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"A relational approach to the geography of innovation: a typology of regions"

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Abstract

The aim of this study was to devise a method for computing a composite indicator that measures the regional degree of exposure to external knowledge sources. On the basis of this indicator, we propose a typology of regions according to their potential capacity to access extra-local items of knowledge, which might help them to recombine complementary elements of such an asset to produce a higher number of new ideas. Building on various research streams that have been relatively independent to date, we summarize a non-exhaustive instrumental list of recent studies that motivates our approach and the construction of our complex indicator, which can be used to appraise the extent to which each region is in an optimal position to access external innovative resources.

JEL classification: B41, C8, O18, O31, O33, R0
***Keywords*:** knowledge networking regions, knowledge diffusion, formal, informal, European regions.

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1. Introduction

Agents do not create in isolation. Indeed, the production of innovation relies on the recombination of existing knowledge and ideas. Employees within a firm and across its different departments create and recombine ideas through a process of collective learning that is structured within the organization (Lorenz, 1996; March, 1991). Organizations produce innovations by combining existing knowledge that goes beyond the limits of their boundaries. In short, firms turn to external sources of ideas (Rosenkopf and Almedia, 2003) and their ability to recombine and exploit such knowledge is pivotal to boost their competitive advantage (Dosi, 1988; Singh and Agrawal, 2011). Cassiman and Veugelers (2006), among others, have consistently shown that complementarities between firms' internal R&D activities and their external knowledge acquisition are strong predictors of performance.

Recognition of the critical role of knowledge flows, knowledge diffusion and knowledge recombination dates back to the well-known Marshallian externalities. Several decades later, endogenous growth models (Grossman and Helpman, 1991; Lucas, 1988; Romer, 1990) put knowledge spillovers at the forefront of the mainstream research agenda. Furthermore, during the nineties, empirical analysis from the geography of innovation (Feldman, 1994; Feldman and Audretsch, 1999; Jaffe 1986, 1989; Jaffe et al., 1993) and new economic geography models (Martin and Ottaviano, 1999) indicated the localized pattern of knowledge spillovers and their role in explaining both the high spatial concentration of economic activity and spatial differences in economic growth. Central to this reasoning is the assumption that corporate and public R&D investment spills over to third parties in the form of an externality, but 'the ability to receive knowledge spillovers is influenced by distance from the knowledge source' (Audretsch and Feldman, 1996, p. 630).

Recently, scholars have started to claim that excessively close actors may have little to exchange after a certain number of interactions (Boschma and Frenken, 2010). Indeed, the production of ideas requires the combination of different –though related, complementary pieces of knowledge to be most effective. However, at some point, co-located agents may start to combine and recombine local knowledge that eventually becomes redundant and less valuable. As a result, processes of lock-in may begin to occur (Arthur, 1989; David, 1985). Conversely, firms looking for external sources of knowledge that lie beyond their own boundaries may find that the knowledge they require is available beyond the boundaries of the region (Bergman and Maier, 2009). This strategic behaviour increases the probability of gaining *first mover* advantages in the market for the focal firm (ibid.) and consequently for the region. Hence, if there are strong internal connections between firms within a given region, but weak external connections to other sources of knowledge, 'there is the risk of localism, which implies that a regional economy is unable to acquire and master external knowledge and is hence likely to be less innovative' (Fratsei and Senn, 2009, p.17). Thus, it is important to balance internal and external, local and nonlocal interactions, to ensure a satisfactory amount of adoption and creation of knowledge.

We build our empirical strategy on this idea and develop a method that tries to quantify to what extent actors in regions can access sources of knowledge that lie beyond the confines of their cluster. This puts regions in a better strategic position to potentially use extra-regional ideas in the production of innovations. In so doing, we expect to increase our understanding of why some regional economies become locked into non-dynamic development paths, whilst others seem able to reinvent themselves continuously (Martin and Sunley, 2006).

To the best of our knowledge, little attention has been paid to this issue from an academic or policymaking perspective. The case of Europe is a paradigmatic example. In spite of recent empirical evidence and the importance European policymakers place on interregional connections to build a coherent and integrated European Research Area (European Commission 2007, 2010), policy reports do not tend to consider the external dimensions of regional innovation (e.g. the Regional Innovation Scoreboard, 2009). We strongly believe that connections to external sources of knowledge are as important for regions as their scientific and technological base. Consequently, we aim to fill this knowledge gap.

In this paper, we describe a method for constructing a synthetic indicator able to identify the regions in the best (and worst) position to access sources of knowledge from beyond their boundaries. To do this, we feed from various research streams –geography of innovation, regional economics, innovation economics, regional innovation systems (RIS) literature, and we survey and discuss the most recent conceptual and empirical contributions. On the basis of this review, we conceptually model the ways in which organizations and other actors in regions access external-to-the-region pieces of knowledge. We suggest that two different regimes are at work: (1) informal interactions and unintentional relations arising from serendipitous encounters between actors who lie in close spatial proximity; and (2) formal, intentional relations based on coordinated and well-defined linkages between actors who might, or might not, be in close spatial proximity. Hence, we characterize regions in terms of the ways in which they can potentially access external knowledge. In short, our research will provide a method for quantifying regions' exposure to external knowledge through these two patterns.

On the basis of the proposed method, we aim to develop a typology of regions according to their position in these two dimensions: regions in a superior potential position to build informal connections with the outside world -above the average, but lacking formal, intentional linkages (*clustering regions*); regions with numerous formal relations but potentially few informal connections (*globalizing regions*); regions that do not have an advantageous positions in either of these two dimensions (*non-interactive regions*); and finally, regions with values above the mean in both indices (*knowledge networking regions*). We apply our approach to a group of NUTS2 regions in 31 European countries (EU-27 plus Iceland, Liechtenstein, Norway and Switzerland).

The outline of the paper is as follows: Section 2 reviews some relevant conceptual and empirical studies on the idea that agents access external-to-the-region knowledge to avoid regional lock-in. In this section, we bring together dispersed, but related, literature. Section 3 develops in more detail our conceptual model of connectivity through the two dimensions outlined above, and examines in depth the concept of 'knowledge networking regions'. Section 4 describes the empirical approach taken here. Section 5 summarizes some remarkable findings and Section 6 presents conclusions and policy implications.

2. Review of theoretical and empirical literature

2.1. Physical space and knowledge flows

Most geography of innovation scholars have reiterated that the role of physical proximity in enhancing knowledge creation is critical to understand the uneven distribution of economic and innovation activities across space, as well as the major spatial differences in growth rates between regions, even within the same country. To recap, empirical studies in the geography of innovation (Feldman, 1994; Feldman and Audretsch, 1999; Jaffe 1986, 1989; Jaffe et al., 1993) and economic geography (Martin and Ottaviano, 1999) literature have established that knowledge produced by a firm is only partially appropriated by the producer itself, whereas part of this knowledge spills over to other firms and institutions, reducing in this way innovation costs of these other organisations, as shown by endogenous growth models (Lucas, 1988; Romer, 1986, 1990). Face-to-face interactions between employees (Allen, 1977; Krugman, 1991b), frequent meetings, monitoring of competitors (Porter, 1990), spin-offs, trust building (Glaeser et al., 2002) and the like, which are essential to the effective exchange of ideas, have been indistinctly taken to explain the mechanisms by which knowledge spills over as an externality. Due to the nature of these mechanisms and the highly contextual features of the knowledge that is transferred, knowledge barters are assumed to occur among members of a co-located community and, therefore, knowledge is considered to be spatially sticky.

To sum up, the hypotheses hold that a firm’s insertion into a given cluster provides it with advantages that are not available to firms outside the cluster. Co-location creates an ‘industrial atmosphere’ (Becattini, 1979; Marshall, 1920) or ‘local buzz’ (Storper and Venables, 2004), where information flows, knowledge transfers and learning opportunities take place continuously in both organized and accidental meetings (Bathelt et al., 2004). A key point is that little effort is needed to participate in the buzz, i.e. flows are more or less automatically received by those who share the physical space (op. cit.).

