Exploring the impact of inter-regional linkages on regional diversification in Europe in the context of smart specialisation

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Contents

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ABSTRACT

Regional capabilities are regarded a key pillar of Smart Specialization (S3) policy. There is yet little focus in S3 on the role of inter-regional linkages, as there is little understanding of how inter-regional linkages may affect the development of new activities in regions, and to what extent these linkages may compensate for the lack of regional capabilities. The report analyses 292 NUTS2 regions in Europe and finds that inter-regional linkages have a positive effect on the probability of regions to diversify, on top of the impact of regional capabilities. Moreover, it seems this is especially true for inter-regional linkages that give access to new capabilities that are related to existing capabilities in the region. Finally, a complementarity indicator has been developed that can be used by regions in their S3 strategy to identify regional strategic partnerships, depending on the presence of complementary capabilities in other regions.

1. INTRODUCTION

There is a large body of literature showing that regions tend to build on existing capabilities to develop new activities (Boschma 2017). The role of local capabilities as source of regional change has been regarded a key pillar of smart specialization (S3) policy from its very start (Foray 2015; Balland et al. 2019). The objective of S3 is building competitive advantage in new domains in which regions possess capabilities. However, there is yet little focus on the role of inter-regional linkages in S3, despite claims in the literature to do so (Thissen et al. 2013; Radosevic and Ciampi Stankova 2015; Iacobucci and Guzzini 2016; Sörvik et al. 2016; Los et al. 2017; Santoalha 2018; Varga et al. 2018; Barzotto et al. 2019).

There have been recurrent claims that inter-regional linkages give regions access to external knowledge that is regarded as crucial to tackle or avoid a tendency of regions to get locked-in (e.g. Camagni 1991; Grabher 1993; Asheim and Isaksen 2002; Bathelt et al. 2004; Boschma and Iammarino 2009; Tavassoli and Carbonara 2014; Grillitsch and Nilsson 2015; Miguelez and Moreno 2018). However, studies in regional diversification have primarily focused on regional capabilities but neglected the role of inter-regional linkages (Boschma 2017).

The same applies to the literature on new path development that has paid little to no attention to inter-regional linkages (Trippl et al. 2018). So, there is little understanding of how inter-regional linkages may affect the development of new activities in regions, and to what extent inter-regional linkages may compensate for the lack of capabilities in a region.

This project makes a first step to fill that gap by analyzing 292 NUTS2 regions in Europe. The first objective is to analyze the impact of external ties on technological diversification in European regions, while controlling for regional capabilities. So, we test whether inter-regional linkages have a positive effect of regions to diversify, on top of the impact of regional capabilities. Moreover, we test which inter-regional linkages matter in particular: do linkages that give access to additional capabilities in other regions that are related to existing capabilities of regions have a stronger impact on regional diversification? The second objective is to develop a complementarity indicator that can be used by regions in their S3 strategy to identify regional strategic partnerships, given the capabilities in other regions. This enables us to map for each region to what extent other regions in Europe have complementary capabilities that are missing in the region.

The report is structured as follows. Section 2 gives a short literature review. Section 3 describes the patent dataset and presents the findings on the effect of the quantity and nature of inter-regional linkages on regional diversification. Section 4 presents an indicator that regions can use to map complementary capabilities in other regions. Section 5 concludes.

2. INTER-REGIONAL LINKAGES, RELATEDNESS AND SMART SPECIALIZATION

To develop new economic activities in regions is a key objective of S3 policy. Balland et al. (2019) argue that S3 policy should target new economic activities that have high growth potential (to accrue economic benefits) and that can build on existing capabilities in regions (to lower costs of diversification). The idea is that regions are more likely to develop new activities related to existing local activities, because these provide similar (but not identical) capabilities, such as knowledge, skills and institutions. New capabilities that are needed to develop new activities are easier to acquire when close to local capabilities. By contrast, unrelated diversification requires a complete transformation of local capabilities, which is accompanied by high costs and a high risk of failure, and thus less likely to happen.

This claim has found confirmation in empirical research in the last decade (Boschma 2017; Hidalgo et al. 2018). The product space literature (Hidalgo et al. 2007) found that new export products are no random events, but strongly embedded in capabilities at the national scale. The economic geography literature found a similar tendency of regions to diversify into new activities that are related to existing activities (Neffke et al. 2011; Kogler et al. 2013; Muneepeerakul et al. 2013; Rigby 2015). Despite the use of different research layouts (e.g. focusing on different activities such as industries, technologies or jobs, or employing different relatedness measures), studies find that related diversification is the rule: local capabilities condition which new activities are more likely to develop in regions.

