involved in education and training
Education Labour Force	% of employed persons with tertiary education (levels 5-6 ISCED 1997).
Education Population	% of total population with tertiary education (levels 5-6 ISCED 1997).
Agricultural Labour Force	Agricultural employment as % of total employment
Long Term Unemployment	People aged 15-24 as % of total population
Young People	Long term unemployed as % of total unemployment.

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