Critical to this line of argument is the explicit differentiation between tacit knowledge and codified/explicit knowledge. Tacit knowledge is highly contextual, difficult to transfer and share across long distances and therefore better transmitted in the form of meetings and face-to-face interactions (Breschi and Lissoni, 2001a,b) that are facilitated most by co-location (Breschi et al., 2010). Codified/explicit knowledge may travel frictionless across the space by means of information and communication technologies. Tacit knowledge is therefore relatively immobile, which implies that actors can only share it when they have a similar social context. This social context is also assumed to be bound in space (Gertler, 2003).

These are undoubtedly pivotal elements within the literature. However, an important point has been made by several scholars from innovation economics and organizational science. In their view, two contradictory arguments explain the diffusion of knowledge and its spatial stickiness (Torré, 2008): (1) tacit knowledge is a public good and its appropriateness escapes the control of its producers, who cannot prevent others from benefitting from it; (2) because it is highly contextual, tacit knowledge needs frequent interactions to be transmitted. Objections to this contradictory logic have led researchers to show that co-location favours the transmission of knowledge, instead, via market mechanisms and pecuniary externalities across members of the same epistemic community, including local networks (vertical and horizontal) and local mobility of the labour force. These transmission methods have nothing to do with pure knowledge externalities (Almeida and Kogut, 1997, 1999; Breschi and Lissoni, 2009; Camagni and Capello, 2009; Rychen and Zimmermann, 2008; Torré, 2008; Zucker et al., 1998). Thus, spatial proximity is not a necessary or sufficient condition for knowledge to flow across agents (Boschma, 2005). In contrast, social and other forms of non-spatial proximity, which are in the very nature of the relationships between members of the same epistemic community, are essential. As a result, highly contextual knowledge might not be as spatially sticky as is usually assumed in the geography of innovation literature, if other types of proximity are also at work. As we will discus in more detail in Section 3, the reality probably lies somewhere between these two approaches. Thus, pure localized knowledge externalities may still play a role (Iammarino and McCann, 2006), especially in the early stages of an industry life cycle (Audretsch and Feldman, 1996).

2.2. From localization to a balanced internal-external mix of knowledge flows

Indeed, an increasing number of academics have called into question the widely accepted assumption that knowledge flows are that localized. This assumption, they argue, might have limited our understanding of the ways in which knowledge flows across space (Coe and Bunnell, 2003). Certainly, recent empirical evidence casts doubts on the orthodox viewpoint outlined above. Some studies have started to explore the influence of extra-local knowledge sources on firms' innovative performance, though the results are ambiguous. For instance, in their analysis of the Boston biotech community, Owen-Smith and Powell (2004) showed that while membership to local networks, rather than centrality within these networks, was a conduit to better company performance, central positions in geographically dispersed networks increased firms' patent volume. Thus, 'being situated at the intersection of numerous formal pipelines enhances firm-level knowledge outputs' (op. cit., p. 16). Gittelman (2007) suggested that geographical proximity matters for innovation, but opportunities for learning by interacting also exist beyond regions' boundaries in the case of US biotech firms. Indeed, he estimated that distant research teams received more citations of their output than teams formed in closer proximity. In parallel, Gertler and Levite (2005) found that the most successful Canadian biotech firms are externally oriented. Thus, patenting Canadian biotech firms are more likely to have foreign partners in their collaborative projects than their non-patenting counterparts. This suggests that the best places for biotech innovators are not only those with a strong 'local buzz', but also regions that are well connected extra-locally.

Trippl et al. (2009) analysed the software cluster in Wien. It was found that the local context remains highly relevant as a source of knowledge and information, but extra-local connections (national and European customers, suppliers, competitors, and service companies) also play an important role. The authors concluded that the interplay between local, national and global seems to drive innovation-oriented firms in the software industry. Similar conclusions were drawn in Giuliani and Bell (2005) for the case of a Chilean wine cluster. According to the authors, two types of behaviour characterize knowledge dynamics in this cluster: (1) although local linkages are prominent, they are highly selective, rather than unstructured and unplanned; and (2) for some firms, learning links are partially or almost exclusively found outside the cluster. Further examples are case studies by Asheim and Isaksen (2002), who analysed three Norwegian clusters (shipbuilding, mechanical engineering, and electronics). They found external-to-the-region contacts to be crucial in the innovation process of firms. As the authors pointed out, firms in clusters tend to exploit both place-specific resources and external knowledge sources to increase their innovation rates. Similar conclusions were made by Vang and Chaminade (2007) in a study of Toronto's film industry and by Belussi et al. (2010) in a paper on life science firms in the Emilia Romana region (Italy).

In a similar vein, Rosenkopf and Almedia (2003) convincingly argued that, in spite of the larger pools of knowledge available at local level, firms need to search for knowledge sources beyond their geographical and technological vicinity as the distant context may offer particularly useful ideas and insights for recombination. Using data on patents, citations, inter-firm alliances and labour mobility, the aforementioned authors evaluated various knowledge inflows at different spatial scales. Despite their claims, the positive effects of distant relationships (in the form of alliances and mobility) were not supported by the data. Simonen and McCann (2008) drew similar conclusions in a different context. Their study on inter-firm labour mobility in a sample of Finish firms shows that labour inflows from the same area are positively related to firms' innovative performance. Meanwhile, outside-the-region inflows are only related to firms' performance when the incoming worker belongs to high-tech sectors that are similar to the focal firm. Boschma et al. (2009) found similar results for Swedish firms. They argued that the positive effects of employee inflows might depend on the skills portfolio of the incumbent workers, as well as on whether or not they come from the firm's geographical area. Therefore, they split inflows according to the employees' skills (i.e. similar, related, and unrelated skills). They found that both related and unrelated skills had a positive effect when incumbent workers come from the firm's own area, whilst only related skill inflows had a positive impact in the case of extra-local workers. Their explanation is based on the following logic: incumbent workers with very similar skills to the receiving firm do not add any value to its current knowledge base, whilst workers with different, but related, skills do contribute to firms' performance even if they move in from a different spatial context.

This empirical evidence goes hand in hand with an increasing number of claims from prominent academics who have raised concerns in this area. Thus, several scholars have lately stressed the need for firms to network with extra-local knowledge pools to overcome potential situations of regional 'entropic death', 'lock-in' or 'over-embeddedness' (Boschma, 2005; Camagni, 1991; Grabher, 1993; Uzzi, 1996). These claims have contributed to a lively current debate among research streams about the conditions in which tacit knowledge can be transmitted at a distance and go beyond a region's confines, as well as the extent of such transmission. Indeed, it has been argued that two very close actors may have little knowledge to exchange and that innovative production usually requires the combination of dissimilar, but related, complementary knowledge (Boschma and Frenken, 2010; Boscham and Iammarino, 2009).[1] Thus, as time passes and local interactions lead to the combination and recombination of the same pieces of knowledge, organizations end up stuck in strong social structures that tend to resist social change (Boschma and Frenken, 2010; Morrison et al., 2011) and prevent them from recognizing opportunities in new markets and technologies (Lambooy and Boschma, 2001). Thus, 'distant contexts can be a source of novel ideas and expert insights useful for innovation processes (…). Firms therefore develop global pipelines not only to exchange products or services, but also in order to benefit from outside knowledge inputs and growth impulse' (Maskell et al., 2006, p. 998). As already asserted in the social network literature, non-redundant rather than repeated ties are the most apposite to increase knowledge flows and innovation (Burt, 1992; Granovetter, 1973).

Truly dynamic regions in the era of the knowledge economy are therefore characterized not only by dense local learning and interaction, but also by the ability to identify and establish interregional and international connections to outside sources of ideas (Gertler and Levitte, 2005; Maskell et al., 2006). Thus, certain actors within dynamic regions can build connections with more or less remote actors, to form non-redundant ties that bring new knowledge into a given local network (Burt, 1992). These actors function as knowledge gatekeepers, setting up global bridges between the local network and outside sources of knowledge (Glucker, 2007). Thus, they introduce knowledge variation into the regional economy, which can prevent the region from entering non-dynamic development paths. In sum, regions that host globally connected organizations end up being more successful than others (Bergman and Maier, 2009).