However, these studies primarily focus on the role of regional (and national) capabilities. As a consequence, they draw little attention to inter-regional linkages that may affect regional diversification (Boschma 2017). Also the path development literature has paid little attention to the potential role of inter-regional linkages for new path creation (Trippl et al. 2018). This is remarkable, as studies on clusters, industrial districts, regional innovation systems and value chains have not only claimed but also empirically examined the role of extra-regional linkages for regional development (Camagni 1991; Asheim and Isaksen 2002; Bathelt et al. 2004; Giuliani and Bell 2005). Almost without exception, they refer to their crucial role to prevent regions to end up in a lock-in situation.

There are forces at work that make individuals, firms and regions prone to lock-in. What is key is that economic actors are subject to bounded rationality: access to information is limited, and, above all, firms have limited capacity to absorb external information. To reduce uncertainty, firms search for new knowledge close by (Nelson and Winter 1982). As a result, the process of knowledge creation is cumulative, path-dependent and localized (Dosi 1982). Also geographical proximity matters: access to distant knowledge is poor in general, and knowledge sharing often requires frequent face-to-face contact, the more so when knowledge is tacit. Therefore, knowledge spillovers are often geographically bounded (Jaffe et al. 1993). The potential downside of this tendency is too much inward orientation. Knowledge exchange with the same local actors may lose value over time (Maskell and Malmberg 1999), and can lead to cognitive lock-in (Nooteboom 2000; Boschma 2005). This implies there is a tendency of regions to get locked in and become over-specialized (Grabher 1993).

This lock-in process may be avoided or overcome by linking to agents in other regions, to get access to external pools of knowledge (Maskell and Malmberg 2007; Crespo et al. 2014). Bathelt et al. (2004) argued that cluster firms need to supplement local knowledge with external knowledge, and for that purpose build global pipelines. Network studies show that firms in clusters need to connect to bodies of knowledge residing elsewhere: the best performing cluster firms are well connected to the outside (Giuliani and Bell 2005; Boschma and Ter Wal 2007). Studies also investigate the role of gatekeepers who link local actors to knowledge outside a cluster (Owen-Smith and Powell 2004; Morrison 2008; Graf 2011; Morrison et al. 2013 Broekel and Mueller 2018). What these studies show is that diffusion of external knowledge into a cluster is limited. As firms require absorptive capacity to exploit external knowledge, not all cluster firms are able to benefit from non-local knowledge.

Studies on knowledge networks using a proximity framework also refer to the crucial role of inter-regional linkages. Geographical proximity of local actors may contribute to lock-in. This problem of lock-in may be overcome by local agents connecting to others outside the region (Boschma 2005). Studies indeed demonstrate that non-local knowledge linkages are effective for knowledge acquisition and innovation when combined with local knowledge linkages. Non-local linkages are regarded as crucial for peripheral regions because local networks and resources are weak in these places (Fitjar and Rodríguez-Pose 2011; Grillitsch and Nilsson 2015). De Noni et al. (2018) showed that firms in lagging regions are more innovative when engaged in collaborative extra-regional networks with knowledge-intensive regions.

While these network studies on clusters and regions have increased our understanding of the role of external knowledge flows, they suffer from a number of limitations. First, studies tend to examine just one single case (a cluster or a region), making it hard to generalize on the importance of non-local external linkages (Breschi and Lenzi 2015). Second, this literature often suggests that local and non-local linkages *in tandem* are crucial for knowledge creation and productivity in regions (De Noni et al. 2017). However, Morrison et al. (2013) argue that "… the still unresolved issue is how to generate an effective mix" (p. 93). Moreover, Grillitsch and Nilsson (2015) claim that non-local linkages do not necessarily complement local knowledge spillovers, and can even compensate for the lack of local knowledge spillovers in peripheral regions. How far one can go in learning from access to non-local capabilities when regional capabilities are missing in a region is, however, still an open question. Third, the cluster literature focuses attention almost exclusively on the role of extra-cluster linkages for the capacity of clusters to renew themselves (Menzel and Fornahl 2010). However, we still have little understanding of the role of inter-regional knowledge sourcing during the emergence phase of clusters (Ter Wal and Boschma 2011; Henn 2013; Vicente 2018). The same applies to their role in new path development in regions (Trippl et al. 2018).