Analogously, the regional innovation system (RIS) literature (Autio, 1998; Cooke et al., 2000) has generally looked at regions in an isolated manner, that is, without any specific consideration of interrelationships across regional systems or on larger spatial scales. However, recent contributions within this stream have also started to tackle this issue (Tödtling and Trippl, 2005). Indeed, external links provide access to ideas and technologies that are not endogenously generated within the regional system, which is actually far from being self-sustained (op. cit.). In consequence, recent works have suggested the concept of "Open RIS" (Belussi et al., 2010).

[1] Note that, as stressed in Boschma and Iammarino (2009, p.295), 'extra-regional knowledge that is complementary, but not similar, to existing competences in the region will particularly enhance interactive learning. (…). If the external knowledge is unrelated, the industrial base of the region cannot absorb it and is unlikely to benefit from it. When the external knowledge is the same (…), it can be absorbed locally, but the new knowledge will not add much to the existing local knowledge base'. As we will show later on, our empirical application does not consider this distinction, which is left for future extensions.

Following on from part of these theoretical and empirical contributions, Bathelt et al. (2004) envisage a conceptual model that is concerned with the coexistence between a vibrant 'local buzz' and a number of 'pipelines' that provide access to relevant pools of knowledge outside the 'buzz'. These authors hint at the fact that in reality firms build pipelines to benefit from knowledge hotspots around the world, and do not build their knowledge stock solely from local interactions (Bahlmann et al., 2008). The logic in Bathelt's et al. (2004) implies that[2]: (1) new (tacit) knowledge is created around the globe and firms that can access it through global pipelines gain competitive advantage; (2) this knowledge acquired from abroad may spill over or be transferred within the local cluster through the local network of a firm or individual; consequently (3) there is a kind of trade-off between 'a too much inward-looking and a too much outward-looking' structure of grabbing knowledge (Bathelt et al., 2004, p. 46); and (4) there are limits to the number of pipelines a firm can manage at the same time, and therefore it is better to have several firms managing a set of pipelines than for one large firm that manage a high, but limited, number of pipelines. Pioneering contributions along these lines were made, however, by Hägerstrand (1965), who distinguished between contagious and hierarchical patterns of information diffusion. In the contagious diffusion regime, information flows first at close proximity from the originating source, then with effort at greater distances. According to the hierarchical regime, information first diffuses from relatively large cities to other equal-sized cities, even those at large physical distances, between which communication infrastructures are supposed to be more developed. Maggioni et al. (2007) and Maggioni and Uberti (2011) took these insights into account and developed an extensive research agenda based on the distinction between unintended cross-regional spatial spillovers and intentional relations based on a-spatial networks. Their logic is straightforward: knowledge is created in central organizations that tend to co-locate. Subsequently, knowledge is diffused either through a trickle down process of spatial contagion of neighbouring regions (by means of face-to-face interactions and other 'unintended' means) or through a-spatial networks structured in the form of contractual agreements between organizations that connect clusters, irrespective of the spatial distance between them.

Tödtling et al. (2006) and Trippl et al. (2009) use a broader set of dimensions to classify the ways in which knowledge flows within and between clusters and regions. For these authors, knowledge diffusion processes can be summarized by differentiating between two dimensions. The first dimension distinguishes between traded and untraded interdependencies (following Storper, 1997) on the basis of whether or not there is monetary or similar compensation. The second dimension

[2] Note that in their model they allow the scope of the 'local buzz' to go beyond the limits of the administrative region into neighbouring regions that might totally or partially belong to this same 'buzz'. In contrast, 'pipelines' are established with actors located at a distance. Moreover, whereas information inflows within the 'local buzz' do not require a major effort as they are more or less automatically received, the construction of 'pipelines' requires a conscious, intentional commitment to identify potential partners and build formal relations.

distinguishes between static and dynamic knowledge exchanges, that is, respectively, transfers of pieces of already available knowledge or barters that involve interactive learning processes between agents (see also Capello, 1999).

As we will see in more detail in Section 3, our conceptual framework is based on these early contributions, though some differences will be worth mentioning.

2.3. Do regions 'pipe' external knowledge? Some evidence at regional level

Within regional science, the number of studies that address cross-regional relationships and their impact on economic outcomes has sharply increased in the last 25 years. A clear example is the growing number of papers that apply spatial econometric techniques at regional level. These papers have been more or less concerned with estimating cross-regional knowledge externalities in knowledge production function (KPF) frameworks (Acs et al., 1994; Anselin et al., 1997; Bottazzi and Peri, 2003). Indeed, as stated by prominent scholars, there is no reason to assume that knowledge stops flowing because of regional borders (Audretsch and Feldman, 2004; Krugman, 1991a). Therefore, spatial econometric techniques and the spatial weight matrix have notably improved the way such externalities are measured (Autant-Bernard and Massard, 2009). Admittedly, this approach is no more than a corollary of the traditional localized knowledge spillovers (LKS) story, although it considers that externalities may spread to regions in the immediate vicinity.

Other studies within this stream have tried to go one step further. Moreno et al. (2005) and Parent and LeSage (2008), among others, have exploited the concept of technological proximity between regions *vis-à-vis* spatial proximity in estimates of cross-regional externalities. Their underlying logic relies on the idea that knowledge externalities flow easily among members of epistemic communities of scientists and technicians in highly specialized technological fields, irrespective of their geographical location, due to the fact that they share a specific knowledge background and common jargon and codes. Similarly, Kroll (2009) and Ponds et al. (2010) have built weight matrices using collaborative research data across regions to proxy the social distance between them at aggregate level. In this way, they show the importance of reflecting non-spatial, more meaningful measures of proximity across regions in estimations of the effects of cross-regional knowledge flows on regional innovative performance. The aforementioned study by Maggioni et al. (2007) follows a similar approach, as spatial contagious effects *vis-à-vis* network effects in the form of research collaborations are estimated in a spatial KPF framework. However, their approach reveals that when the spatial weight matrix is subtracted from the network matrix and a pure social matrix is considered on its own, important spatial effects are unaccounted for.

In spite of these and other contributions, the literature on cross-regional knowledge diffusion and regional innovation is relatively scant, apart from studies on the purely spatial approach. Likewise, supra-national organizations' policy reports on regional innovation do not tend to consider that extra-regional linkages are part of the regional innovation performance, either from an input or output perspective. For instance, the latest Regional European Scoreboard (2009) takes into account a number of regional innovation indicators, such as human capital, R&D expenditure, ICT penetration, employment in high technologies and patents. However, it does not include indicators concerning a region's degree of openness to external sources of knowledge, in neighbouring or distant regions, that may have a definite impact on regional innovative output and, subsequently, on economic development. By means of principal component analysis, the Regional Innovation Monitor (European Commission, 2011) produces a typology of innovative regions using several indicators, including public and private R&D, patents, population with tertiary education. None of these indicators appraise a region's capacity to access and use external knowledge in its innovation processes. Similar approaches are followed by the Global Innovation Index (INSEAD, 2011), the OECD (Marsan and Maguire, 2011) and Navarro et al. (2009). Only recently, in its annual assessment of the performance of regions (OECD, 2009), the OECD included co-patenting with external-to-the-region inventors as an indicator of knowledge sharing.

Similarly, regional innovation datasets (OECD[3] or Eurostat[4]) barely reflect the relational dimensions of regions as entities that establish relationships through their actors that usually go beyond the regions' boundaries and are beneficial for their innovative performance, as they are their human capital or R&D efforts.

In consequence, we believe that the approaches that are currently used to assess the innovation performance of regions are far too simplistic. Our research project tries to fill this gap by proposing a method for computing a composite indicator that evaluates the extent to which regions can access external pieces of knowledge and information, either by a process of informal barters between agents located in neighbouring regions or by means of formal linkages with outsiders. Subsequently, our strategy will provide a taxonomy of regions that is based on the mechanisms for accessing external knowledge: formal versus informal interactions.

[3] http://stats.oecd.org/Index.aspx?datasetcode=REG_DEMO_TL2.
[4] http://epp.eurostat.ec.europa.eu/portal/page/portal/region_cities/regional_statistics/data/main_tables.

3. Towards the 'knowledge networking region'

The above review helps us to build a conceptual framework for the 'knowledge networking region' notion, which we develop in the present section. Again, our primary aim in this paper was to develop a simple method for appraising the external dimension of regional knowledge production. In doing so, we obtain an instrument for classifying regions into different tiers, according to their capacity to access external sources of knowledge and innovation. To achieve this, we distinguish between two ways in which regional agents access external knowledge. As outlined above, the approach chosen at this stage resembles that of Bathelt et al. (2004) and Maggioni et al. (2007). Thus, actors access external knowledge pools by means of two distinct patterns, i.e.

- an informal, non-intentional, serendipitous pattern of knowledge interactions that take place between agents located in spatial proximity and
- a formal, intentional, and conscious pattern of linkage formation between actors, irrespective of their geographical location.

Below, these two patterns are illustrated in detail. Note that our distinction has nothing to do with the usual classifications, such as *tacit* (assimilated to informal) vs. *codified* (assimilated to formal) knowledge. Again, the tacit property has been widely advocated as the reason why knowledge of this type is easily transmitted by means of face-to-face contacts, and therefore co-location is required (Breschi and Lissoni, 2001a,b). However, several authors stress that even when knowledge is totally codified, what is required is a tacit understanding of the message that is transmitted, which is a property of the epistemic community and may have little to do with the territory in which the knowledge is produced (Breschi and Lissoni, 2001a,b; Cowan et al., 2000; Steinmueller, 2000). Note also that our attention is totally focused on the dichotomy between informal/formal mechanisms, rather than whether the linkages are in neighbouring regions or not. In this way, we allow for cross-regional formal knowledge flows between contiguous regions. Finally, among the formal cross-regional linkages considered, we include collaborations between actors, as in many previous studies. However, we also include geographical mobility of highly-skilled labour and access to codified knowledge located outside the region. Bearing this in mind, we will now describe in detail the logic behind each of the patterns of regional capacity to access external knowledge.

3.1. Informal pattern of knowledge diffusion

Co-location brings people together, facilitates contacts for information and enhances the exchange of knowledge. In other words, agents who are spatially concentrated benefit from knowledge externalities. In this case, the producer of a given piece of knowledge cannot internalize all its effects and part of it spills over to other agents, who do not compensate the initial producer. These kinds of knowledge flows occur via informal face-to-face interactions, monitoring of competitors, advisor-student relationships, and so on. Just being in a location is enough to contribute to and benefit from continuous flows of information and updates, gossip, news, rumours, and recommendations (Bathelt et al., 2004; Gertler, 1995).

As we discussed in previous sections, empirical studies tend to confirm that knowledge externalities are geographically bound, in which no other forms of proximity are necessarily involved. The transfer of knowledge takes place without explicit coordination between agents. Thus, firms near knowledge sources show better innovative performance than firms located elsewhere (Audretsh and Feldman, 1996). In many instances, the administrative boundaries of a region do not coincide with the boundaries of the 'local buzz'. When the sender and the receiver of the externality are not located (sometimes by chance) in the same region, spillovers across regions occur.

As already stated, the spatial economics and econometrics literature has long dealt with the estimation of cross-regional knowledge externalities in a KPF framework (Acs et al., 1994; Anselin et al., 1997, among many others). For instance, well-known studies on Europe have estimated the spatial scope of knowledge spillovers to be around 250-300 km (Bottazzi and Peri, 2003; Moreno et al., 2005).[5]

Needless to say, the informal pattern of interaction described here does not measure knowledge externalities *per se*. In fact, knowledge spillovers are invisible (Krugman, 1991a), although they may sometimes leave a paper trail (Jaffe et al., 1993). The variables chosen in our analysis only let us assess the extent to which each region is well positioned to endorse informal interactions and serendipitous encounters that may encourage knowledge diffusion between actors of neighbouring regions. What is actually measured, as in the literature, is the potential for localized spillovers (D'Este and Iammarino, 2010). Whether or not knowledge indeed flows across regions is an

[5] These estimations imply that spillovers are very likely to cross administrative borders, even at the level of NUTS2 regions and in countries in which this aggregation level translates into large regions, such as Spain.

interesting question, which goes beyond the scope of the present analysis.[6] The following variables could be used to proxy the advantageous position of regions that may receive knowledge flows from informal interactions:

- R&D expenditure in neighbouring regions: R&D is well established as being the greatest source of new knowledge (Arrow, 1962) and a source of spatial informal knowledge exchanges through pure externalities (Jaffe, 1986, 1989). Thus, cross-regional R&D externalities have been widely investigated (Anselin et al., 1997; Bode, 2004; Bottazzi and Peri, 2003).
- Patent applications in neighbouring regions: patent applications have been used as an indicator of R&D productivity at regional level. Therefore, patent applications in neighbouring regions can be used as an indicator of potential informal access to knowledge from innovation outputs (Autant-Bernard and LeSage, 2011).
- Human capital in neighbouring regions: theoretical and empirical contributions have shown the existence of human capital externalities (Lucas, 1988; Moretti, 2004; Rauch, 1993), arguing that skilled individuals tend to be more productive when they are surrounded by their peers. Though studies regarding cross-regional informal flows from human capital stocks are less preponderant, human capital externalities may well go beyond the boundaries of the administrative region.

3.2. Formal pattern of knowledge exchange

In recent years, several authors have pointed out that, even at close spatial proximity, knowledge flows are not automatically received just by 'being there', as previous literature tends to assume. Rather, knowledge flows follow specific transmission channels, which are mainly based on market interactions (Breschi and Lissoni, 2001a,b). In some instances, actors look for external-to-the-firm pieces of knowledge in knowledge pools that lie beyond the boundaries of their own region. Thus, some members of a region can activate linkages with these pools. As reviewed in Section 2, such linkages are pivotal to access external pieces of ideas and information that would otherwise not be available for the local cluster.

These members therefore play the role of 'knowledge gatekeepers'. This figure is derived from the concept of 'technological gatekeeper', proposed by Allen (1977). Knowledge gatekeepers make a conscious effort to establish formal linkages with knowledge hotspots outside the region,

[6] Yet, the ability of actors within regions to absorb, understand and take advantage of incoming spillovers might also be dependent on their absorptive capacity (Cohen and ***Levinthal, 1990).***

irrespective of the geographical distance. Contrary to informal knowledge diffusion mechanisms, the links that are built are not automatic and participation in them is not free. Their establishment requires a costly process. Gatekeepers take the role of global bridges (Glucker, 2007) that link the 'local buzz' with external knowledge sources, thus covering 'structural holes' between networks (Burt, 1992). For a knowledge gatekeeper to be effective for the region as a whole, it has to be inserted in global networks and well-embedded in the 'local buzz' through which the incoming insights are diffused. If this is the case, the more connected a gatekeeper is with external partners, the more potentially connected the region will be with distant pools of knowledge, and therefore the higher the probability of gaining competitive advantages in the market, both for the focal firm and for the entire region (Bergman and Maier, 2009).

This knowledge transfer, which can take place across large distances (although not exclusively), requires other forms of proximity to be effective. Other dimensions of proximity (such as social, cognitive, institutional and organizational) are key in understanding interactive learning and diffusion of knowledge between partners that are located at a distance (Boschma, 2005).[7]

Naturally, a large number of connections between agents and external sources of knowledge does not ensure that the knowledge will enter and spread into the region. Ultimately, this will depend on the absorptive capacity of the gatekeeper (Cohen and Levinthal, 1990) and, more importantly, on whether or not this gatekeeper is willing to share its knowledge within the 'local buzz'. If the connected agents behave as external stars (Morrison et al., 2011), then the region as a whole will not benefit from their external connections.

Like Bathelt et al. (2004) and Maggioni et al. (2007), we believe that alliances between organizations are critical to build 'pipelines' with outsiders. However, as in Boschma et al. (2009), we extend the formation of external linkages to the issue of the geographical mobility of knowledge workers who embody tacit knowledge (see also Coe and Bunnell, 2003; Rosenkopf and Almedia, 2003). The capacity of particular agents to connect with external sources of codified knowledge is also considered. In sum, the following measures may proxy for these formal linkages:

— Cross-regional co-patents. Networks of inventors are a source of potential knowledge flows, as individuals connected within a collaborative framework are more willing to learn from each other than isolated inventors (Breschi and Lissoni, 2004, 2009; Cowan and Jonard, 2004; Gomes-Casseres et al., 2006; Singh, 2005).

[7] See also previous studies by the French School of Proximity (for a thorough review of this literature, see Carrincazeaux et al., 2008).