Recently, scholars have expressed great interest in including inter-regional connections in S3 policies. Thissen et al. (2013) looked at inter-regional trade linkages in Europe, and how this can be incorporated in S3 policy. They make a distinction between demand-led growth (i.e. growth of markets in a region's export destinations) and structural growth (i.e. development of new export products). While this first type of growth tends to be more important but beyond the control of S3 policy, the second type of growth seems to come closest to S3 policy that aims to develop new export products. However, it is not entirely clear how S3 policy should promote such new activities, and it is not explained how existing activities in other regions can contribute to that diversification process.

Studies on global networks have advocated a S3 policy that attach great importance to inter-regional linkages (Radosevic and Ciampi Stankova 2015). The literature on global value chains (Gereffi et al. 2005) has shown how regions play different roles in global networks: some regions are centres of corporate control and house dynamic high-end activities like R&D facilities, while other regions have evolved into branch plant economies. This global division of labour may reflect that regions are locked-in or trapped in certain activities (Blazek 2016). This makes relevant the question from a S3 perspective whether regions have possibilities to enter new value chains and upgrade their activities along existing value chains (Los et al. 2017). However, this literature has been less explicit on how inter-regional linkages can contribute to new path development (Trippl et al. 2018).

Interestingly, studies are starting to incorporate the role of extra-regional linkages for regional diversification and new path development. Studies have focused on the importance of neighbour countries (Bahar et al. 2014) and neighbour regions (Boschma et al. 2017). These studies find that regions are more likely to develop new export industries in which their neighbour regions are already specialized. Neighbour regions also tend to have more similar export structures when they are connected. Andersson et al (2013) found high-quality imports to be crucial for the entry of new high-quality export products in regions. Santoalha (2018) looked at the role of cooperation inside and across European regions and concluded that both forms of cooperation boost regional diversification. However, these studies do not account for the nature of inter-regional linkages that may affect regional diversification.

Boschma and Iammarino (2009) applied a relatedness framework to characterise the type of inter-regional linkages. Using trade data, they found that regional growth is not simply affected by having extra-regional linkages, or by having access to a diversified set of external knowledge sources. Instead, they found a positive effect of extra-regional linkages on employment growth in a region when the cognitive proximity between the knowledge base of a region and the extra-regional knowledge is neither too small nor too large. In a similar way, Boschma et al. (2014) looked at the impact of relatedness between the inflow of external knowledge and the local knowledge base on new biotech activities in global cities. Miguelez and Moreno (2018) examined the effect of the nature of extra-regional linkages on the type of innovation in European regions. They found that extra-regional knowledge linkages have a higher impact on innovation when the similarity between these flows and the local knowledge base is higher. Their study showed that extra-regional knowledge linkages enhance incremental innovation when regional knowledge bases are similar, while they promote radical innovations when based on related (rather than similar) technologies.

Barzotto et al. (2019) applied a relatedness framework while estimating the role of extra-regional linkages for technological development in EU regions. They find that the level of extra-regional collaboration is often higher in peripheral regions where it promotes innovation. Their findings suggest that regions with weaker knowledge capabilities may benefit more from extra-regional knowledge inputs. Interestingly, they also found a negative effect of technological similarity between external knowledge through collaboration and the knowledge base of the region. As a result, Barzotto et al. (2019) plead for a place-based S3 policy in which a focus on extra-regional linkages is less relevant for core regions, but would make more sense for peripheral regions, but only when promoting diversity in extra-regional collaborations, rather than collaborations based on relatedness. What this study did not look at, however, is the effect of extra-regional linkages on regional diversification: it might still be the case that extra-regional collaborations provide access to specific knowledge that initiated new path development in particular technologies.

When exploring the effect of extra-regional linkages, there is also focus in the literature on what types of linkages matter. Breschi and Lenzi (2015) investigated the role of external linkages and gatekeepers for the evolution of the knowledge base in US cities. They argued that cities with a specialized, localized knowledge base benefit more from external knowledge through gatekeepers, in contrast to other regions where direct external linkages contribute to the broadening and rejuvenation of their knowledge base. Moreover, studies have explored the effect of inflow of external firms on regional diversification, especially on unrelated diversification in regions (Neffke et al. 2018; Elekes et al. 2019).