- Inflows of inventors. Mobility may also favour knowledge diffusion. The movement of skilled individuals across locations contributes to knowledge mobilization throughout the space. Skilled workers take their knowledge with them and share it in a workplace with their new employer and colleagues. In return, they acquire knowledge from their new colleagues and, in general, promote new combinations of knowledge (Laudel, 2003; Trippl and Maier 2010).
- Citations made to outside-the-region patents. We use this proxy as it indicates the extent to which regional actors rely on already codified sources of knowledge that go beyond regional boundaries. Patent citations have been used widely in studies of innovation to measure the scope of knowledge flows (Jaffe et al., 1993, Peri, 2005).

3.3. A simple typology

In short, up to six variables (three for each regime) are assembled to approximate the extent to which a region can take advantage of cross-regional knowledge diffusion.

The computation of the two sub-indices will shed some light on each region's specialization pattern, in terms of its level of connectivity with external knowledge. Combinations of regions' specialization in one regime or the other will produce the following typology:

- *Clustering regions:* regions showing higher than average values for potential informal linkages but lower than average values for formal linkages.
- *Globalizing regions:* regions characterized by lower than average values for informal linkages but higher than average values for formal linkages.
- *Non-interactive regions:* regions showing lower than average values for both indicators.
- *Knowledge networking regions:* regions showing higher than average values for both synthetic indicators: informal and formal linkages.

Figure 1 graphically summarizes the suggested typology. In a nutshell, 'knowledge networking regions' are regions that are in a relatively advantageous position to receive and access external pools of knowledge through the two patterns illustrated in the previous sections.

[Insert Figure 1 about here]

4. Empirical approach

Below we summarize the result of applying the method outlined in the previous section to a group of 287 NUTS2 regions belonging to 31 European countries (EU-27 plus Iceland, Liechtenstein, Norway and Switzerland). See the Appendix for the complete list of countries.

4.1. Variable construction

With respect to the construction of the indicator of a region's capacity to access knowledge through informal interactions we consider the following variables:

- R&D expenditure in neighbouring regions (R&D expenditure weighted by a pre-defined spatial weight matrix): average value of R&D expenditure in the neighbouring regions.
- Patent applications in neighbouring regions (patent applications weighted by a pre-defined spatial weight matrix): average value of patent applications in the neighbouring regions.
- Human capital in neighbouring regions (percentage of population aged 15 and over with tertiary education over the total population, weighted by a pre-defined spatial weight matrix): average value of human capital in the neighbouring regions.

The spatial weight matrix taken from the spatial econometrics toolkit will help us to construct this sub-indicator. This is a non-stochastic square matrix that captures an ad-hoc intensity of the interdependencies between each couplet of regions, where $W = \{w_{ij}\}$, leading to a definition of 'neighbouring'. The most usual definition of neighbouring is the first order physical contiguity, that is, if two regions share the same administrative border $w_{ij} = 1$, and $w_{ij} = 0$ otherwise. In this paper, we use a more complex version of this matrix, which takes the physical distance between regions' centroids, instead of contiguity, as a neighbouring criterion and introduces strong spatial decay, giving far more importance to short-distance neighbours than to long-distance neighbours. Concretely, we define $w_{ij} = \exp(-0.01 d_{ij})$, where d_{ij} is the Euclidean distance, in kilometres, between the centriods of region i and region j. Following Bottazzi and Peri (2003), a cut-off of 300 km is introduced.[8]

[8] Other distance decays have been tried, such as 0.02, 0.03, 0.04, 0.05, 0.06, 0.07, 0.08, 0.09, and 0.10.

The proxies used to construct the indicator that capture formal interactions include:

- Co-patents with other regions: the valued degree centrality of cross-regional co-patents. The number of patents co-authored with inventors from outside the region. When a patent involves inventors whose addresses are in different regions, we assume that cross-regional collaborations took place. We ‘full-count’ all the collaborations across regions, irrespective of the number of inventors reported in each patent. For each patent with multiple inventors, all possible pairs of regions ij were created.
- Inflows of skilled workers: valued in-degree centrality of cross-regional inflows of inventors. Number of inflows of inventors from other regions. A ‘mobile’ inventor is broadly defined as an individual who moves across different regions, irrespective of whether the focal individual changes his employer or not. Mobility is computed through observed changes in the inventor’s region of residence, as reported in the patent documents.[9] Admittedly, in this manner we only capture mobility if the inventor applies for a patent before or after a move, which probably underestimates real mobility. We compute the movement in time between the origin and the destination patent, but only if there is a maximum lapse of 5 years between them.
- Cross-regional patent citations: valued in-degree centrality of cross-regional patent citations. Number of citations made to patents of other regions.

The socio-matrix, taken from social network analysis (SNA), is used to build the variables that make up this indicator. This is a tabular representation in matrix form that measures social relationships between the members of a network. Networks are formed by actors, or nodes (regions in our case), which are connected to one another by means of relations or ties. These connections form relationships between nodes that can be represented in the socio-matrix, whose elements capture the intensity of the relationship between node i and node j. Relations in a network might be undirected when the relationships are symmetric, or directed when the direction of the relation between a given pair of points does matter. Additionally, the relations between nodes might be binary (1 when a relationship exists, and 0 otherwise) or valued (the intensity of the relationship matters and numerical values are ‘attached’ to each of the lines). One of the most important point measures in SNA is that of degree centrality. The aim is to detect the most central (i.e. the most popular) actor within the structure. This is defined as simply the number of incumbent linkages that a given node has. When networks are directed, the degree centrality may include separately in-

[9] Note that a single ID for each inventor and anyone else involved is missing. Hence, to compile the mobility history of inventors, we need to identify them individually by name and surname, as well as via other useful information contained in the patent document. Data cleaning and parsing, name matching, and name disambiguation are the different stages undertaken to single out who is who in these patents, see Miguélez and Gómez-Miguélez (2011).

degree centrality (the number of edges directed to the vertex) and out-degree centrality (the number of edges that the vertex directs to other vertices).

Using the different variables suggested and the corresponding instruments, we compute a single measure that allows us to assert whether or not a given region is a knowledge networking region. In addition, we obtain a composite indicator for the formal linkages dimension and another for informal linkages.

Both synthetic indicators corresponding to each dimension are developed following the procedure used in the European Innovation Scoreboard (2009). Specifically, since the indicator variables we are using for the two different categories of linkages can be highly volatile and have skewed data distributions (where most regions show low performance levels and a few regions show exceptionally high performance levels), data will be modified firstly using a square root transformation. Secondly, based on the square root values, rescaled values are obtained by subtracting the minimum value and then dividing by the difference between the maximum and minimum value. The maximum rescaled score is thus equal to 1 and the minimum rescaled score is equal to 0.[10] For each kind of linkage (informal and formal) a composite indicator is calculated as the unweighted average of the rescaled scores for all indicators within the respective dimension. In sum, knowledge networking regions are regions above the European average in terms of specialization on both types of linkages.

4.2. Data sources

The raw data corresponding to informal knowledge diffusion variables (R&D expenditure, patents, and human capital) were assembled by CRENoS, using manifold data sources: Eurostat, OECD REGPAT database, ISTAT and the Institut National de la Statistique et des Études Économiques. A summary of data sources can be found in Table 1, where the time span considered for each variable is also reported.

[Insert Table 1 about here]

[10] To determine the maximum and minimum scores in the normalization process, we exclude outliers. Positive outliers are identified as values that are higher than the average plus 2 times the standard deviation. Negative outliers are identified as values that are lower than the average minus 2 times the standard deviation.

The data source for the formal knowledge exchange variables was the OECD REGPAT database (January 2010 edition). The OECD citations database (January 2010 edition) was used for the cross-regional citations. A socio-matrix was built for each of the variables, and degree centrality (or in-degree centrality) measures were calculated.

Population data from Eurostat was used to normalize all six measures to the size of the region (see Table 1 again).