We can conclude that few studies have estimated the effect of inter-regional linkages on regional diversification, and no study yet has examined the extent to which the nature of inter-regional linkages (in terms of relatedness) has had an impact on the diversification process in regions. This report will address this gap in the literature, with the objective of adding a third dimension to S3 policy. This requires investigation of the impact of the intensity and nature of inter-regional linkages on regional diversification. Doing so, we examine the relative importance of inter-regional linkages, controlling for local capabilities. Finally, a framework is proposed that enables a region to identify capabilities in other regions it could connect to, in order to get access to capabilities that might help the region to diversify in new activities.

3. IMPACT OF INTER-REGIONAL TIES ON TECHNOLOGICAL DIVERSIFICATION IN EUROPEAN REGIONS

So, the first objective is to analyze the impact of inter-regional ties on technological diversification in European regions, while controlling for regional capabilities. This enables us to estimate the extent to which a lack of capabilities in a region may be compensated by access to capabilities through inter-regional connections. Moreover, we test which capabilities in those extra-regional linkages matter in particular. We expect that linkages that give access to additional capabilities in other regions that are related to existing local capabilities have a stronger impact on regional diversification (Boschma and Iammarino 2009).

Following Boschma, Balland, and Kogler (2015), a regional diversification model is estimated with respect to new technologies. Patent data are used and derived from the OECD REGPAT dataset (2019 version). We identify patents in 654 technological classes (CPC) for 292 European regions (NUTS-2 level). The NUTS-2 regions include regions in all EU countries and all EFTA-countries (Iceland, Liechtenstein, Norway and Switzerland). Regional economic data from EUROSTAT are used to build control variables.

The dependent variable is the entry, or not, of a new specialization in a technology in a region. A linear probability model is used to assess the probability that a region develops a Relative Technological Advantage (i.e. RTA>1) in a new technology in the period 1992-2016. As other studies, the entry probability of a new technology in a time window of 5 years is assessed, for 5 subsequent periods (1992-1996; 1997-2001; 2002-2006; 2007-2011; 2012-2016). See Appendix 1 for details.

All independent variables are measured in the period before the time window of 5 years. As other studies, a Relatedness Density (RD) measure is constructed to assess the effect of regional capabilities. RD is measured as the proximity between a technology and the overall technological portfolio of a region. Appendix 2 provides the technical details. The effect of inter-regional linkages is measured as the number of ties with inventors in other regions (NL). We also constructed a variable Complementary inter-regional Linkages (CL) that measures whether a region collaborates with other regions that are specialized in technologies that can provide knowledge complementary to the potential new technology. While RD reflects the local supply of related internal knowledge in which a region can tap in to diversify in a new technology, CL captures the supply of related external knowledge in which a region can tap into to diversify. Appendix 3 provides the details of this inter-regional linkage measure.

We also include control variables: (1) population (log) to account for different population sizes of regions; and (2) GDP per capita to account for the level of economic development. Appendix 4 provides summary statistics for the variables.

Figure 1 presents the findings of the regional entry model. As expected, we find a strong and positive effect of relatedness density (RD) in all specifications. This is a confirmation of earlier studies on the importance of relatedness for technological diversification of regions (Kogler et al. 2013; Rigby 2015; Balland et al. 2019). Moreover, we find a positive impact of the number of inter-regional connections (NL). So, both regional capabilities and inter-regional linkages tend to contribute to the entry of new technologies in European regions.

In Model 3, the new variable of complementarity of inter-regional linkages (CL) is added. As expected, we found a strong and positive effect: a new technology has a higher probability to enter a region when this region has connections with other regions that provide related (and thus relevant) capabilities with respect to this new technology. What is also interesting is that the positive effect of inter-regional connections *per se* (NL) turns into a negative effect, once we control for complementarity in inter-regional linkages (CL). This suggests that inter-regional connections are costly: adding connections with other regions that are not relevant to the technological structure of regions comes with a price. In Model 4, we find a positive interaction effect of local relatedness with related inter-regional ties (RD*CL): this means that the higher the internal relatedness in a region is, the stronger the impact of external relatedness. So, it turns out that related inter-regional linkages tend to reinforce, not weaken, the effect of local relatedness on technological diversification in regions. Finally, the coefficients of our control variables are positive and in most cases significant: population size and GDP per capita tend to increase the entry probability of new technologies in regions.

Figure 1. Diversification model

	Dependent variable:Entry			
	(1)	(2)	(3)	(4)
Relatedness Density (RD)	0.003***	0.003***	0.004***	0.002***
	(0.00003)	(0.00003)	(0.00004)	(0.0001)
Number of inter-regional linkages (NL)		0.005***	-0.025***	-0.017***
		(0.0003)	(0.001)	(0.001)
Complementarity inter-regional linkages (CL)			0.027***	0.018***
			(0.001)	(0.001)
RD*CL (interaction term)				0.0002***
				(0.00001)
GDP per capita	0.001***	0.0001	0.0002**	0.0001
	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Population (log)	0.015***	0.010***	0.011***	0.010***
	(0.001)	(0.001)	(0.001)	(0.001)
Period	-0.007***	-0.008***	-0.008***	-0.008***
	(0.001)	(0.001)	(0.001)	(0.001)

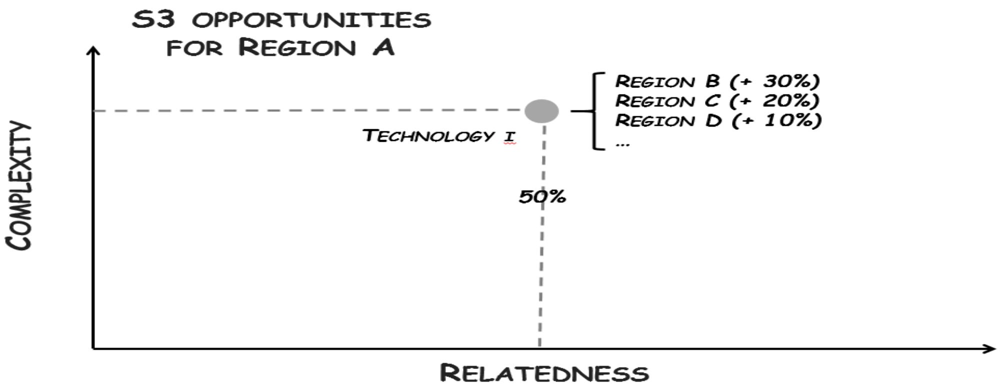
Constant	-0.142***	-0.083***	-0.172***	-0.120***
	(0.010)	(0.011)	(0.011)	(0.011)
Observations	379,876	379,876	379,876	379,876
R^2	0.037	0.038	0.044	0.044
Adjusted R^2	0.037	0.038	0.044	0.044
Residual Std. Error	0.318 (df = 379871)	0.318 (df = 379870)	0.317 (df = 379869)	0.317 (df = 379868)
F Statistic	3,658.418*** (df = 4; 379871)	2,970.927*** (df = 5; 379870)	2,885.502*** (df = 6; 379869)	2,522.347*** (df = 7; 379868)
Note:				*p**p***p<0.01

4. INTER-REGIONAL LINKAGES IN A S3 FRAMEWORK

Now the big question is how to incorporate this role of inter-regional linkages in a S3 policy framework. What is common is to calculate a technological similarity measure to identify regions with a similar technological structure: this measures how many technologies two regions have in common. However, what we need instead is a complementarity measure, which can assess for each technology that a region wants to prioritize in its S3 strategy which other regions can provide complementary capabilities. This measure can be used by European regions to identify regional strategic partnerships, given the capabilities in other regions.

This indicator maps for each region to what extent other regions in Europe have complementary capabilities that are missing in the respective region. This is illustrated in Figure 7. The S3 strategy of region A is based on the development of a new technology i that is highly complex (like biotech). Biotech is related to 10 other technologies. Region A has strong expertise in 5 out of these 10 technologies, leading to a level of relatedness density of 50%. Analysing the technological portfolio of other European regions would reveal that region B has strong expertise in 3 technologies that are related to biotech in which region A has no expertise in. So, region A could develop a S3 strategy in which it connects to region B. Through the creation of this inter-regional link, the relatedness density of region A would go up by 30%. This means it might make sense for region A to connect to region B, as it would increase its probability to diversify successfully into a new biotech activity.

Figure 7. Diversification opportunities of region through complementary inter-regional linkages



For illustrative purposes, we show to which European regions the Île-de-France region could connect if it aims to develop new key technologies like batteries (Figure 8) or hydrogen (Figure 9) as part of its S3 strategy. In Balland and Boschma (2019), we showed how much potential the Île-de-France region itself had (as measured by its relatedness density) to develop these two new key technologies. In this report, we show the potential increase of the relatedness density of Île-de-France region if it would connect to another European region. Île-de-France is marked black. Figure 8 shows European regions like Chemnitz, Rhône-Alpes and Dresden would be good partners to link to in order to develop new battery technologies. Figure 9 shows that European regions like Lorraine, Brussels region and Dresden could be relevant strategic partners for the Île-de-France region to develop new hydrogen technologies.