We are completely aware of the caveats of using patent data in economic analysis. For instance, it is well known that not all inventions are patented, they do not have the same economic impact, and not all patented inventions are commercially exploitable (Griliches, 1991). Additionally, it is known that firms frequently patent for strategic reasons, to build up a patent portfolio to improve their position in negotiations or their technological reputation (Verspagen and Schoenmakers, 2004). Equally, the socio-matrices that were built reflect, to some extent, either the innovation capacity of regions, the degree of decentralization of innovation activity in the different national states, or the different sectoral specializations in regions, which in turn determine the regional propensity to apply for patents (pharmaceuticals and biotech firms have an above average patent propensity).[11] Bearing these shortcomings in mind, we still find the empirical analysis worthwhile.

5. Results

We built both sub-indicators using the procedure described above. Figure 2 shows the scatter plot of the sub-indicators that were computed. Clearly, a strong positive relationship arose, as the correlation coefficient is 0.73. Note that the majority of the regions were either non-interactive (113) or knowledge networking regions (118). Meanwhile, only 41 regions were clustering regions, and 15 were globalizing regions. Clearly, there seems to be a relationship between both sub-indices. We believe that this relationship is not accidental. Whether or not there is a causal relationship between the two sub-indices or the direction of this causality are interesting questions which are beyond the scope of the present analysis, though.

[Insert Figure 2 about here]

Figure 3 maps the spatial distribution of the four categories of regions considered. A short description of each type of region is given below, based on Figures 2 and 3.

[11] See Ter Wall and Boschma (2009) for a discussion of additional shortcomings of using patents in regional analysis, and Lenzi's (2010) awareness of the use of inventors identified through patents.

Clustering Regions. We computed that 41 regions out of 287 could be labelled as clustering regions. These are regions that are located in relatively close proximity to other highly innovative regions (in terms of R&D, patents and human capital) and therefore can potentially receive informal knowledge flows governed by physical distance. However, and more importantly, these regions lack a critical number of formal, intentional knowledge linkages with external sources of knowledge. Amongst them, we identified regions in the centre of Spain and north of Italy, some French regions close to Paris and Germany, some regions in the north and west of England, part of Ireland, and the regions of southern Norway. To sum up, the Clustering regions seem to belong to the EU15 and are close to core regions that are both informally and formally specialized. Broadly speaking, they are low-to-medium technologically advanced regions that, by happy chance, are located physically near to knowledge poles and are therefore dragged into innovative activities by their innovative neighbours.

Globalizing Regions. We computed that 15 regions out of 287 were labelled as globalizing regions. These regions are well connected by formal linkages to external areas, in spite of being relatively physically isolated from other innovative regions. Broadly speaking, these regions tend to perform notably better than clustering regions in terms of innovation activity. The list includes 1 German region (Dresden), 4 French regions (Île de France, Bourgogne, Provence-Alpes-Côte d'Azur and Bretagne), 2 British regions (East Anglia and North Eastern Scotland), Emiglia Romana in Italy, Trondelag in Norway, Wien in Austria, Pohjois Suomi in Finland, 2 Swedish regions (Vaestsverige and Örve Norrland) and 2 Slovenian regions (Zahodna Slovenija and Vzhodna Slovenija). Note that 2 of these 15 regions contain important capital cities, e.g. Paris and Wien. This kind of region acts more intensely as a regional knowledge hub, since it is connected to external knowledge sources by means of formal relations, and enables actors in nearby regions to access knowledge by means of a contagious process of informal interactions. This is particularly true for the two aforementioned capitals.

Non-interactive Regions. We computed that 113 regions out of 287 were non-interactive regions. These regions, which lack potential access to external knowledge by means of formal and informal linkages, are mainly those belonging to the New Entrant countries and some specific regions in southern European countries (all of Portugal and Greece, most of Spain except the central area and the south of Italy).

Knowledge Networking Regions. Networking regions are concentrated in the centre of Europe as well as in the Scandinavian countries. These regions are physically located close to high performing regions, so they are potentially in an advantageous position to benefit from informal knowledge diffusion mechanisms. However, they also act as knowledge hubs that are formally connected to external knowledge pools. As we can see, this sub-sample consists of 118 regions out of 287, which are mostly located in Germany, the Netherlands, Belgium, Denmark, southern Sweden, southern Finland, Switzerland, northern Italy, south-east England and part of France. Therefore, apart from 3 northern Italian regions, no other region in Southern or Eastern Europe appears on the list. This supports a clear core-periphery pattern in the geographical distribution of the regions that in one way or another rely on external sources of knowledge for the development of innovation. Therefore, broadly speaking, knowledge networking regions are those that are better positioned to benefit more from spatial knowledge diffusion, through different regimes and at different spatial scales, and from the construction of the European Research Area.

[Insert Figure 3 about here]

5.1. Robustness analysis

Here we list a number of robustness checks that we have performed for the calculation of the two sub-indicators presented so far. The results (the number and type of regions in each category) do not vary to a large extent. Consequently, most of the results are not presented here to save space. However, they can be provided by the authors on request. A few of the maps resulting from these checks are shown in Figure 4 below.

Firstly, we recalculated the informal linkages composite indicator using different weight matrices. Concretely, less complex matrices were used, such as a first-order contiguity matrix (Figure 4.1), an inverse distance matrix, and a squared inverse distance matrix (Figure 4.2). Any significant variation must be set apart (as expected, the first-order contiguity weight matrix slightly shifted the typological classification of some of the regions, which reflects the heterogeneous size of European NUTS2 regions).

Secondly, we recalculated the formal linkages indicator by subtracting all the linkages made with regions contiguous to the focal region (Figure 4.3), regions whose centroid lies within 300 km of the centroid of the focal region, regions belonging to the same NUTS1 as the focal region, and regions belonging to the same country as the focal region (Figure 4.4). Even though a few changes were observed, the general picture remains the same.

[Insert Figure 4 about here]

6. Concluding remarks and policy implications

In the previous sections, we described a detailed method to construct a composite indicator and two sub-indices that examine the ways in which actors in regions may access external-to-the-region pools of different and complementary knowledge. In motivating our approach, we extensively surveyed an instrumental list of theoretical and empirical studies across different disciplines and sub-disciplines. These studies have more or less dealt with the mechanisms through which knowledge diffuses, especially across space and between different locations. Based on our method, we also provided a typology of regions that captures their diversity in terms of their degree of openness to external sources of knowledge. Finally, the NUTS2 regions of 31 European countries were used to apply our novel approach and derive preliminary conclusions and policy implications from the results.

In spite of increasing evidence of the role of knowledge diffusion across different geographical areas and the importance of this phenomenon for regional innovation, our review showed that mainstream research and policymakers barely consider this issue when they assess the innovative performance of cities, regions or countries. We believe that connections to external sources of knowledge are as important for regions as their scientific and technological base, and policies that specifically focus on this issue might be required. For years, regional policy programs have aimed to strengthen the local cluster knowledge base and its social pre-conditions for innovation (Rodríguez-Pose and Crescenzi, 2008). Here, we call into question this narrow approach and propose that the external dimension of regions is also relevant. Since this dimension has been quietly overlooked so far, policymakers lack a critical pillar for the development of regional innovation systems. However, as stressed in Bathelt et al. (2004), the 'local buzz' basically takes care of itself, whilst external linkages specifically require institutional and infrastructure support. The present inquiry was an attempt to open up a future research agenda within the literature to improve our understanding of the external dimension of regional innovation systems and consequently develop a battery of policies on this issue.

Next, our empirical approach provided a typology of four distinct types of regions according to their degree of openness to external sources of knowledge, as well as their specialization in the different ways in which actors in these regions may access external knowledge, that is, formal and informal linkages. This diversity of regions suggests that specific policies should be applied to each type of region, not only according to their innovative performance and social pre-conditions, but also according to the ways in which they connect with outsiders. This typology also translates into a ranking, which could serve as a guideline for regions to identify other areas with similar development conditions that have achieved a better rank and whose best practices could serve as a benchmark for implementing similar policies elsewhere.

Finally, our study also provides elements that could help firms' localization policies. As stressed in Gertler and Levitte (2005), firms' location decisions are influenced by the endogenous characteristics of regions and by opportunities to benefit from linkages worldwide, through which they can access manifold knowledge pools.