Figure 8. Map of complementarity of all European regions to Île-de-France region in new battery technologies

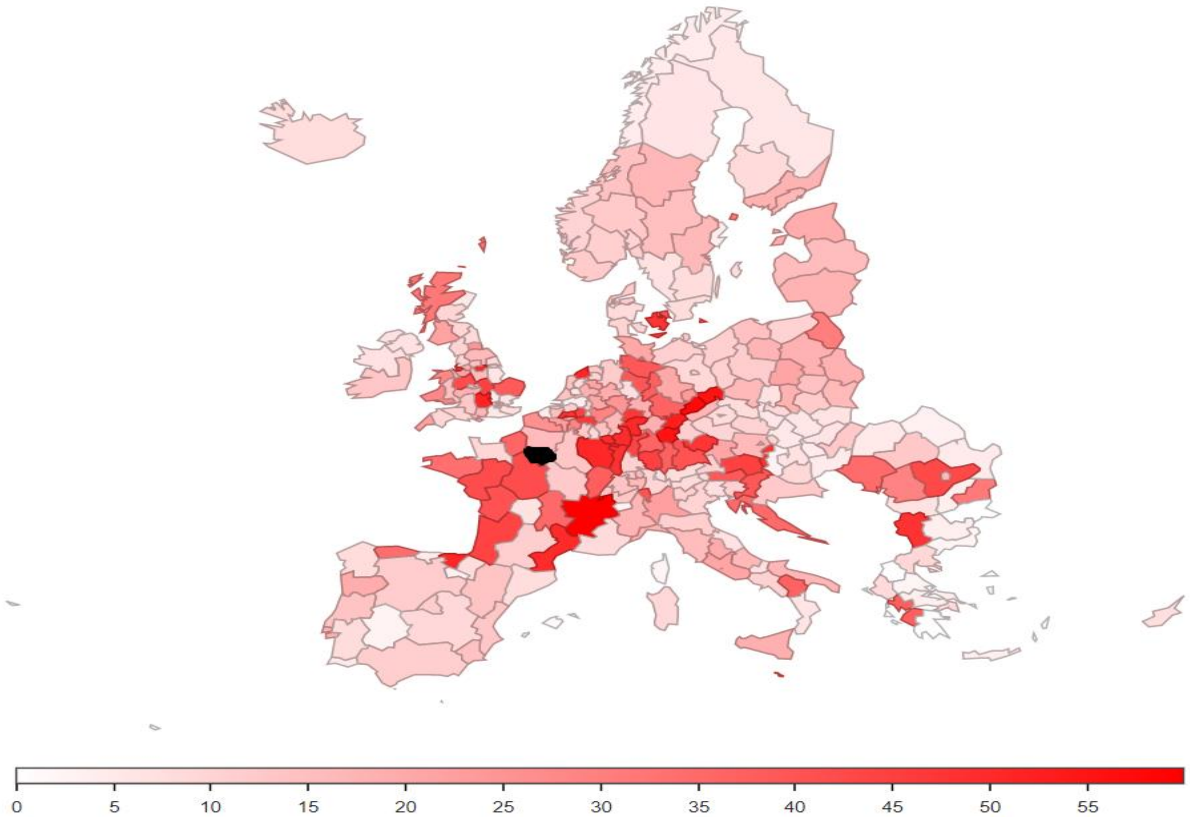
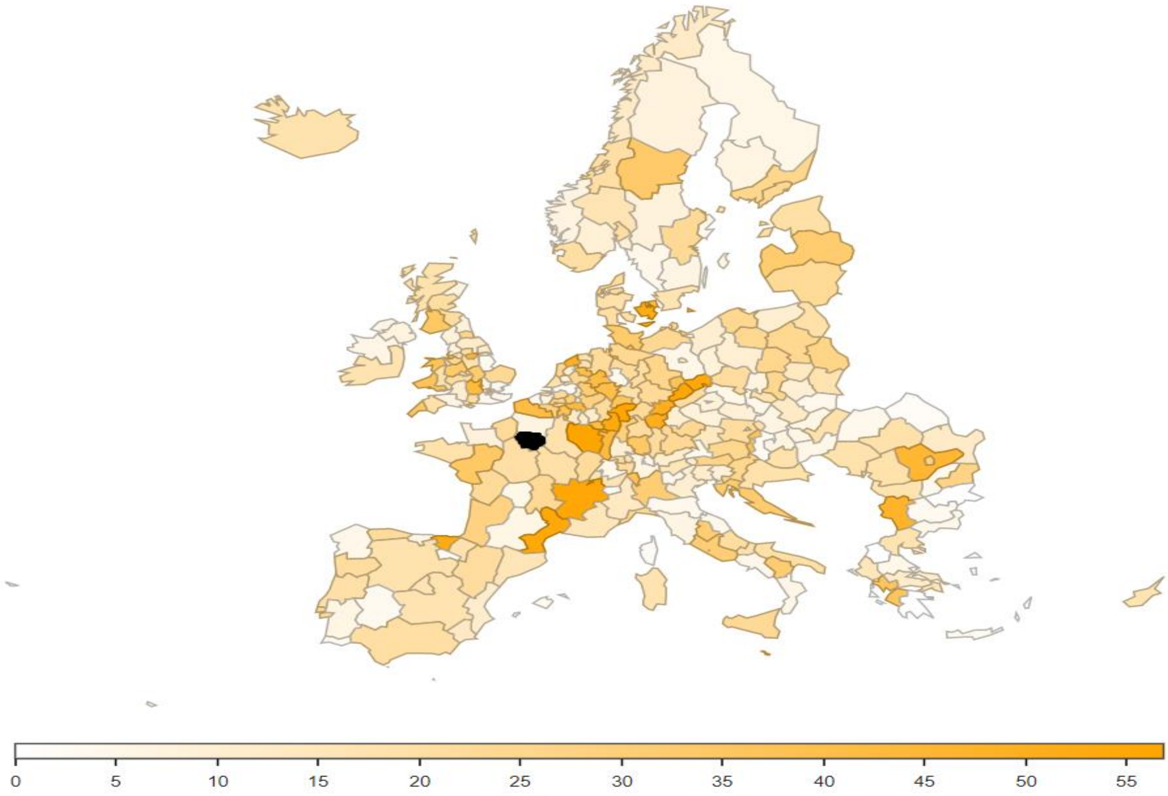