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ANNEX

Figure 1. A typology of regions according to the type of linkages to external sources of knowledge

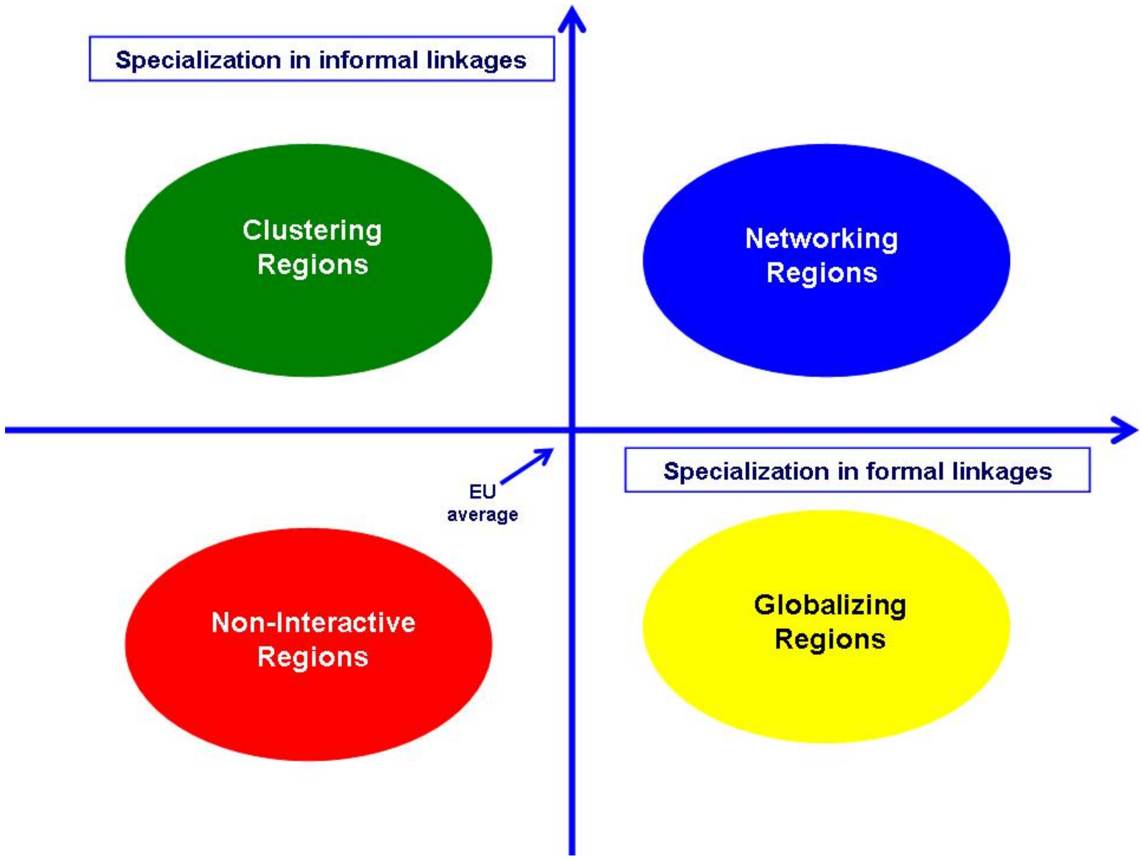


Table 1. Description of the variables used for the synthetic indicators

Variable	Description	Sources	Years considered	Weight
VARIABLES USED FOR THE CONSTRUCTION OF THE SYNTHETIC INDICATOR ON SPATIAL LINKAGES				
R&D exp. per capita in the neighbouring regions	Average value of the millions of Euros spent on RD activities over population in the closest neighbouring regions: wij=exp(-0.01·dij), cut-off 300 km	Compiled by CRENoS using Eurostat, ISTAT and Institut National de la Statistique et des Études Économiques	2006-2007	1/3
Patent activity per capita in the neighbouring regions	Average number of patents released over population in the closest neighbouring regions: wij=exp(-0.01·dij), cut-off 300 km	Compiled by CRENoS using the OECD REGPAT database	2005-2006	1/3
Human capital in the neighbouring regions	Percentage of population aged 15 and over with tertiary education in the closest neighbours: wij=exp(-0.01·dij), cut-off 300 km	Compiled by CRENoS using Eurostat	2005-2007	1/3
VARIABLES USED FOR THE CONSTRUCTION OF THE SYNTHETIC INDICATOR ON A-SPATIAL LINKAGES				
Co-patents per capita	Number of patent co-authored with inventors from outside the region over population	Compiled by AQR using the OECD REGPAT database	2002-2004	1/3
Inflows of inventors per capita	Number of inflows of inventors coming from other regions over population	Compiled by AQR using the OECD REGPAT database	2002-2004	1/3
Cross-regional citations per capita	Number of citations made to patents from other regions over population	Compiled by CRENoS using the OECD REGPAT and citations database	2002-2004	1/3

Figure 2. Scatter plot of European regions. Formal linkages vs. informal linkages

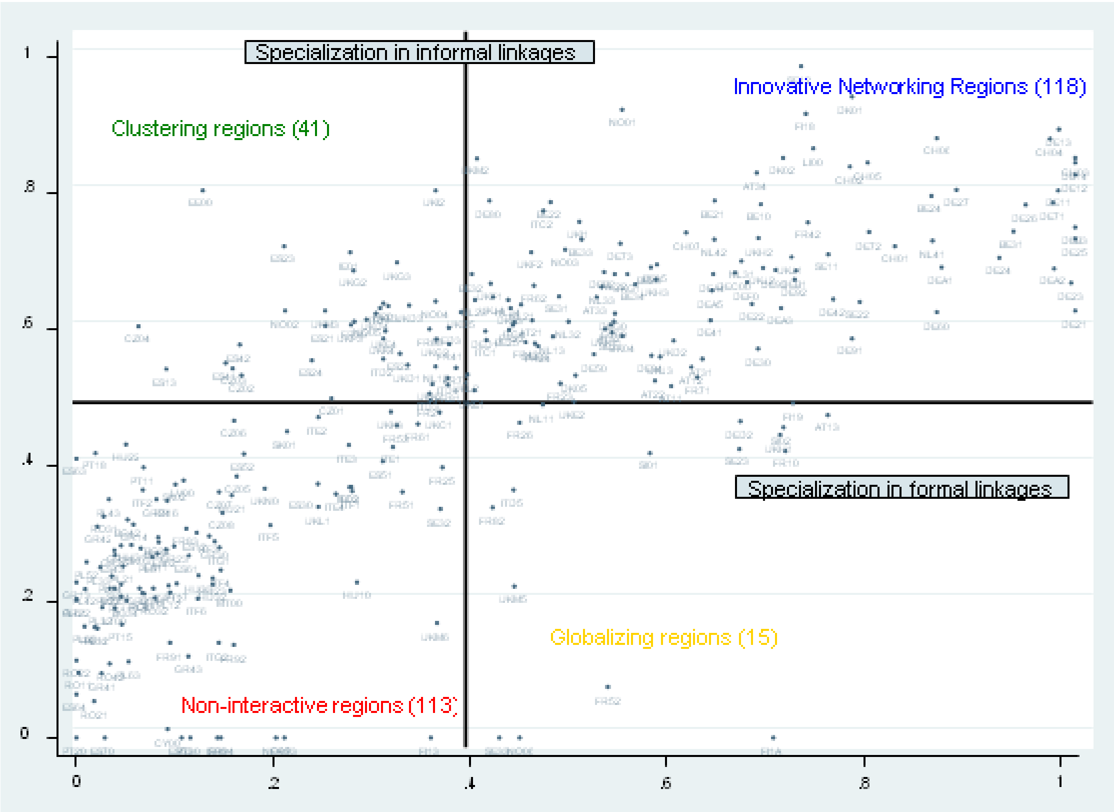


Figure 3. Typology of regions depicted on a map

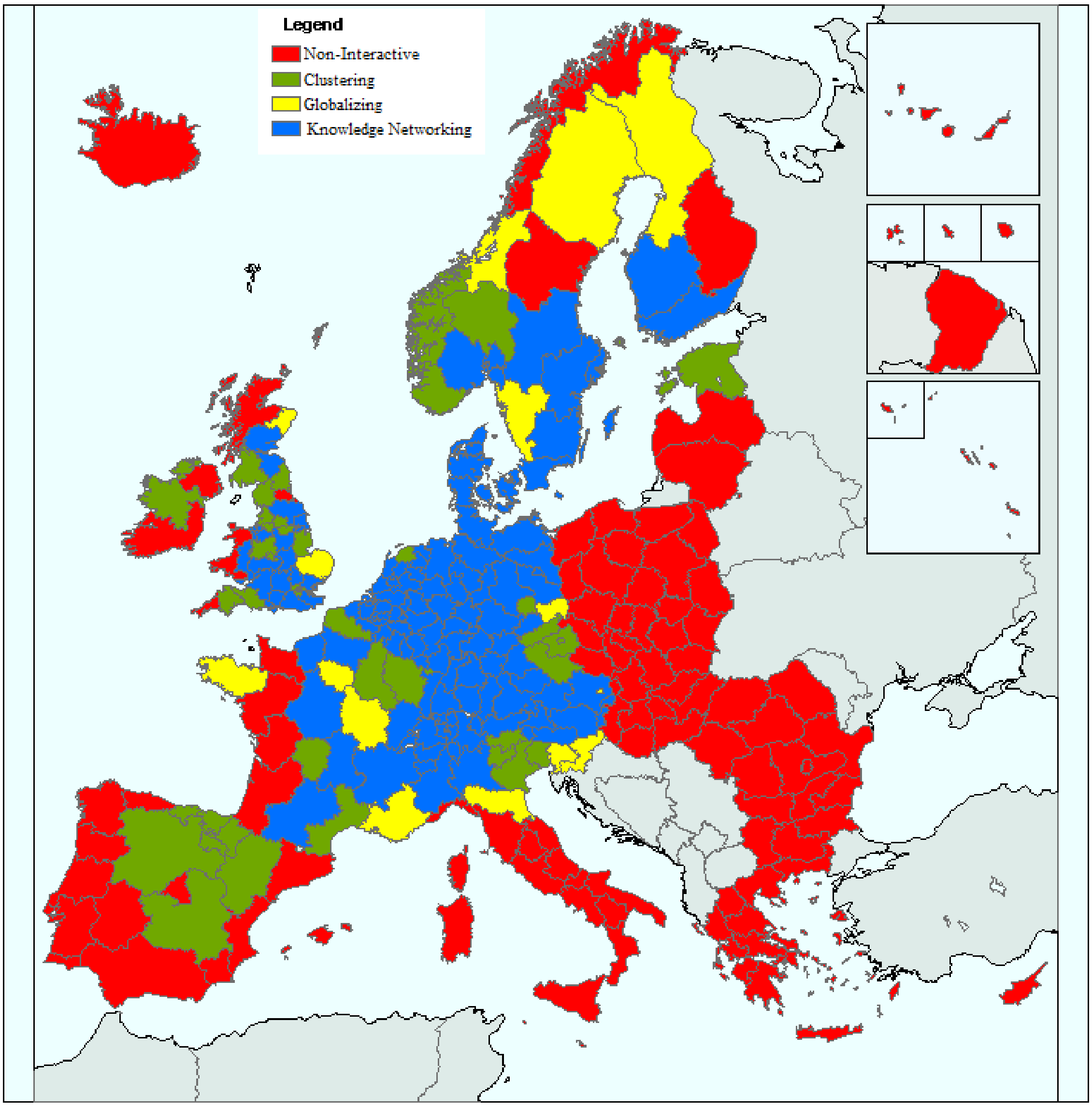


Figure 4. Typology of regions depicted on a map. Robustness analysis

Figure 4.1. First order contiguity weight matrix

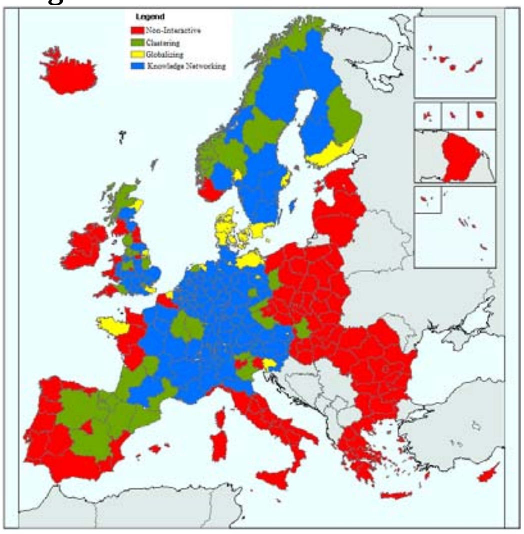


Figure 4.2. Inverse of the squared distance weight matrix

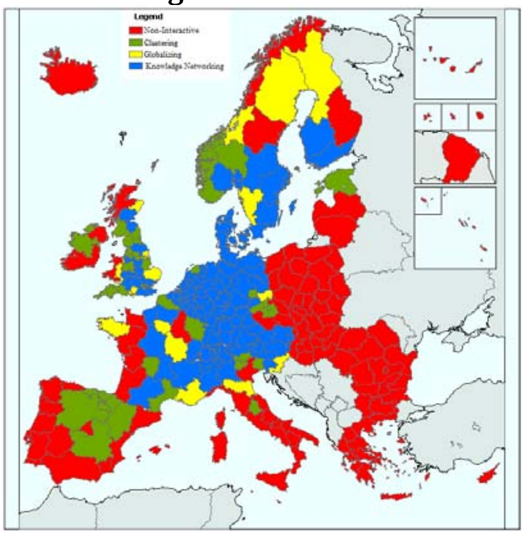


Figure 4.3. Formal linkages between contiguous regions excluded

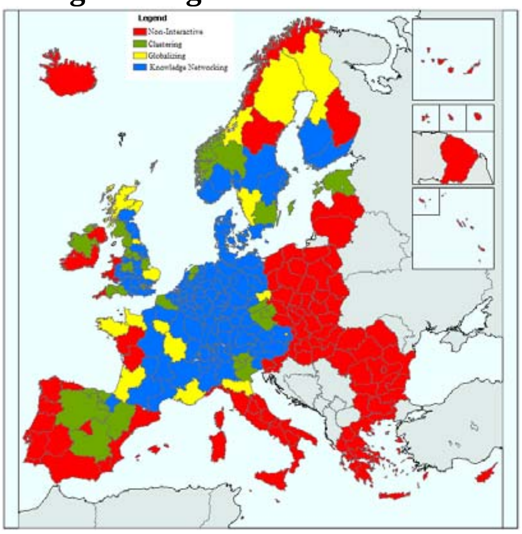
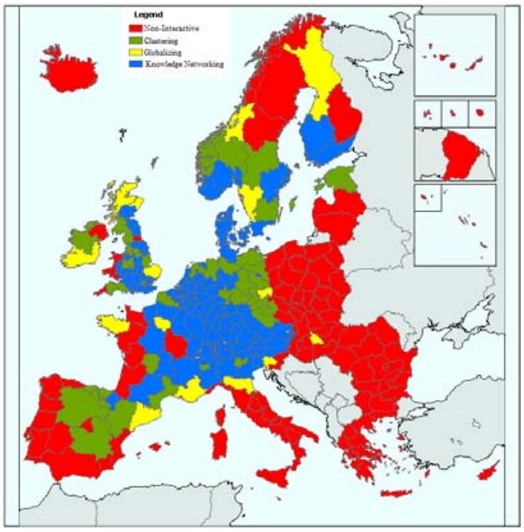


Figure 4.4. Formal linkages within countries excluded



Appendix. List of countries (and number of regions in each one):

Austria, AT (9), Belgium, BE (11), Bulgaria, BG (6), Switzerland, CH (1), Cyprus, CY (1), Czech Republic, CZ (8), Germany, DE (39), Denmark, DK (5), Estonia, EE (1), Spain, ES (19), Finland, FI (5), France, FR (26), Greece, GR (13), Hungary, HU (7), Ireland, IE (2), Iceland, IS (1), Liechtenstein, LI (1), Italy, IT (20), Lithuania, LT (1), Luxemburg, LU (1), Latvia, LV (1), Malta, MT (1), the Netherlands, NL (12), Norway, NO (7), Poland, PL (16), Portugal, PT (7), Romania, RO (8), Sweden, SE (8), Slovenia, SI (2), Slovakia, SK (4), United Kingdom, UK (12).

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