Figure 9. Map of complementarity of all European regions to Île-de-France region in new hydrogen technologies



This complementarity measure enables regions to develop a S3 strategy in which inter-regional linkages are also incorporated. This measure helps to assess diversification opportunities of regions by identifying complementarities in capabilities across European regions. It aims to identify other regions that could act as strategic partners to develop new and more complex activities in a region as part of its S3 strategy. In this project, we have mapped for each potential new technology (645 technologies) in each European region (292 NUTS-regions) to what extent other regions in Europe have complementary capabilities that are missing in the respective region. This information is useful for regions to identify and select other regions as the most relevant strategic partners in their S3 strategies because of complementarities in their capabilities. This sheds new light on the need to make connections between regions, as the policy focus is more about the exploitation of complementarities rather than about the making of inter-regional connections *per se*.

The two inter-regional metrics have been visualized and made available as an interactive network graph and as region-centered fully searchable tables.

5. CONCLUSIONS

Regional capabilities are regarded a key pillar of smart specialization (S3) policy. However, there is yet little focus in S3 on the role of inter-regional linkages. There is little understanding of how inter-regional linkages may affect the development of new activities in regions, and to what extent these linkages may compensate for the lack of regional capabilities. This paper analyzes how and to what extent 292 NUTS2 regions in Europe source external knowledge to fill internal knowledge gaps. The analysis finds that inter-regional linkages have a positive effect on the probability of regions to diversify, on top of the impact of regional capabilities. This is especially true for inter-regional linkages that give access to new capabilities that are related to existing capabilities in the region. The report also developed an indicator that can be used by regions to identify regional strategic partnerships, given the capabilities in other regions. This indicator maps for each region the extent to which other regions in Europe have complementary capabilities that are missing in the respective region.

Needless to say that this report has a number of limitations. First, there are the usual caveats of using patent data to estimate diversification potentials in regions. This applies especially to peripheral regions where other types of capabilities in low and medium tech may be more important, and should be made part of their S3 policy (Balland and Boschma 2019). Second, when looking for other regions as strategic partners, it could also be relevant, besides complementary capabilities, to take into consideration geographical and cultural proximity between the region and its potential partner regions. That is, once a set of regions has beenidentified as having complementary capabilities, a region might prefer to connect to those regions that are geographically near, or that share the same language or similar norms and values. Third, we did not look at the role of regional institutions. Poor institutions such as a low quality of government might impact negatively on the diversification opportunities of regions, especially in some peripheral regions (Cortinovis et al. 2017). So even when regional capabilities and inter-regional linkages are in place, a weak institutional structure might still prevent a successful diversification process in regions. Finally, one has to take into consideration that the degree of political autonomy of regions in Europe differs between countries, and even within countries. In Germany, for example, political power is more concentrated at the NUTS1 level (Länder), rather than the NUTS2 regions (Regierungsbezirke). This may have implications for the implementation of S3 policy more in general, and for the capacity of regions to link to other regions in particular.

APPENDIX 1. RELATIVE TECHNOLOGICAL ADVANTAGE (RTA)

We estimate an entry model that estimates the probability that a region specializes in a new technology. Following other studies, we calculate the Relative Technological Advantage (RTA) to assess whether a region becomes specialized in a technology that is new to the region. RTA is a binary variable that assumes the value 1 when a region possesses a greater share of patents in technology class *i* than the reference category (EU as a whole), and assumes value 0 otherwise. A region *r* has RTA in the production of technological knowledge *i (r = 1,..., n; i = 1, …, k)* such that $\boldsymbol{RTA_{r,i}^{t} = 1}$ if:

$$\frac{patents_{r,i}^{t} / \sum_i patents_{r,i}^{t}}{\sum_r patents_{r,i}^{t} / \sum_r \sum_i patents_{r,i}^{t}} > 1$$

APPENDIX 2. RELATEDNESS DENSITY MEASURE

First, we have calculated the degree of *relatedness* between each pair of technologies (654 CPC technology classes). We make use of co-occurrence analysis of technology classes on a patent document, which measures the frequency of occurrence of combinations of two technology classes on a patent. Following other studies, we interpret a high frequency as an indicator of technological relatedness. This allows us to draw an European knowledge space.

This relatedness information is used to calculate a *relatedness density* (RD) measure, following other studies (Boschma et al. 2015; Balland et al. 2019), to assess the effect of regional capabilities on regional diversification. That is, for each region *r*, we calculated the density of technology production in the vicinity of individual technologies *i*. Following Hidalgo et al. (2007) and Boschma et al. (2015), the density of knowledge production around a given technology *i* in region *r* at time *t* is derived from the technological relatedness $\varphi_{i,j,t}$ of technology *i* to all other technologies *j* in which the region has relative technological advantage (RTA), divided by the sum of technological relatedness of technology *i* to all the other technologies *j* in the reference region (Europe) at time *t*:

$$\text{RELATEDNESS\_DENSITY}_{i,r,t} = \frac{\sum_{j \in r, j \neq i} \varphi_{ij}}{\sum_{j \neq i} \varphi_{ij}} * 100$$

APPENDIX 3. INTER-REGIONAL LINKAGE MEASURE CL

There are two main steps in the construction of the metric CL. First, we measure the amount of relatedness density that a region j can potentially add to the relatedness density of a region i in technology t. Let's assume that technology t is related to two technologies *m* and *n*. Region i has a RTA in technology *m* and region j has a RTA in both *m* and *n*. Region j will add 50% relatedness density to region i in technology t (1/2), while region i will add 0% to region j in t (0/2). Second, we use information on the links (co-patents) between regions to see if regions actually collaborate or not with their perfect matches. If a region actively collaborate with other regions that have high potential of complementarity, CL will go up. Let's say that region j can add 50% to region i in technology t, and region l can add 10% to region i in technology t. We know that i and j have 10 links, and i and l only have 5 links. CL (total) of region i around technology t will be = 50*10 + 10*5 = 550.

APPENDIX 4. DESCRIPTIVES OF THE VARIABLES

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(75)	Max
Period	791,240	3.500	1.118	2	2.8	4.2	5
Entry	655,539	0.108	0.310	0.000	0.000	0.000	1.000
RD	781,576	20.987	19.584	0.000	4.730	32.040	100.000
CL	777,485	1.801	0.494	1.000	1.479	2.000	5.200
NL	791,240	6,091.848	14,654.640	0	164	5,588.5	139,701
GDP	490,595	22.345	9.416	3.650	17.050	26.820	93.380
Pop	672,685	1,831,434.000	1,457,450.000	25,060.400	1,008,866.000	2,308,808.000	11,725,090.000
Pop.Dens	610,460	357.861	872.758	2.660	74.050	296.055	9,813.840

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